Chaire en éco-conseil
Université du Québec à Chicoutimi

Annexe 2
Revue de littérature sur le portrait des moyens visant à atteindre la carboneutralité

Préparé pour

GNL Québec

Chaire en éco-conseil
Université du Québec à Chicoutimi
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1. Mandat et contenu du livrable

En décembre 2018, GNL Québec a confié à la Chaire en éco-conseil de l'Université du Québec à Chicoutimi le mandat de répondre à la question : « Comment un grand émetteur final canadien de gaz à effet de serre établi au Québec peut-il aspirer à la carboneutralité? ». Cette recherche a donc pour objectif d'identifier des moyens crédibles pour un grand émetteur final canadien de devenir carboneutre au Québec.

Le contenu de ce premier livrable consiste en un portrait des moyens identifiés dans la littérature visant à atteindre la carboneutralité d'ici 2050 à l'échelle globale. Concrètement ce livrable présente :

1) Une revue de littérature portant sur les moyens de réduction des gaz à effet de serre (GES) pour les principaux secteurs économiques et les méthodes d'élimination du CO_2 de l'atmosphère
2) Le choix des moyens de réduction et d'élimination : aspects et enjeux économiques
3) Les méthodologies permettant de certifier des réductions de GES

2. Revue de littérature

Des aspects généraux et importants sur les inventaires et la comptabilisation des émissions de GES doivent être introduits ici afin de bien cadrer cette section. Les GES considérés dans l'analyse des moyens identifiés dans cette section sont le dioxyde de carbone (CO_2), le méthane (CH_4), le protoxyde d'azote (N_2O) et certains gaz fluorés, soit les perfluorocarbones (PFC), les hydrofluorocarbones (HFC) et l'hexafluorure de soufre (SF_6) (UNEP 2017). Ces GES ont des pouvoirs réchauffants différents dus à ces facteurs : leur propriété radiative (interaction avec les rayons infrarouge), leur durée de vie dans l'atmosphère et leur effet sur le forçage radiatif (contribution au bilan énergétique mondial). Ce pouvoir réchauffant d'un gaz est appelé « potentiel de réchauffement global » (PRG) et s'exprime en équivalent CO_2 (éq-CO_2), où un gaz donné a un PRG *X* fois plus élevé comparé au CO_2, utilisé comme gaz de référence. Les PRG présentement utilisés dans les inventaires nationaux de GES sont ceux du quatrième rapport du Groupe d'experts intergouvernemental sur l'évolution du climat (GIEC), selon la décision 24/CP.19 (IPCC 2006, 2007, UNFCCC 2014). Par exemple, le CH_4 et le N_2O ont des PRG sur une période de 100 ans de 25 et 298, respectivement. Ainsi, le CH_4 et le N_2O ont des pouvoirs réchauffant 25 et 298 fois plus élevés que le CO_2.

Les émissions mondiales de GES de l'année 2017 ont totalisé 53,5 Gt équivalent CO_2 (éq-CO_2) (UNEP 2018). Les objectifs de l'Accord de Paris visent à limiter le réchauffement climatique en deçà de 1,5 °C par rapport à l'ère préindustrielle (Nations Unies 2015a). L'atteinte de cet objectif nécessite une réduction des émissions mondiales de GES d'au moins 45% d'ici 2030 par rapport au niveau de 2010 et un bilan nul de GES d'ici 2050, soit une carboneutralité (IPCC 2018). Cette section traite des moyens identifiés visant à l'atteinte de ces objectifs.

2.1 Moyens de réduction des GES : principaux secteurs économiques

Les émissions mondiales annuelles de GES en 2030 ne devront pas dépasser un total de 24 Gt éq-CO_2 afin de limiter le réchauffement en deçà de 1,5 °C d'ici 2100 par rapport à l'ère préindustrielle, selon une probabilité de 66% (UNEP 2018) (Tableau 1). Le profil de scénarios où les politiques climatiques actuelles seraient appliquées et maintenues (profil d'évolution actuel) prévoit des émissions annuelles de 59 Gt éq-CO_2 en 2030 (UNEP 2018). Ainsi, un écart de 35 Gt éq-CO_2 serait à combler afin de limiter le réchauffement en deçà de 1,5 °C d'ici 2100 (UNEP 2018). Cet écart diminuerait si les contributions déterminées au niveau national (CDN; objectifs de réduction des émissions de GES des pays signataires de l'Accord de Paris) étaient appliquées et maintenues pour 2030. Le plus faible écart de réduction annuelle des émissions à combler en 2030 serait de 13 Gt éq-CO_2 en supposant l'application de CDN conditionnelles (*i.e.*, selon le processus d'adoption des lois dans les pays, les actions ambitieuses des pays et le support financier et technique) afin d'atteindre l'objectif de limiter le réchauffement en deçà de 2 °C d'ici 2100 (UNEP 2018). L'écart à combler pour limiter le réchauffement en deçà de 1,5 °C avec l'application des CDN conditionnelles est de 29 Gt éq-CO_2 (UNEP 2018).

Tableau 1. Émissions mondiales annuelles totales de gaz à effet de serre (GES) en 2030 selon différents scénarios, les incidences sur les températures et les écarts d'émissions à combler entre les besoins et les perspectives en matière de réduction afin de limiter le réchauffement en deçà d'un seuil de température donné. Ce tableau est tiré du Emission Gap Report (UNEP 2018).

Scénario (arrondi à la Gt la plus proche)	**Nombre de scénarios envisagés**	**Total des émissions mondiales en 2030 (Gt éq-CO_2)**	**Températures estimées**			**Écart entre les besoins et les perspectives de réduction des émissions en 2030 (Gt éq-CO_2)**		
			50% de probabilité	**66% de probabilité**	**90% de probabilité**	**En deçà de 2 °C**	**En deçà de 1,8 °C**	**En deçà de 1,5 °C**
Scénario de référence	179	65 (60-70)	–	–	–	–	–	–
Profil d'évolution actuel	4	59 (56-60)	–	–	–	18 (16-20)	24 (22-25)	35 (32-36)
CDN non conditionnelles	12	56 (52-58)	–	–	–	15 (12-17)	21 (17-23)	32 (28-34)
CDN conditionnelles	10	53 (49-55)	–	–	–	13 (9-15)	19 (15-20)	29 (26-31)
En deçà de 2 °C (66% de probabilité)	29	40 (38-45)	Plafonnement : 1,7 – 1,8 °C En 2100 : 1,6 – 1,7 °C	**Plafonnement : 1,9 – 2,0 °C En 2100 : 1,8 – 1,9 °C**	Plafonnement : 2,4 – 2,6 °C En 2100 : 2,3 – 2,5 °C	–	–	–
En deçà de 1,8 °C (66% de probabilité)	43	34 (30-40)	Plafonnement : 1,6 – 1,7 °C En 2100 : 1,3 – 1,6 °C	**Plafonnement : 1,7 – 1,8 °C En 2100 : 1,5 – 1,7 °C**	Plafonnement : 2,1 – 2,3 °C En 2100 : 1,9 – 2,2 °C	–	–	–
En deçà de 1,5 °C (66% de probabilité)	13	24 (22-30)	Plafonnement : 1,5 – 1,6 °C En 2100 : 1,2 – 1,3 °C	**Plafonnement : 1,6 – 1,7 °C En 2100 : 1,4 – 1,5 °C**	Plafonnement : 2,0 – 2,1 °C En 2100 : 1,8 – 1,9 °C	–	–	–

Remarque : Les chiffres et les fourchettes relatifs à l'écart sont calculés sur la base des chiffres originaux (sans arrondi), qui peuvent être différents des chiffres arrondis (troisième colonne) figurant dans le tableau. Les chiffres sont arrondis à la Gt éq-CO_2 supérieure. Les émissions de GES ont été cumulées avec les valeurs du potentiel de réchauffement global (PRG) sur une durée de 100 ans figurant dans le deuxième Rapport d'évaluation du GIEC (IPCC 1995). Les CDN et les prévisions relatives aux émissions produites selon les profils d'évolution actuels peuvent être légèrement différentes des chiffres présentés dans l'encadré inter-chapitres 11 du Rapport spécial du GIEC (IPCC 2018), en raison de la prise en compte de nouvelles études après la date limite fixée par le GIEC pour la publication des sources. Les profils d'évolution ont été regroupés en trois catégories selon que leurs émissions cumulées de CO_2 maximales étaient inférieures à 600 Gt CO_2, situées entre 600 et 900 Gt CO_2 ou entre 900 et 1 300 Gt CO_2, à compter de 2018 jusqu'à la tenue de l'objectif de zéro émission nette de CO_2, ou jusqu'à la fin du siècle si l'objectif n'est pas atteint d'ici là. Les profils d'évolution supposent une action limitée jusqu'en 2020, suivie d'une atténuation optimale en termes de coûts. Les températures estimées sont fondées sur la méthode utilisée dans le 5e Rapport d'évaluation du GIEC (IPCC 2013).

Les principaux secteurs économiques pour lesquels des moyens de réduction d'émission de GES sont : l'agriculture, les bâtiments, l'énergie, la foresterie, l'industrie, le transport et autres secteurs (Tableau 2) (UNEP 2017). Les moyens de réduction de base sont estimés à un coût d'application < 100 $USD t^{-1} éq-CO_2 et démontrent une certitude acceptable (±25%) quant à la possibilité d'effectivement réduire les GES (UNEP 2017). Les moyens qualifiés d'additionnels sont plus incertains que les moyens de base et auraient fort probablement un coût d'application > 100 $USD t^{-1} éq-CO_2 (UNEP 2017). Un total de réduction des émissions mondiales de GES de 33 Gt éq-CO_2 an^{-1} pourrait être atteint si tous les moyens de base étaient appliqués, ce total passerait à 38 Gt éq-CO_2 an^{-1} si les moyens additionnels étaient aussi appliqués (UNEP 2017). Ainsi, l'écart de 35 Gt éq-CO_2 an^{-1} pourrait être comblé pour respecter l'objectif de limiter le réchauffement en deçà de 1,5 °C d'ici 2100 par l'application de toutes ces mesures d'ici 2030 (UNEP 2017, 2018). Un effort de réduction supplémentaire serait toutefois nécessaire après 2030 afin d'atteindre une carboneutralité d'ici 2050.

Tableau 2. Compilation des réductions potentielles d'émissions de gaz à effet de serre (GES) selon les principaux secteurs économiques. Ce tableau est tiré du Emission Gap Report (UNEP 2017).

Secteur	Catégorie	Potentiel de réduction des émissions d'ici 2030 (Gt éq-CO_2 an^{-1})	Catégorie	Potentiel agrégé du secteur (Gt éq-CO_2 an^{-1})
Agriculture	Gestion des terres cultivées	0,74	Base	3,0 (2,3 – 3,7)
	Gestion du riz	0,18		
	Gestion du bétail	0,23		
	Gestion des pâturages	0,75		
	Restauration des terres agricoles	0,5-1,7		
	Restauration de tourbières dégradées et contrôle de l'incidence des feux en tourbière	1,6	Additionnel	3,7 (2,6 – 4,8)
	Biochar	0,2		
	Changements de régimes alimentaires	0,37 – 1,37		
	Diminution des pertes et du gaspillage alimentaire	0,97 – 2,0		
Bâtiments	Nouveaux bâtiments	0,68 – 0,85	Base	1,9 (1,6 – 2,1)
	Bâtiments existants	0,52 – 0,93		
	Énergie renouvelable – bio	0,39		
	Énergie renouvelable – solaire	0,21		
	Éclairage	0,67	Base (émissions indirectes)	Voir secteur Énergie
	Appareils électroménagers	3,3		
Énergie	Énergie solaire	3 – 6	Base	10,0 (9,3 – 10,6)
	Énergie éolienne	2,6 – 4,1		
	Hydroélectricité	0,32		
	Énergie nucléaire	0,87		
	Bioénergie	0,85		
	Géothermie	0,73		
	Capture (piégeage) et stockage du carbone (*Carbon capture and storage* – CCS)	0,53		
	Bioénergie avec CCS	0,31	Additionnel	0,3 (0,2 – 0,4)

Secteur	Catégorie	Potentiel de réduction des émissions d'ici 2030 (Gt éq-CO_2 an^{-1})	Catégorie	Potentiel agrégé du secteur (Gt éq-CO_2 an^{-1})
	Méthane provenant du charbon	0,41	Base	2,2 (1,7 – 2,6)
	Méthane provenant du pétrole et du gaz naturel	1,78		
Foresterie	Restauration de forêts dégradées	1,6 – 3,4	Base	5,3 (4,1 – 6,5)
	Réduction de la déforestation	3,0		
Industrie	Efficacité énergétique – indirecte	1,9	Base (émissions indirectes)	Voir secteur Énergie
	Efficacité énergétique – directe	2,2	Base	5,4 (4,2 – 6,6)
	Utilisation d'énergie renouvelable pour la production de chaleur	0,5		
	GES autres que le CO_2	1,5		
	CCS	1,22		
Transport	Potentiel des véhicules lourds (efficacité, changement de mode)	0,88	Base	4,7 (4,1 – 5,3)
	Potentiel des véhicules légers (efficacité, changement de mode, véhicules électriques)	2,0		
	Efficacité du transport maritime pour les marchandises	0,7		
	Efficacité du transport aérien	0,32 – 0,42		
	Biocombustibles	0,63 – 0,81		
Autres	Récupération des gaz de sites d'enfouissement	0,4	Base	0,4 (0,3 – 0,5)
	Mesures améliorées d'altération de minéraux pour l'élimination du CO_2 de l'atmosphère	0,73 – 1,22	Additionnel	1,0 (0,7 – 1,2)
Potentiel de réduction des émissions totales avec des moyens de base				**33 (30 – 36)**
Potentiel de réduction total des émissions incluant les moyens additionnels				**38 (35 – 41)**

Note : Bien qu'une seule valeur soit présentée pour plusieurs catégories de moyens de réduction, l'incertitude présumée est à ±25%. Pour les moyens de réduction concernant la dégradation des tourbières et les incidences de feux en tourbière, le biochar et l'efficacité énergétique, le potentiel de réduction pour 2030 est plus incertain. Ainsi, un spectre d'incertitude plus élevé de 50% est appliqué pour ces catégories de secteur. À la dernière colonne (à droite), les catégories sont agrégées au niveau du secteur. Les valeurs de la troisième colonne (à partir de la gauche) ne sont pas corrigées pour les chevauchements entre les mesures. Les valeurs à la dernière colonne (à droite) sont corrigées pour les chevauchements et cette correction est appliquée dans les potentiels totaux. Ainsi, la valeur du total des potentiels de réduction est plus faible que la somme des potentiels individuels présentés à la troisième colonne (à partir de la gauche). Les potentiels agrégés des réductions d'émissions indirectes pour les secteurs des bâtiments et de l'industrie sont appliqués dans le potentiel de réduction du secteur énergie.

Les moyens de réduction présentés permettraient de combler l'écart afin de limiter le réchauffement en deçà de 1,5 ou 2 °C (Tableau 2). Toutefois, à quels coûts se chiffrent ces efforts de réduction? Un constat clair et remarquable est que la grande partie des potentiels de réduction repose sur simplement six catégories : l'utilisation d'énergie de sources renouvelables 1) solaire et 2) éolienne, l'efficacité énergétique pour 3) les appareils électroménagers et 4) les véhicules légers, 5) le boisement et reboisement et 6) l'arrêt de la déforestation (UNEP 2017). La somme de l'application de ces potentiels de réduction serait de 18,5 Gt éq-CO_2 an^{-1} en 2030 (UNEP 2017), représentant un peu plus que la moitié de l'écart à combler. L'application de ces moyens se ferait également à des coûts bien modestes (UNEP 2017). Plusieurs pays ont déjà annoncé des cibles et des politiques pour l'utilisation des énergies renouvelables comme l'énergie solaire et éolienne : ces mesures contribuent à décarboniser ce secteur (UNEP 2017). Des normes de performance et d'efficacité énergétique s'instaurent graduellement dans plusieurs pays (UNEP 2017). De plus, des pays comme la Chine, le Costa Rica et la Corée montrent des exemples prometteurs de reboisement de forêts dégradées (UNEP 2017). Toutes ces mesures ont un potentiel de contribuer à l'atteinte des cibles de réduction fixées pour 2030.

Les prochaines sections présentent en détail les moyens de réduction des émissions de chacun des secteurs économiques avec une brève description des technologies ou procédés ainsi que les références de publications documentant ces moyens. Une grande part de l'information présentée provient du *Emission Gap Report* (UNEP 2017) ayant dressé un portrait complet et global des moyens de réduction de GES applicables d'ici 2030. Le *Emission Gap Report* est produit annuellement par le Programme des Nations unies pour l'environnement et documente l'écart entre les réductions de GES nécessaires pour respecter les cibles de l'Accord de Paris et les CDN des pays signataires.

2.1.1 Moyens de réduction des GES en agriculture

Les moyens de base de réduction des GES en agriculture portent sur l'application de mesures de gestion des terres cultivées, du riz, du bétail, des pâturages et des terres agricoles (Tableaux 2 et 3) (UNEP 2017). Toutefois, des protocoles d'obtention de crédits compensatoires ne sont pas encore disponibles pour tous ces moyens bien que des réductions certaines aient été documentées par des études (Tableau 3). De plus, ces moyens pourraient être intégrés dans le cours normal des affaires selon les législations des pays, ce qui écarterait la possibilité d'obtenir des crédits compensatoires. D'autres moyens additionnels mais plus incertains pourraient mener à des réductions de GES d'ici 2030. Ces moyens consistent en la restauration des tourbières dégradées en terres agricoles, le contrôle des incidences des feux en tourbière, l'utilisation du biochar, des changements de régimes alimentaires et la diminution des pertes et du gaspillage alimentaire (Tableaux 2 et 3). Dans ces deux derniers cas, même si le potentiel de réduction est réel, il est très peu probable qu'il puisse jamais être encadré par une méthodologie permettant de générer des unités de réduction échangeables sur les marchés.

Tableau 3. Compilation des moyens de réduction potentiels d'émissions des gaz à effet de serre (GES) pour le secteur de l'agriculture. Une partie de l'information présentée dans ce tableau est tirée du *Emission Gap Report* (UNEP 2017).

Moyen de réduction	**Description du moyen et des procédés**	**Références**
Gestion des terres cultivées	-L'objectif est de favoriser la séquestration du carbone dans les sols agricoles	Smith *et al.* (2007) Smith *et al.* (2008) Asgedom et Kebreab (2011) Smith P. *et al.* (2014) Rempel *et al.* (2016) Smith (2016) Pesic *et al.* (2018) Sarkar *et al.* (2018)
	-Semis direct	Dimassi *et al.* (2014) USEPA (2014)
	-Recyclage des résidus de culture	USEPA (2014)
	-Pratiques agronomiques liées à une utilisation raisonnée d'engrais synthétiques	USEPA (2014) Singh et Strong (2016)
Gestion du riz	-Une réduction de 25% des GES est estimée par ce moyen en comparaison avec le scénario appliquant les politiques actuelles	USEPA (2014)
	-Ajustement des régimes d'inondation	
	-Semis direct	
	-Utilisation raisonnée de fertilisants variés et selon les principes agronomiques	
Gestion du bétail	-Les émissions de GES actuelles sont surtout liées à la fermentation entérique et la gestion des fumiers	Nelson *et al.* (2010) USEPA (2012)
	-Réduction du CH_4 de la fermentation entérique :	
	• Utilisation de vaccins anti-méthanogène réduisant la production de CH_4 dans le rumen	
	• Pâturage intensif	
	• Utilisation d'additifs permettant le conversion d'hydrogène en propionate plutôt qu'en CH_4	
	-Gestion des fumiers et déchets :	
	• Utilisation de digesteurs pour réduire les GES	
Gestion des pâturages	-Les terres en pâturage sont normalement soumises à une gestion moins intensive que celles cultivées, permettant ainsi un plus grand potentiel de réduction des GES par des mesures de gestion	Smith *et al.* (2008)
	-Ajustement de l'intensité des pâtures pour permettre la croissance de biomasse	
	-Augmenter la productivité des terres en réduisant les carences en nutriments	
	-Pratiquer une fertilisation de précision :	

Moyen de réduction	Description du moyen et des procédés	Références
	• Appliquer les principes agronomiques pour optimiser les doses en lien avec les rendements	
	-Gestion des feux :	
	• Réduire la fréquence et l'intensité sur les territoires sensibles aux feux	
	-Introduction d'espèces cibles :	
	• Espèces avec haute productivité et faible besoin en azote	
Restauration des terres agricoles	-Remise en culture de terres abandonnées avec une gestion agronomique appropriée	Evangelou *et al.* (2012) GCEC (2015)
Restauration de tourbières dégradées et contrôle de l'incidence des feux en tourbière	-Ce sont des tourbières d'abord drainées pour l'agriculture et laissées dans un état dégradé	Smith *et al.* (2008)
	-Le principe émetteur de GES est lié au drainage des tourbières menant à l'oxydation de la matière organique générant du CO_2 d'origine fossile car la tourbe s'accumule sur des milliers d'années	
	-Sous-secteur à émissions considérables représentant 25% de celles provenant de l'utilisation des terres	Bonn *et al.* (2014)
	-La restauration des tourbières agricoles abandonnées :	
	• Blocage des canaux de drainage suivi de l'introduction d'espèces cibles	
	-Prévention des feux de tourbières	Joosten *et al.* (2012) Wichtmann *et al.* (2016) World Bank (2016)
Biochar	-Le biochar est le résidu solide provenant du processus de pyrolyse de la biomasse	
	-Propriétés du biochar sur les sols agricoles associées à la lutte contre les changements climatiques	Lehmann (2007) Woolf *et al.* (2010) Ennis *et al.* (2012) Homagain *et al.* (2014) Brassard *et al.* (2016) Laghari *et al.* (2016) Kuppusamy *et al.* (2016) Mandal *et al.* (2016) Wang *et al.* (2016) Xie *et al.* (2016) Kammann *et al.* (2017) Qambrani *et al.* (2017) Tan *et al.* (2017)

Moyen de réduction	**Description du moyen et des procédés**	**Références**
		Xiao *et al.* (2017) Callegari et Capodaglio (2018) Kavitha *et al.* (2018) Liu *et al.* (2019) Puro (2019) Schmidt *et al.* (2019) Tan (2019)
	• Augmente la fertilité des sols	
	• Réduit les émissions de N_2O selon le type de sol et sous certaines conditions	Cayuela *et al.* (2014)
	• Contribue au stockage du carbone dans le sol	
Changements de régimes alimentaires	-Réduction de la demande pour des produits nécessitant des diètes animales intensives et par conséquent demandant en ressources et émettrices de GES	Stehfest *et al.* (2013)
Diminution des pertes et du gaspillage alimentaire	-Réduire les pertes liées aux récoltes :	Lundqvist (2009) Nellemann *et al.* (2009) Stehfest *et al.* (2013)
	• Modifier les conditions de récolte et d'entreposage pour minimiser les pertes	
	-Réduire le gaspillage alimentaire par un changement de comportement des consommateurs	

2.1.2 Moyens de réduction des GES pour les bâtiments

Les moyens de base de réduction des GES pour le secteur des bâtiments sont associés à deux concepts clés : l'efficacité énergétique et l'utilisation d'énergie de sources renouvelables (Tableaux 2 et 4) (UNEP 2017). Si les politiques actuelles étaient maintenues pour 2030, les émissions de GES de ce secteur totaliseraient 12,6 Gt éq-CO_2 an^{-1} (UNEP 2017). Une proportion de 29% de ces émissions seraient directes et proviendraient des systèmes de chauffage et de production d'eau chaude et 71% des émissions indirectes proviendraient de l'utilisation d'énergie pour les appareils électroménagers et l'éclairage (UNEP 2017). Des potentiels de réduction d'émissions directes et indirectes de 5.87 Gt éq-CO_2 an^{-1} pourraient être réalisés si des mesures étaient appliquées d'ici 2030, soit une réduction de près de la moitié de celles estimées s'il n'y avait aucun changement dans l'application des politiques actuelles (Tableaux 2 et 4) (UNEP 2017). De nouvelles politiques sont justement graduellement appliquées dans plusieurs pays afin de répondre au besoin d'efficacité énergétique nécessaire pour réduire les émissions. Ces politiques concernent l'application de l'approche des bâtiments à émissions nulles, d'une meilleure isolation, d'installation de fenêtres intelligentes et l'automatisation des bâtiments dans le but de réduire la demande en énergie (UNEP 2017). La production de chaleur à partir d'énergie renouvelable comme l'énergie solaire et éolienne (où l'hydroélectricité n'est pas disponible) et l'utilisation de biocombustibles solides, liquides et gazeux sont à préconiser (UNEP 2017). Toutes ces mesures de réduction sont applicables pour les bâtiments existants qui demanderaient à être rénovés, de même que pour les nouveaux bâtiments où les concepts de réduction des GES pourraient être intégrés en amont dans les plans de construction (UNEP 2017). L'utilisation du matériau bois dans la construction des bâtiments permettrait également de réduire les GES (Tableau 4).

Tableau 4. Compilation des moyens de réduction potentiels d'émissions des gaz à effet de serre (GES) pour le secteur des bâtiments. Une partie de l'information présentée dans ce tableau est tirée du *Emission Gap Report* (UNEP 2017).

Moyen de réduction	**Description du moyen et des procédés**	**Références**
Efficacité énergétique (Émissions directes)	-Pour la construction de nouveaux bâtiments et rénovation de bâtiments existants :	GBPN (2013) Bloomberg (2014) UNEP (2015a) Climate Action Tracker (2016) Creutzig *et al.* (2016)
	• Bâtiments à émissions nulles	
	• Amélioration de l'isolation	
	• Installation de fenêtres intelligentes	
	• Automatisation des bâtiments	
	• Éclairage	UNEP (2014) Molenbroek *et al.* (2015)
	• Appareils électroménagers	Waide (2011) Molenbroek *et al.* (2015)
Utilisation d'énergie de sources renouvelables (Émissions indirectes)	-Énergie solaire	IRENA (2016)
	-Énergie éolienne	
	-Énergie hydroélectrique	
	-Utilisation de biocombustibles sous formes solide, liquide et gazeuse	
Utilisation du matériau bois	-Le remplacement du ciment (ou d'autres matériaux dont les procédés émettent des GES) par le matériau bois dans la construction des bâtiments	Laurent *et al.* (2018) Puro (2019)

2.1.3 Moyens de réduction des GES pour l'énergie

Les moyens de réduction des GES pour le secteur de l'énergie reposent essentiellement sur le remplacement des énergies fossiles par de l'énergie de sources renouvelables (Tableaux 2 et 5) (UNEP 2017). Les deux sources d'énergie renouvelable ayant le plus grand potentiel de réduction sont les sources solaire et éolienne (UNEP 2017). Si les politiques actuelles sont maintenues, alors les émissions de GES de ce secteur seraient de 21,3 Gt éq-CO_2 an^{-1} en 2030, dont la majeure partie (77%) proviendrait des centrales de production d'électricité (USEPA 2012, IEA 2016, UNEP 2017). Les moyens de réduction de GES se détaillent comme suit (Tableau 5) :

- Énergie de sources solaire et éolienne
  - À elles seules, les sources solaire et éolienne ont un potentiel de réduction des GES pouvant atteindre jusqu'à 10,1 Gt-éq.CO_2 an^{-1} en 2030, soit une réduction de près de la moitié des émissions prévues si les politiques actuelles étaient maintenues (Tableau 2). Toutefois, pour réaliser ces réductions, les apports d'énergie de sources renouvelables doivent se substituer à des quantités équivalentes d'énergie de sources fossiles et occasionner la fermeture de ces dernières, sinon elles font simplement varier l'intensité carbonique.
- Capture et stockage du carbone
  - Des mesures de capture et stockage du carbone (en anglais : *Carbon capture and storage* – CCS) devraient être mises en place afin de maximiser les réductions de GES (UNEP 2017) et contribuer à l'atteinte d'un bilan net nul d'émissions de GES d'ici 2050. La capture directe de CO_2 de l'atmosphère consiste à séparer le CO_2 de l'air ambiant par des procédés chimiques et physiques (UNEP 2017). La technologie a été développée originalement pour les domaines de l'aérospatiale et des sous-marins. Le CO_2 capturé peut ainsi être stocké en profondeur par géoingénierie ou sous forme de matériaux durables. Le procédé du CCS doit utiliser une source d'énergie renouvelable pour pouvoir affirmer être au minimum à émissions nettes nulles et un moyen contribuant à des émissions négatives (UNEP 2017). Le CCS peut s'intégrer aux systèmes de production d'énergie à base de combustibles fossiles mais également aux systèmes basés sur la bioénergie. Toutefois, ces deux moyens sont émergents et nécessitent de la recherche et développement afin d'en réduire les coûts d'opération (UNEP 2017).
- Microalgues pour la production de biocarburants
  - La production de biocarburants à partir des microalgues est aussi un domaine émergent avec un certain potentiel de substitution des carburants fossiles, donc de réductions des GES (Tableau 5).
- Mines de charbon et transport de combustibles fossiles
  - La réduction de GES pour les domaines des carburants fossiles peut s'effectuer par des mesures à implanter à plus grandes échelles pour réduire les émissions de CH_4 des mines de charbon et des systèmes d'extraction, de raffinement et de transport du pétrole et gaz naturel (UNEP 2017).
- Gaz naturel renouvelable
  - Des études récentes réalisées pour le compte de l'entreprise Énergir ont estimé que 2/3 du volume de gaz naturel distribué au Québec pourrait être de sources renouvelables d'ici 2030 (Deloitte et WSP 2018, Aviseo Conseil 2019) (Tableau 5). Si une telle production se réalise, alors ce moyen permettrait de réduire les émissions de GES du Québec de 7,2 Mt éq-CO_2 an^{-1} d'ici 2030, soit une réduction de 9% en référence au bilan 2016 des GES au Québec (Deloitte et WSP 2018, MELCC 2018, Aviseo Conseil 2019). Pour GNL Québec et le projet Énergie Saguenay, le remplacement du gaz naturel d'origine fossile par des origines

renouvelables consisterait en un moyen de réduction du type substitution et pourrait ainsi être comptabilisé dans les efforts de réduction à l'usine même : les émissions réduites seraient soustraites aux déclarations annuelles obligatoires des GES de l'usine.

Tableau 5. Compilation des moyens de réduction potentiels d'émissions des gaz à effet de serre (GES) pour le secteur de l'énergie. Une partie de l'information présentée dans ce tableau est tirée du *Emission Gap Report* (UNEP 2017).

Moyen de réduction	Description du moyen et des procédés	Références
Énergie solaire	-Potentiel de réduction d'ici 2030 :	
	• Production annuelle en 2016 : 303 GW	REN21 (2017)
	• Cible de production pour 2030 : 3 725 GW	Teske *et al.* (2015)
	• Potentiel de production pour 2030 avec le maintien des politiques actuelles : 708 GW	
	• Indicateurs que la cible de 2030 pourrait être atteinte :	
	• La croissance de production d'énergie solaire doit être de 14-20% an^{-1} d'ici 2030 mais cette croissance est de 48% an^{-1} pour la dernière décennie. Cette tendance actuelle démontre que la cible est atteignable.	Teske *et al.* (2015) Creutzig *et al.* (2017)
	• Potentiel de production allant jusqu'à 7 100 – 9 100 GW avec l'une augmentation de la capacité photovoltaïque globale de 26 – 29% an^{-1} et réductions de GES attendues de 5,5 – 7,2 Gt éq-CO_2 an^{-1}	Breyer *et al.* (2017)
	• Potentiel de production de 3 885 – 8 722 GW en 2030 engendrant des réductions de 2,49 – 6,17 Gt éq-CO_2 an^{-1}	Afanador *et al.* (2015) SITRA (2015)
Énergie éolienne	-Potentiel de réduction d'ici 2030 :	
	• Production annuelle en 2016 : 487 GW	REN21 (2017)
	• Cible de production pour 2030 : 2 110 – 3 064 GW	Teske *et al.* (2015) GWEC (2016)
	• Potentiel de production pour 2030 avec le maintien des politiques actuelles : 940 GW	
	• Indicateurs que la cible de 2030 pourrait être atteinte :	
	• La croissance de production d'énergie solaire doit être de 11-15% an^{-1} d'ici 2030 mais cette croissance est de 21% an^{-1} pour la dernière décennie. Cette tendance actuelle démontre que la cible est atteignable.	
Hydroélectricité	-Potentiel d'augmentation de 147 GW d'ici 2030	IEA (2016)
Énergie nucléaire	-Potentiel d'augmentation de 154 GW d'ici 2030	IEA (2016)
Bioénergie	-Ce mode de production mène à la production de biocarburants tels le méthane (gaz naturel renouvelable), l'éthanol, les biohuiles (par pyrolyse), etc.	Ho *et al.* (2014) Nanda *et al.* (2015) Riding *et al.* (2015) Teske *et al.* (2015) Acheampong *et al.* (2017) Arodudu *et al.* (2017) Robledo-Abad *et al.* (2017) Fernandez *et al.* (2017)

Moyen de réduction	**Description du moyen et des procédés**	**Références**
		Sikarwar *et al.* (2017) Cherubin *et al.* (2018) Dar *et al.* (2018) Gontard *et al.* (2018) Kougias et Angelidaki (2018) Qin *et al.* (2018) Vasco-Correa *et al.* (2018) Delangiz *et al.* (2019)
	-Ce mode de production peut être une solution alternative à l'enfouissement de matières organiques putrescibles et ainsi réduire les GES	
Géothermie	-Récupération de chaleur provenant de couches en profondeur	Teske *et al.* (2015) Soltani *et al.* (2019)
Capture (piégeage) et stockage du carbone (*Carbon capture and storage* – CCS)	-Capture du carbone provenant de l'utilisation de combustibles fossiles. Le carbone capté peut aussi être utilisé à des fins énergétiques (*Carbone capture and utilization* – CCU) et stocké après utilisation (*Carbone capture utilization and storage* – CCUS).	IPCC (2005) Cuéllar-Franca et Azapagic (2015) Lee et Park (2015) Mumford *et al.* (2015) Shakerian *et al.* (2015) van den Broek *et al.* (2015) Wang *et al.* (2015) Creamer et Gao (2016) ElMekawy *et al.* (2016) Hu *et al.* (2016) Jang *et al.* (2016) Nanda *et al.* (2016) Nogia *et al.* (2016) Tan *et al.* (2016) Zeng *et al.* (2016) Al-Mamoori *et al.* (2017) Aminu *et al.* (2017) Araujo et de Medeiros (2017) Chang *et al.* (2017) Cook (2017) Cota et Martinez (2017)

Moyen de réduction	Description du moyen et des procédés	Références
		IEA (2017) (2017) Leeson *et al.* (2017) Lin *et al.* (2017) Liu *et al.* (2017b) Patel *et al.* (2017b) Rahman *et al.* (2017) Rudin *et al.* (2017) Sharma *et al.* (2017) Zhao *et al.* (2017) Bernin et Hedin (2018) Bhagat *et al.* (2018) Bonaventura *et al.* (2018) Cai *et al.* (2018) Gaurina-Medimurec *et al.* (2018) Hanak *et al.* (2018) Kelektsoglou (2018) Koytsoumpa *et al.* (2018) Kumar *et al.* (2018) Miguez *et al.* (2018) Newman *et al.* (2018) Norhasyima et Mahlia (2018) Onyebuchi *et al.* (2018) Saran *et al.* (2018) Song *et al.* (2018) Tapia *et al.* (2018) Teixeira *et al.* (2018) Wang *et al.* (2018) Zhang *et al.* (2018) Dindi *et al.* (2019) Gerres *et al.* (2019) Ghoniem *et al.* (2019) Hu *et al.* (2019) Ibrahim *et al.* (2019) Li *et al.* (2019)

Moyen de réduction	**Description du moyen et des procédés**	**Références**
		Weng *et al.* (2019)
	• Le mode d'opération du CCS consomme de l'énergie :	
	• Quantité de CO_2 évité (réduction) < Quantité de CO_2 capturé. Ce ratio varie entre 70 et 90%.	IPCC (2005)
Bioénergie avec CCS	-Capture du carbone provenant de l'utilisation de biocarburants	Powell et Lenton (2012) Cheah *et al.* (2016) IEA (2017) Mendiara *et al.* (2018) Stavrakas *et al.* (2018)
	-Pour le moment, ce moyen est émergent et serait évalué à > 100 \$USD t^{-1} éq-CO_2 bien que d'autres estimations montrent des coûts de 80 – 90\$USD t^{-1} éq-CO_2	McGlashan *et al.* (2012) Arasto *et al.* (2014) Johnson *et al.* (2014)
Méthane provenant du charbon	-Réduction des émissions de CH_4 provenant de l'exploitation des mines de charbon :	UNEP (2017)
	• Dégazage en amont de l'exploitation minière	
	• Installation de ventilation oxydant l'air, donc l'oxydation du CH_4	
	• Potentiel de réduction de 56% en 2030 (0,41 Gt éq-CO_2 an^{-1}) en comparaison aux émissions actuelles	
Méthane provenant du pétrole et du gaz naturel	-Réduction des émissions de CH_4 provenant de la production et distribution du gaz naturel et du pétrole	UNEP (2017)
	• Récupération et utilisation des gaz provenant des activités de torchage et dégazage	
	• Potentiel de réduction de 75% en 2030 (1,78 Gt éq-CO_2 an^{-1}) en comparaison aux émissions actuelles	
Microalgues	-Production de biocarburants à partir des microalgues :	Pires *et al.* (2012) Avagyan (2017) Carneiro *et al.* (2017) Correa *et al.* (2017) Katiyar *et al.* (2017) Patel *et al.* (2017a) Pires (2017) Show *et al.* (2017) Khan *et al.* (2018) Raheem *et al.* (2018) Sharma *et al.* (2018) Shuba et Kifle (2018)

Moyen de réduction	Description du moyen et des procédés	Références
		De Bhowmick *et al.* (2019) Mathimani et Pugazhendhi (2019) Singh et Dhar (2019)
	• Croissance des microalgues par utilisation des eaux usées	
	• Séquestration de carbone par les microalgues	
Gaz naturel renouvelable (GNR)	-Principe de substitution des émissions de GES :	Deloitte et WSP (2018) Aviseo Conseil (2019)
	• Le GNR se substitue au gaz naturel d'origine fossile et contribue à la réduction des émissions de GES à l'usine même :	
	• L'épuration du gaz reçu par gazoduc émet du CO_2 d'origine biogénique et ne fait pas partie des déclarations obligatoires de GES de l'usine	
	• À l'extérieur du périmètre de l'usine, la consommation du GNR émet du CO_2 d'origine biogénique et ne fait pas partie des déclarations obligatoires du distributeur. Bien que cette pratique soit externe au périmètre de l'usine, elle contribue globalement à la lutte contre les changements climatiques.	
	-Trois générations de technologie peuvent générer du GNR :	
	• 1ère génération :	
	• Biométhanisation : processus de décomposition anaérobique en conditions contrôlées pouvant générer du CH_4 dans des proportions de 50 à 70%.	
	• Captage du biogaz des sites d'enfouissement	
	• 2^{e} génération :	
	• Pyrolyse : combustion en conditions contrôlées en absence d'oxygène. Ce procédé génère des résidus solide (biochar), liquide (biohuiles) et gazeux (syngas). Les conditions de la pyrolyse peuvent être réglées pour produire les résidus en proportions désirées. Ainsi les conditions de la pyrolyse peuvent être réglées pour augmenter la proportion de syngas et de CH_4.	
	• Hydrogénation pyrocatalytique : ce procédé est la première étape de la pyrolyse suivie par une hydrogénation du syngas par catalyseur. Le procédé est émergent et ne sera probablement pas mature en 2030.	
	• 3^{e} génération :	
	• Technologie Power-to-Gas : combinaison d'électricité avec du CO_2 pour produire du CH_4. Procédé s'effectuant par électrolyse de l'eau suivie d'une méthanation d'hydrogène en présence de CO_2. Le procédé est émergeant et ne sera probablement pas mature en 2030.	
	-Le GNR peut bénéficier à trois secteurs au Québec :	

Moyen de réduction	Description du moyen et des procédés	Références
	• Les municipalités : par la réduction de l'élimination ultime par enfouissement	
	• Agriculture : réduction des odeurs liées à la gestion des fumiers, lisiers et à l'épandage, production de digestat fertilisant résultant de la biométhanisation	
	• Foresterie : utilisation des résidus forestiers pour la pyrolyse	
Autres types d'énergies renouvelables	-Énergie thermique	Li et Zheng (2016)

2.1.4 Moyens de réduction des GES applicables par la foresterie

Les deux principaux moyens de réduction des GES par la foresterie concernent la restauration des forêts dégradées et la réduction ou l'arrêt de la déforestation (Tableaux 2 et 6) (UNEP 2017). Depuis la publication du cinquième rapport du GIEC, le potentiel de réduction des émissions de GES associé au secteur de la foresterie, avec des coûts < 100$USD t^{-1} éq-CO_2, se situent entre 0,2 – 13,8 Gt éq-CO_2 an^{-1}, tout dépendant des modèles utilisés (IPCC 2013, Smith P. *et al.* 2014). Les dernières évaluations chiffrent un potentiel de réduction de GES de 5,3 Gt éq-CO_2 an^{-1} pour 2030 s'il y a application des deux principaux moyens de réduction (Clarke *et al.* 2014, Verdone *et al.* 2015, UNEP 2017) (Tableau 6). D'autres pratiques d'aménagement forestier peuvent être appliquées pour contribuer à la réduction des GES (Tableau 6).

Tableau 6. Compilation des moyens de réduction potentiels d'émissions des gaz à effet de serre (GES) pour le secteur de la foresterie. Une partie de l'information présentée dans ce tableau est tirée du *Emission Gap Report* (UNEP 2017).

Moyen de réduction	**Description du moyen et des procédés**	**Références**
Restauration de forêts dégradées	-Aménagement et reboisement de territoires forestiers dégradés	UNEP (2017)
	-Cible mondiale de restauration de forêts : 350 millions ha	Messinger et DeWitt (2015)
	-Engagements internationaux associés à ce moyen :	
	• Bonn Challenge	Bonn Challenge (2019)
	• Déclaration sur les forêts de New York	NYDF (2019)
Réduction ou arrêt de la déforestation	-Réduction ou arrêt de l'extraction de la ressource forestière pratiquée sans plan de reboisement ou pour changer l'affectation des terres	UNEP (2017)
	-Une grande incertitude existe sur le potentiel de réduction de GES de ce moyen dû aux scénarios de référence variés selon le contexte de réduction ou arrêt de la déforestation et les gains quantifiables en réduction de GES, selon la loi et normes en vigueur	GCEC (2015)
Autres pratiques d'aménagement forestier	-Au Québec et ailleurs dans le monde, diverses pratiques d'aménagement forestiers durables peuvent être appliquées pour réduire les émissions de GES et favoriser la séquestration du carbone :	MFFP (2015)
	• Instruments économiques pour la réduction des GES en foresterie	Pesic *et al.* (2018)
	• Amélioration de l'efficacité, de la valeur et la durabilité par les opérations forestières et l'extraction de biomasse ligneuse	Anderson et Mitchell (2016)
	• Effet de la fertilisation azotée sur les émissions de GES de forêts aménagées	Shrestha *et al.* (2015)
	• L'atténuation des effets des changements climatiques par la biodiversité sur le fonctionnement des écosystèmes forestiers	Hisano *et al.* (2018)
	• Effets des récoltes, feux, insectes et sécheresses sur le bilan en carbone de forêts aux États-Unis	Williams *et al.* (2016)
	• Calculateurs de carbone dans les forêts comme outils pour les gestionnaires, décideurs et éducateurs	Zald *et al.* (2016)
	• Bioénergie à partir de la biomasse forestière	Pleguezuelo *et al.* (2015)

2.1.5 Moyens de réduction des GES applicables à l'industrie

Les deux importantes sources de GES du secteur de l'industrie sont les émissions directes et indirectes (via la consommation d'électricité – secteur énergie) provenant de l'utilisation de combustibles fossiles (UNEP 2017). Les autres sources de GES concernent l'utilisation de combustibles fossiles pour d'autres fins que l'énergie, entre autres les émissions liées à des procédés chimiques, et les émissions de procédés industriels, comme ceux ayant cours dans les cimenteries (UNEP 2017). Si les politiques actuelles étaient maintenues, les émissions de GES du secteur de l'industrie se chiffreraient à 19,3 Gt éq-CO_2 an^{-1} en 2030 (UNEP 2017). Une réduction potentielle de 28% (5.4 Gt éq-CO_2 an^{-1}) est possible en 2030 si ces moyens étaient appliqués : une efficacité énergétique pour les sources directes et indirectes, l'utilisation d'énergie renouvelable pour la production de chaleur, un changement de pratiques pour éviter des émissions de GES autre que le CO_2 et le CCS (Tableaux 2 et 7) (Fischedick *et al.* 2014, UNEP 2017).

Tableau 7. Compilation des moyens de réduction potentiels d'émissions des gaz à effet de serre (GES) pour le secteur de l'industrie. Une partie de l'information présentée dans ce tableau est tirée du *Emission Gap Report* (UNEP 2017).

Moyen de réduction	**Description du moyen et des procédés**	**Références**
Efficacité énergétique	-Potentiel global de réduction annuel se chiffrant aux environs de 30% si ce moyen est appliqué d'ici 2030 pour les sources directes et indirectes	Saygin *et al.* (2011) Akbar *et al.* (2014) Griffin *et al.* (2016) UNEP (2017) Worrell et Carreon Jesus (2017) Bataille *et al.* (2018)
Utilisation d'énergie renouvelable pour la production de chaleur	-Énergies renouvelables sous formes solides, liquides et gazeuses ainsi que les énergies thermiques de types solaire et géothermique :	IRENA (2016) Nkwetta et Sandercock (2016) UNEP (2017)
	• Potentiel de production de 9,7 EJ (exajoules), soit 7,8 EJ de plus comparé à l'application des politiques actuelles	
Changement des pratiques pour réduire les GES autres que le CO_2	-Réduction de l'utilisation des hydrofluorocarbures (HFC)	Purohit et Höglund-Isaksson (2017)
	-Modification des procédés, diminution de production ou substitution pour :	USEPA (2014)
	• Les acides nitriques et adipiques	
	• Les perfluorocarbures (PFC) dans la production primaire d'aluminium	
	• L'hexafluorure de soufre (SF_6) dans les systèmes de production d'électricité et du magnésium	
CCS	-Présenté pour le secteur de l'énergie	Voir le secteur de l'énergie pour ce moyen

2.1.6 Moyens de réduction des GES pour le transport

La principale source d’émissions de GES du transport provient de la consommation de combustibles fossiles. Ainsi, les moyens de réduction de GES pour ce secteur concernent la substitution des combustibles fossiles par de l’énergie de sources renouvelables, tels que l’électricité et les biocarburants (Tableaux 2 et 8) (UNEP 2017). De plus, les moyens portent sur l’efficacité énergétique (UNEP 2017). Si les politiques actuelles étaient maintenues jusqu’en 2030, les émissions du secteur du transport seraient de 9,7 Gt éq-CO_2 an^{-1} (UNEP 2017). Les réductions les plus importantes de GES seraient pour le transport routier, soit les véhicules légers et lourds. D’autres réductions seraient pour le transport naval et aérien (UNEP 2017). Tous ces moyens de réduction permettraient de réduire les émissions de GES du secteur transport de 48% (4,7 Gt éq-CO_2 an^{-1}) en 2030 (UNEP 2017).

Tableau 8. Compilation des moyens de réduction potentiels d'émissions des gaz à effet de serre (GES) pour le secteur du transport. Une partie de l'information présentée dans ce tableau est tirée du *Emission Gap Report* (UNEP 2017).

Moyen de réduction	**Description du moyen et des procédés**	**Références**
Véhicules légers et lourds	-Efficacité énergétique	ICCT (2012)
	-Changement de mode par l'utilisation de véhicules électriques :	ICCT (2012) IRENA (2016) Bloomberg New Energy Finance (2017)
	• On prévoit que 7-10% des ventes de nouveaux véhicules seront pour des véhicules électriques en 2030	
Transport naval	-Moyens de réduction portant sur l'économie de carburant et l'efficacité énergétique	Alvik *et al.* (2010) Eide *et al.* (2011) Faber *et al.* (2011) Hoffmann *et al.* (2012) Gençsü et Hino (2015) Wang *et al.* (2017) Balcombe *et al.* (2019)
Transport aérien	-Moyens de réduction portant sur l'utilisation de combustibles alternatifs moins émetteurs et l'amélioration de l'utilisation des infrastructures et technologies	ICCT (2012) ICAO (2013) Gençsü et Hino (2015)
Utilisation de biocarburants	-Les biocarburants réduisent les émissions de GES de 70 à 90% comparé à l'utilisation de combustibles fossiles	ICCT (2012) BLE (2016) IRENA (2016) Ecofys (2017)

2.1.7 Moyens de réduction des GES pour les autres secteurs

Certains moyens de réduction de GES ne se classent pas dans un des secteurs déjà mentionnés ci-dessus parce qu'ils peuvent couvrir plus d'un secteur. Le principal secteur transversal à tous ceux décrits plus haut est celui de la gestion des déchets. Le principal GES émis des sites d'enfouissement est le CH_4, dans une proportion de 90% (Tableaux 2 et 9) (UNEP 2017). Le CH_4 est produit par la méthanogénèse ayant cours lors de la décomposition anaérobique de la matière disposée dans les sites d'enfouissement (IPCC 2006). Un autre moyen concernant le secteur de la gestion des déchets porte sur des mesures améliorées de l'altération de matériaux destinés à l'élimination ultime mais pouvant être récupérés pour l'élimination physico-chimique du CO_2 de l'atmosphère, soit le ciment, le fer et l'acier (UNEP 2017) (Tableau 9).

Tableau 9. Compilation des moyens de réduction potentiels d'émissions des gaz à effet de serre (GES) pour les autres secteurs. Une partie de l'information présentée dans ce tableau est tirée du *Emission Gap Report* (UNEP 2017).

Moyen de réduction	**Description du moyen et des procédés**	**Références**
Gestion des déchets	-Récupération des gaz de sites d'enfouissement :	USEPA (2014) Anyaoku et Baroutian (2018) Bharathiraja *et al.* (2018) Krause (2018)
	• Ce moyen représente une réduction de 42% des émissions de GES du secteur des déchets en comparaison avec l'application des politiques actuelles pour 2030	
	-Modification de la gestion des sites d'enfouissement pour réduire les émissions de GES	Lee *et al.* (2018)
	-Mesures améliorées d'altération de minéraux pour l'élimination du CO_2 de l'atmosphère :	Renforth *et al.* (2011) Olivares-Marín et Maroto-Valer (2012) Reddy *et al.* (2019)
	• Les matériaux visés sont ceux destinés à l'élimination ultime mais pouvant encore être récupérés pour l'élimination physico-chimique du CO_2 de l'atmosphère, soit le ciment, le fer et l'acier	

2.2 Méthodes d'élimination du CO_2 de l'atmosphère

Les méthodes d'élimination du CO_2 consistent à extraire directement le CO_2 de l'atmosphère. Deux grandes catégories de méthode peuvent contribuer à l'élimination du CO_2, soit les méthodes dites « naturelles ou biologiques » et les méthodes relevant de l'ingénierie (IPCC 2014b, UNEP 2017) (Tableau 10). Les méthodes de type naturel consistent à utiliser la fonction de puits de carbone des écosystèmes terrestres, principalement dans les secteurs de la foresterie, de l'agriculture et des milieux humides (Tableau 10). Les méthodes utilisant l'ingénierie nécessitent l'application de technologies ayant pour objectifs d'extraire le CO_2 de l'atmosphère par des procédés physico-chimiques et d'en faire le stockage soit par couplage sur une matrice donnée, un enfouissement géologique ou par son intégration dans des matériaux durables (Tableau 10). Une troisième méthode hybride consiste à extraire le CO_2 de l'atmosphère via les puits naturels et à stocker ce CO_2 à l'aide de la technologie (Tableau 10).

Tableau 10. Compilation des méthodes d'élimination du CO_2 de l'atmosphère. L'information présentée dans ce tableau est tirée du *Emission Gap Report* (UNEP 2017).

Stratégie	**Catégorie**	**Potentiel de réduction des émissions de GES**	**Coût d'application**
Puits naturels de carbone via les écosystèmes terrestres	Boisement et reboisement	Entre 4 – 12 Gt éq-CO_2 an^{-1} (Smith 2016) Jusqu'à 28 Gt éq-CO_2 an^{-1} (Griscom *et al.* 2017)	< 50 \$USD t^{-1} C (Nielsen *et al.* 2014)
	Autres utilisations des terres et marais	• Impacts évités sur les marais côtiers : 0,3 Gt éq-CO_2 an^{-1} (Griscom *et al.* 2017) • Impacts évités sur l'utilisation des tourbières : 0,7 Gt éq-CO_2 an^{-1} (Griscom *et al.* 2017) • Restauration des tourbières : 0,8 Gt éq-CO_2 an^{-1} (Griscom *et al.* 2017)	10 – 100 \$USD t^{-1} CO_2 (Worrall *et al.* 2009)
	Séquestration du carbone dans le sol	• Potentiel technique : 4,8 Gt éq-CO_2 an^{-1} (Smith 2016) • Potentiel faisable : 1,5 – 2,6 Gt éq-CO_2 an^{-1} (Smith *et al.* 2008, Smith 2016)	• 20 – 100 \$USD t^{-1} C pour le potentiel faisable (Smith *et al.* 2008, Smith 2016) • -45 – 10 \$USD t^{-1} C pour les terres en culture et pâturages (Smith 2016) • Économie de 7,7 milliards \$USD an^{-1} avec un taux de séquestration de 2,6 Gt éq-CO_2 an^{-1} : économies brutes de 16,9 milliards \$USD moins des coûts de 9,2 milliards (Smith 2016)

Stratégie	Catégorie	Potentiel de réduction des émissions de GES	Coût d'application
	Biochar	1,8 – 3,3 Gt éq-CO_2 an^{-1} (Woolf *et al.* 2010)	18 – 166 $USD t^{-1} éq-CO_2 (Woolf *et al.* 2010)
Technologie	Capture directe du CO_2 de l'atmosphère	• Potentiel technique : 20 Gt éq-CO_2 an^{-1} (National Research Council 2015) • Potentiel faisable : 2 – 5 Gt éq-CO_2 an^{-1} (National Research Council 2015)	200 – 600 $USD t^{-1} CO_2 (APS 2011)
	Altération accélérée des minéraux	0,7 – 3,7 Gt éq-CO_2 an^{-1} (Lenton 2014, Smith 2016)	Information non quantifiée
	Augmentation de l'alcalinité des océans	100 Gt C – 1 Tt C au total (Renforth et Henderson 2017)	10 – 600 $USD t^{-1} éq-CO_2 (Renforth et Henderson 2017)
	Conversion du CO_2 en matériaux durables	1 – 7 Gt éq-CO_2 an^{-1} (CO_2 Sciences 2016)	Information non quantifiée
Combinaison des puits naturels de carbone et de la technologie	Bioénergie avec capture et stockage de carbone (CCS)	2 – 18 Gt éq-CO_2 an^{-1} (McLaren 2012, Kemper 2015, National Research Council 2015)	Coûts d'investissement en 2050 : 138 milliards $USD an^{-1} pour l'énergie et 123 milliards $USD an^{-1} pour les combustibles (Smith 2016)

Les méthodes d'élimination du CO_2 de l'atmosphère devront être mises en place et appliquées d'ici 2050, année cible où un bilan net nul des émissions de GES est nécessaire pour limiter le réchauffement des températures en deçà de 1,5 °C par rapport aux niveaux préindustriels (UNEP 2017, IPCC 2018). Les méthodes d'élimination du CO_2 font ainsi parties des technologies à émissions négatives et devront être employées en complément des moyens de réduction de GES visés pour les principaux secteurs économiques (UNEP 2017). Si les politiques globales maintiennent le cap pour limiter le réchauffement en deçà de 1,5 °C, alors les méthodes d'élimination du CO_2 devront contribuer à extraire 810 Gt CO_2 d'ici 2100 (spectre d'incertitude pour la période 2010-2100 de 440 à 1 020 Gt CO_2) (UNEP 2017). L'extraction nécessaire est toutefois un peu plus faible si les politiques globales tendent à limiter le réchauffement en deçà de 2 °C, soit une élimination de 670 Gt CO_2 d'ici 2100 (spectre d'incertitude pour la période 2010-2100 de 320 à 840 Gt CO_2) (UNEP 2017). Ces contributions à l'élimination de CO_2 pourraient toutefois diminuer si la consommation d'énergie allait en diminuant, puisque la production d'énergie génère des émissions de GES (UNEP 2017). Cette mesure nécessiterait un changement des modes de vie actuels.

2.2.1 Méthodes d'élimination du CO_2 basées sur les puits de carbone naturels – les écosystèmes terrestres

Les méthodes d'élimination du CO_2 basées sur les puits de carbone naturels utilisent principalement la fonction de séquestration du carbone via les écosystèmes forestiers, agricoles et les milieux humides (Tableau 11) (UNEP 2017). La production de biochar contribue également à cette fonction de puits, puisque ce matériel produit à partir de la pyrolyse de la biomasse est une forme stable de carbone récalcitrant et résistant à la décomposition. Plusieurs de ces méthodes sont appliquées actuellement ou pourront être applicables à plus grandes échelles selon les politiques des juridictions. Toutefois, ces méthodes d'élimination basées sur les puits naturels ont quelques obstacles et incertitudes (UNEP 2017). Pour le moment, des incertitudes demeurent quant à l'effet même des changements climatiques sur l'efficacité de ces méthodes à éliminer le CO_2 car la fonction des écosystèmes à séquestrer le carbone dépend justement de l'interaction avec les conditions climatiques (UNEP 2017).

Tableau 11. Compilation des méthodes d'élimination du CO_2 basées sur les puits de carbone naturels. Une partie de l'information présentée dans ce tableau est tirée du *Emission Gap Report* (UNEP 2017).

Méthode d'élimination	**Description de la méthode et des procédés**	**Références**
Boisement et reboisement	-Le boisement consiste en des plantations d'arbres sur des terres qui étaient non boisées depuis au moins les 50 dernières années. Néanmoins, ce nombre d'années peut varier selon le protocole de quantification des réductions ou selon les lois et règlements sur la tarification du carbone en place dans la juridiction.	Hamilton *et al.* (2010) UNEP (2017)
	-Le reboisement consiste à des plantations d'arbres aux endroits où il y a eu des coupes forestières	UNEP (2017)
	-L'agroforesterie consiste à l'intégration de plantations d'arbres dans des systèmes agricoles	UNEP (2017)
	-Le boisement, le reboisement et l'agroforesterie font partie des méthodes d'élimination du CO_2 intégrées dans des marchés réglementés et volontaires de carbone selon les juridictions en place	Diaz *et al.* (2011) UNEP (2015b) UNEP (2017)
	-Il existe quelques obstacles à l'application de cette méthode :	
	• Les plantations requirent de grands besoins en superficie et ressources (*i.e.*, eau) pour obtenir de grandes quantités de carbone séquestré	Trabucco *et al.* (2008) Houghton *et al.* (2015)
	• Une certaine compétition peut survenir pour la superficie nécessaire pour les plantations et celle utilisée pour l'agriculture bien que celle-ci puisse être minimisée par l'agroforesterie et la sélection stratégique des terres destinées au boisement et reboisement	Williams-Guillén *et al.* (2008) Kimaro *et al.* (2011) Zomer *et al.* (2016)
	• Incertitudes sur les impacts de cette méthode :	
	• Émissions de GES autres que le CO_2 : CH_4 et N_2O	Benanti *et al.* (2014)
	• Albédo vs. séquestration du carbone par le couvert forestier : deux processus antagonistes à impacts variables sur le forçage radiatif	Kirschbaum *et al.* (2011) Zhao et Jackson (2014)
	• Évapotranspiration : effets incertains sur la température locale	UNEP (2017)
	• Émissions de composés organiques volatils : effets incertains sur le forçage radiatif via les réactions physico-chimiques (oxydation) dans l'atmosphère menant à des aérosols organiques secondaires	Arneth *et al.* (2010) Peñuelas et Staudt (2010) Paasonen *et al.* (2013)
	• Effet de saturation de la fonction de puits de carbone pour les vielles forêts	UNEP (2017)
	-Autres bénéfices du boisement et reboisement :	
	• La forêt répond à des objectifs de développement durable, entre autres par ses services écosystémiques	Nations Unies (2015b) UNEP (2017)
Autres utilisations des terres et marais	-Construction ou restauration d'écosystèmes humides à grande capacité d'éliminer et de séquestrer du carbone :	IPCC (2014c) IPCC (2014a)

Méthode d'élimination	Description de la méthode et des procédés	Références
	• Terres humides, tourbières, forêts mangrove, marais côtiers et marais pour le traitement des eaux	
	-Les tourbières et marais côtiers séquestrent entre 44 et 71% du carbone séquestré dans les écosystèmes terrestres :	Zedler et Kercher (2005)
	• La fonction de séquestration de carbone de ces écosystèmes est fragile et réversible, mais tout de même de grande capacité si l'intégrité en est protégée	Parish *et al.* (2008) Page et Hooijer (2016)
	-Incertitudes de la restauration de milieux humides pour l'effet sur les changements climatiques :	UNEP (2017)
	• Les milieux humides émettent du CH_4 et N_2O et ces émissions peuvent surpasser l'effet de la séquestration du carbone sur les changements climatiques à court terme	Mitsch *et al.* (2013)
Séquestration du carbone dans le sol	-Le principe qui élimine le CO_2 de l'atmosphère consiste à changer la gestion du sol pour faire en sorte qu'il y ait augmentation du contenu en carbone dans le sol, donc d'une élimination de l'atmosphère	UNEP (2017)
	-Les pratiques de gestion menant à une séquestration du carbone sont celles mentionnées au tableau 3 :	Smith *et al.* (2008) Lal (2011) Lal (2013) Smith P. *et al.* (2014)
	• Gestion des terres cultivées, gestion du riz, gestion des pâturages, restauration des terres agricoles, restauration de tourbières dégradées et contrôle de l'incidence des feux en tourbière	
Biochar	-Tel qu'introduit au tableau 3, le biochar est le résidu solide provenant de la pyrolyse de la biomasse	
	-L'élimination du CO_2 par le biochar s'exerce par sa résistance à la décomposition et sa fonction stabilisatrice sur la matière organique dans les sols, soit l'augmentation et le maintien de la fonction de puits de carbone	Lehmann *et al.* (2015) Weng *et al.* (2017)
	-La production de biochar à grande échelle fait face à quelques obstacles :	UNEP (2017)
	• La technologie demeure coûteuse et demande des infrastructures additionnelles	
	• Il faut un apport constant en biomasse	
	• L'application du biochar réduit l'albédo du sol : effets incertains sur le forçage radiatif	Bozzi *et al.* (2015)
	• La technologie a un faible soutien politique	

2.2.2 Méthodes d'élimination du CO_2 basées sur la technologie

Les méthodes d'élimination du CO_2 basées sur la technologie consistent à extraire le CO_2 de l'atmosphère via des procédés physico-chimiques relevant principalement du domaine de l'ingénierie UNEP (2017). Ces méthodes utilisent la technologie pour la capture directe du CO_2 de l'atmosphère, le captation du CO_2 par des minéraux altérés, la captation du CO_2 par les océans en augmentant leur alcalinité et l'intégration et la conversion du CO_2 en matériaux durables (Tableau 12) (UNEP 2017). À l'opposé des méthodes basées sur les puits naturels, les méthodes basées sur la technologie ont de faibles besoins en eau, des émissions nulles de GES autres que le CO_2, un haut niveau de certitude quant au flux de CO_2 éliminé et son devenir, de même qu'un potentiel élevé pour l'économie circulaire (UNEP 2017). Toutes ces méthodes sont pour le moment dans leur balbutiement (National Research Council 2015). Ainsi, une contribution réelle et robuste à l'élimination du CO_2 de l'atmosphère d'ici 2030 demeure incertaine. L'élément de nouveauté et d'émergence de ces méthodes les rend pour le moment très coûteuses (Tableau 10). Toutefois, les quantités de CO_2 pouvant être extraites de l'atmosphère via ces méthodes sont présumées plus grandes que pour celles utilisant la fonction des puits de carbone naturels (Tableau 10). De plus, si ces méthodes basées sur la technologie venaient à s'appliquer, les quantités de CO_2 extraites ne seraient pas dépendantes des effets des changements climatiques sur l'efficacité même du processus (UNEP 2017).

Tableau 12. Compilation des méthodes d'élimination du CO_2 basées sur la technologie. Une partie de l'information présentée dans ce tableau est tirée du *Emission Gap Report* (UNEP 2017).

Méthode d'élimination	**Description de la méthode et des procédés**	**Références**
Capture directe du CO_2 de l'atmosphère	-La méthode consiste à la séparation chimique ou physique du CO_2 de l'air ambiant	Lackner *et al.* (1999) Sanz-Pérez *et al.* (2016)
	-La méthode doit être combinée à un stockage du CO_2 capté en profondeur dans des formations géologiques ou sous forme de matériaux durables afin de répondre à l'objectif d'élimination du CO_2 de l'atmosphère	UNEP (2017) Lassiter III et Misra (2016) Marshall (2017) Carbon Engineering (2019)
	-La source d'énergie de la méthode doit être de source renouvelable afin de réaliser une réduction réelle de GES	UNEP (2017)
Altération accélérée des minéraux	-Des minéraux ou des roches altérées de silicates, carbonates et oxydes ont la capacité de capter du CO_2 et ainsi de le stocker de façon permanente :	Chamberlin (1899) Raymo (1991) Lackner *et al.* (1999) Chiang et Pan (2017)
	• Les minéraux ayant cette capacité de capter le CO_2 sont riches en fer, calcium et magnésium (roches ultramafiques) où les réactions peuvent se faire *in situ* ou *ex situ* pour résulter en des carbonates et minéraux stables	Kelemen et Matter (2008)
	-Potentiel théorique illimité vs. potentiel effectif limité :	IPCC (2005)
	• La cinétique des réactions avec le CO_2 est lente et limite les taux effectifs d'élimination du CO_2	IPCC (2005)
	• La disponibilité du matériel minéral captant le CO_2 est limité	Smith (2016) Taylor *et al.* (2015)
Augmentation de l'alcalinité des océans	-La méthode consiste à augmenter l'alcalinité des océans pour permettre une plus grande captation du CO_2; une eau alcaline permet une plus grande dissolution du CO_2. La captation du CO_2 peut se faire selon ces méthodes :	UNEP (2017)
	• Altération des silicates et carbonates sur terre et transfert dans les océans : c'est un ajout d'ions calcium et magnésium	Rau *et al.* (2007) Hartmann *et al.* (2013)
	• Chaulage de l'océan par l'ajout d'oxyde de calcium ou d'hydroxyde de calcium	Kheshgi (1995) Renforth et Kruger (2013)
	• Hydrolyse de l'eau de mer pour libérer du NaOH ou accélérer la dissolution du carbonate de calcium	Rau *et al.* (2004) House *et al.* (2007)
	-Les incertitudes et obstacles :	
	• Disponibilité incertaine des minéraux près des océans pour le transfert	UNEP (2017)
	• Conséquences inconnues de l'augmentation de l'alcalinité sur les écosystèmes marins	Henderson *et al.* (2008)

Méthode d'élimination	Description de la méthode et des procédés	Références
	• Le déversement d'éléments alcalins dans les océans pourraient aller à l'encontre de conventions internationales, principalement la Convention de Londres avec son protocole sur la prévention de la Pollution Marine par immersion de déchets et autres matières	International Maritime Organization (2019)
Conversion du CO_2 en matériaux durables	-La méthode consiste en un processus physico-chimique permettant de convertir le CO_2 en matériaux durables :	Sandalow *et al.* (2017)
	• Polymères, fibre de carbone, graphène et diamant	
	• L'intégration de carbonates dans des matériaux s'apparentant au ciment fait partie de cette méthode	von der Assen *et al.* (2013) Bruhn *et al.* (2016) Puro (2019)
	-Le concept date des années 70 et introduit récemment dans une perspective de lutte contre les changements climatiques	Aresta (2010) Bruhn *et al.* (2016)
	-La méthode est émergente et le marché pour les matériaux est incertain	CO_2 Sciences (2016)

2.2.3 Méthodes d'élimination du CO_2 combinant les puits de carbone naturels et la technologie

La combinaison des puits de carbone naturels avec la technologie consiste à utiliser des méthodes de bioénergie où les émissions de CO_2 sont captées et stockées en profondeur dans des formations géologiques (UNEP 2017). C'est une des méthodes d'élimination du CO_2 qui s'est avérée prometteuse dans les scénarios d'atténuation du GIEC (Fuss *et al.* 2016, Fuss 2017). Cette méthode a un niveau de maturité technologique (NMT) variant entre 4 et 6 selon le type de bioénergie utilisée (4 à 6 pour la combustion; 5 à 6 pour l'utilisation d'éthanol) (McLaren 2012, Gouvernement du Canada 2019). Un NMT de 6 signifie qu'il y a « Démonstration d'un modèle ou d'un prototype du système ou du sous-système dans un environnement pertinent » (Gouvernement du Canada 2019). Un des défis consiste à combiner les méthodes de bioénergie et de capture et stockage du CO_2 (UNEP 2017).

Trois grandes contraintes ont été identifiées pour l'application à grande échelle de cette méthode (UNEP 2017): 1) la faible acceptabilité sociale (de Best-Waldhober *et al.* 2009, Upham et Roberts 2011, Benson *et al.* 2012, Wallquist *et al.* 2012), 2) l'incertitude concernant la réduction réelle en GES lorsque les déplacements d'activités et d'utilisation des terres sont considérés (Searchinger *et al.* 2009, Plevin *et al.* 2010, Havlík *et al.* 2011, Popp *et al.* 2012, Frank *et al.* 2013, Creutzig *et al.* 2015) et 3) le manque d'incitatifs économiques et de barrières règlementaires sur le stockage en profondeur (de Coninck et Benson 2014). D'autres obstacles au déploiement à grande échelle de cette méthode ont été soulevés, notamment en ce qui a trait à la compétition potentielle pour la superficie utilisée pour faire croître la biomasse et le territoire nécessaire pour stocker le carbone en profondeur (Smith 2016). Cet obstacle ne se présente pas si la biomasse utilisée pour la bioénergie provient de résidus agricoles et forestiers, mais la situation est différente lorsque la croissance de la biomasse nécessite de nouvelles terres (Smith 2016, UNEP 2017). Cette méthode aurait également un impact considérable sur l'utilisation de l'eau, car elle pourrait utiliser jusqu'à 3% de l'eau douce présentement destinée aux humains (Smith 2016).

2.2.4 Conclusion sur les méthodes d'élimination du CO_2

L'utilisation de méthodes d'élimination du CO_2 demeure un complément important aux moyens de réduction de GES afin d'atteindre les objectifs de l'Accord de Paris (UNEP 2017). Pour le moment, les méthodes basées sur les puits de carbone naturels sont plus matures que celles utilisant la technologie (UNEP 2017). Outre l'élimination du CO_2 de l'atmosphère, les méthodes basées sur les puits naturels peuvent avoir d'autres bénéfices collatéraux pour l'atteinte d'objectifs de développement durable : l'amélioration de la qualité de l'eau, la restauration d'écosystèmes, la conservation de la biodiversité, la sécurité alimentaire, la création d'emplois et l'amélioration des rendements en agriculture (UNEP 2017).

3. Le choix des moyens de réduction et d'élimination : aspects et enjeux économiques

Afin d'atteindre ses cibles de réduction de gaz à effet de serre, les gouvernements provincial et fédéral se sont dotés d'outils règlementaires et économiques. Le Québec a été précurseur au Canada en introduisant un système de plafonnement et d'échange avec la Californie.

La littérature qui étudie l'environnement et les réductions de gaz à effet de serre peut être séparée en deux angles : l'angle *top-down* et l'angle *bottom-up* (Böhringer et Rutherford 2008, Huang et al. 2016, Levihn 2016). Le point de vue adopté par l'angle *top-down* est global et intègre des éléments sociaux, industriels et certaines dynamiques économiques de marchés (externalités, learning-by-doing etc.). Cette approche est plus utilisée dans l'élaboration et l'évaluation de politiques publiques (Klinge Jacobsen 1998, Böhringer et Rutherford 2008). Le design des marchés du carbone tient de plus en plus compte de la diversité des contextes à travers le monde et tend à intégrer certains détails mieux capturés par l'analyse *bottom-up* (Newell *et al.* 2013).

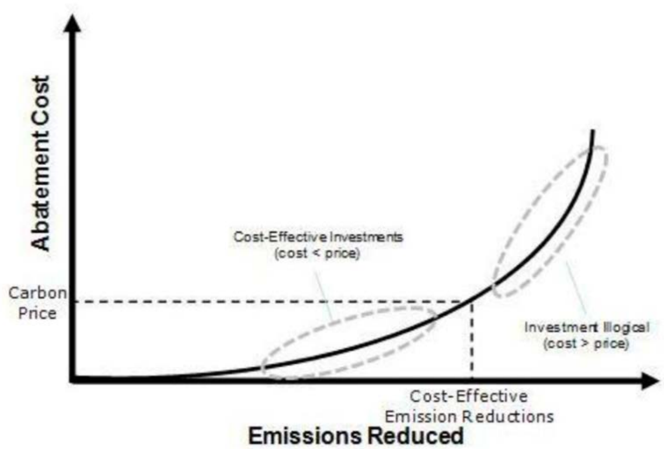
Le point de vue adopté par l'angle *bottom-up* intègre des éléments techniques plus précis, des détails spécifiques à l'industrie à l'étude et des considérations financières (Huang *et al.* 2016). Pour une organisation souhaitant atteindre la carboneutralité, il est important d'analyser toutes les options qui sont présentes sous cet angle.

Nous décrivons sommairement la méthodologie générale à adopter afin d'atteindre la carboneutralité fixée par l'entreprise. L'entreprise devra bien spécifier si des critères de développement local, technologique ou de développement durable viennent modifier le critère du moindre coût associé à l'atteinte de la carboneutralité.

Pour effectuer un choix éclairé des options pour l'atteinte de la carboneutralité, l'entreprise doit sélectionner les options qui apparaissent techniquement faisables parmi celles décrites à la Section 2. Ensuite, une analyse coût-bénéfice (C-B) doit être effectuée afin de trouver le coût de réduction de GES par tonne d'équivalent CO_2 ($ t^{-1} éq-CO_2). La valeur actualisée nette (VAN) est un outil simple et efficace dans l'analyse C-B. Puisqu'un investissement technologique pourra réduire les émissions de GES sur plusieurs années, l'actualisation des bénéfices et coûts courants et/ou futurs est importante. Tout aussi importante est la détermination de l'horizon temporel à l'étude, ainsi que la dépréciation économique et comptable des investissements effectués.

Une fois cette étape effectuée, l'organisation doit ordonner les options techniquement réalisables en ordre croissant de coût de réduction afin de construire une courbe de coût marginal de réduction, ou *Marginal Abatement Cost Curve* (MACC) de GES.

En présence d'options externes (achat de crédits chez des tierces parties, sur des marchés réglementés et/ou volontaires), celles-ci doivent être intégrées à la MACC. En absence de contraintes d'achat, le coût des options externes agis comme un plafond : une firme souhaitant minimiser ses coûts de réduction de GES ne développera pas les stratégies internes si les coûts associés dépassent celles des options externes. La figure suivante illustre cet aspect (Nordrum *et al.* 2011):



En réalité, la MACC aura plutôt la forme d'un escalier, où chaque option sera associée à un coût unitaire et une quantité maximale. Nous identifions, dans la littérature, des estimations de la MACC dans le domaine agricole, de l'industrie lourde et du pétrole et gaz.

Les hypothèses qui sous-tendent l'analyse C-B et les éléments de la VAN doivent aussi être questionnées, particulièrement puisque le projet ne sera en activité que dans plusieurs années. Quel taux d'actualisation est utilisé dans la VAN? Le taux d'actualisation privé est plus faible que le taux d'actualisation social, ce qui peut rendre des projets technologiques socialement désirables impossibles à réaliser par le privé (Klinge Jacobsen 1998).

Le niveau de maturité des technologies à l'étude est très important. D'abord de nouvelles technologies peuvent aussi être plus risquées, ou être associées à des entretiens coûteux dans le futur. Il est alors intéressant de catégoriser les options techniquement réalisables selon leur niveau de risque (Nordrum *et al.* 2011). Une organisation peut aussi approcher le choix de technologies comme le choix d'un portefeuille financier, où les rendements sont risqués; en présence d'incertitude, une certaine diversification des sources de réduction de GES est souhaitable.

Un autre facteur à introduire dans l'analyse C-B est l'introduction de certaines options dès la construction des installations. L'investissement dans ces technologies peut être analysé dans le contexte des options réelles : les coûts sont encourus immédiatement alors que les bénéfices sont incertains, surtout en comparaison des nouvelles technologies plus efficaces ou mieux adaptées qui peuvent être développées entre temps. Cette option a une valeur qu'il faut quantifier (*option value*).

Finalement, le choix optimal des options permettant l'atteinte de la carboneutralité dépend du marché du carbone au Québec, des développements canadiens et nord-américain et de l'évolution de la réglementation encadrant les marchés du carbone. L'efficacité d'une option d'atténuation est toujours relative et dépend du prix de carbone sur les marchés. Certains de ces éléments proviennent d'effets de marchés identifiés par la littérature *top-down*, comme les économies d'échelle dans le développement et la production des mesures d'atténuation (Böhringer et Rutherford 2008, Chen *et al.* 2017), ou encore des enjeux macroéconomiques (taux de change, récession, prix des combustibles fossiles).

Le tableau 13 synthétise les aspects discutés ici pour l'atteinte de la carboneutralité

Tableau 13. Synthèse des aspects économiques à considérer pour l'atteinte de la carboneutralité par une entreprise.

Aspect économique/financier considéré	**Description**	**Références**
Atténuation des GES	Méthodes	(Krause 1996, Delhotal *et al.* 2006, Böhringer et Rutherford 2008, Rehl et Muller 2013, Huang *et al.* 2016, Levihn 2016, Timilsina *et al.* 2017, Wegener *et al.* 2019)
Construction d'une courbe de coût marginal de réduction	Agriculture	(Gallaher *et al.* 2009, Moran *et al.* 2011, Jones *et al.* 2015)
	Autres industries lourdes	(Rehan et Nehdi 2005, Liu *et al.* 2016, Leeson *et al.* 2017, Liu *et al.* 2017a)
	Pétrole et gaz	(Nordrum *et al.* 2011, Chan *et al.* 2016, Chen *et al.* 2017, Yáñez *et al.* 2018, Wegener *et al.* 2019)
	Vision globale (macro)	(Krause 1996, Klinge Jacobsen 1998, Delhotal *et al.* 2006, Lutsey et Sperling 2009, Levihn *et al.* 2014, Vogt-Schilb et Hallegatte 2014)
Facteurs de décision	Risque et options	(Pommeret et Schubert 2009, Nordrum *et al.* 2011, De Cian et Massimo 2012, Vogt-Schilb et Hallegatte 2014, Christiansen et Smith 2015, Chen *et al.* 2017)
	Tarification et SPEDE-WCI	

4. Les méthodologies de réduction et de séquestration des GES

Les crédits compensatoires proviennent d'activité sur le terrain visant à réduire les GES ou à absorber du CO_2 au-delà du cours normal des affaires. Tel que vu dans les précédentes sections, deux types de marchés de crédits compensatoires existent : règlementaire et volontaire. Les crédits compensatoires vendus sur les marchés volontaires suivent généralement les règles prescrites des organismes de normalisation volontaire. Les crédits peuvent être échangés sur un marché primaire (vente du promoteur de projets aux intermédiaires ou directement aux acheteurs finaux) et sur un marché secondaire (des intermédiaires aux acheteurs finaux) (Hamrick et Gallant 2017). En 2016, la plupart des crédits compensatoires vendus sur les marchés volontaires provenaient de projets éoliens, de projets REDD+ ou de projets de méthane de sites d'enfouissement (Hamrick et Gallant 2017).

La meilleure stratégie pour l'achat de crédits compensatoires consiste à rechercher ceux qui répondent à des normes rigoureuses liées à un programme. Il faut également s'assurer que les projets de réduction dont découlent ces crédits ont suivi des méthodologies approuvées et reconnues et que les réductions ou les absorptions soient certifiées par des vérificateurs indépendants (David Suzuki Foundation & Pembina Institute 2009). La qualité des crédits compensatoires est directement proportionnelle à la crédibilité de l'affirmation de carboneutralité.

Les paragraphes suivants présentent quelques programmes, autres que le système de plafonnement et d'échange de droits d'émissions de gaz à effet de serre du Québec (SPEDE) discuter aux sections précédentes, qui ont un registre de projets de réduction et qui proposent des protocoles de réduction.

4.1 Programmes pour des réductions de GES

4.1.1 Verra - The VCS Program

The VCS Program est un programme volontaire de réduction de GES qui est l'un des plus utilisés dans le monde avec plus de 1 300 projets VCS certifiés (200 millions de tonnes d'éq-CO2). The VCS Program a pour mission de s'assurer de la crédibilité des projets de réduction des émissions à l'aide d'un ensemble de règles et d'exigences. Une fois que les projets ont été certifiés selon les exigences du Programme VCS, les développeurs de projets peuvent obtenir des crédits de GES échangeables qui sont appelés « unités de carbone vérifiées (VCU) ». Le rôle de Verra est donc d'élaborer et d'administrer ce programme. Il doit également s'assurer de la surveillance de toutes les composantes opérationnelles de VCS Program et de la mise à jour des règles afin d'assurer la qualité des engagements de conformité volontaire (Verra 2019). On peut trouver la liste des projets à cette adresse : https://www.vcsprojectdatabase.org/#/home.

Solutions Will enregistre ses projets dans ce programme et propose donc des projets issus de la région et du Québec (Solution Will 2019).

4.1.2 Climate Action Reserve

La mission de Climate Action Reserve est d'élaborer, de promouvoir et de soutenir des solutions novatrices et crédibles fondées sur le marché du carbone qui profitent à l'économie, aux écosystèmes et à la société.

Climate Action Reserve établit des normes de qualité pour les projets de réduction et d'absorption, supervise des organismes de vérification indépendants, émet des crédits carbone générés par ces projets et suit les transactions de crédits au fil du temps dans un système transparent et accessible au public.

Son programme de crédits compensatoires de carbone vise à démontrer que ces crédits sont de haute qualité et représentent des réductions réelles. Le programme permet également de stimuler la croissance des nouvelles technologies vertes et permet d'atteindre les objectifs de réduction des émissions à un moindre coût (Climate Action Reserve 2019). On peut trouver la liste de vendeurs à cette adresse : https://www.climateactionreserve.org/how/offsets-marketplace/.

Ce programme n'a aucun projet au Canada. Seulement aux États-Unis et au Mexique.

4.1.3 American Carbon Registry

L'American Carbon Registry (ARC) est un registre de projets de réduction des émissions de GES approuvées pour le California Cap-and-Trade program. Dans ce rôle, l'ACR travaille avec l'Air Resources Board (ARB) pour superviser l'enregistrement et la délivrance des crédits de compensation admissibles au registre (American Carbon Registry 2019).

L'ACR supervise l'enregistrement et la vérification des projets de compensation du carbone selon des méthodologies ou des protocoles approuvés de comptabilisation du carbone. Il émet également des compensations sur un registre d'un marché volontaire et du marché réglementé de la Californie. Les crédits compensatoires sont propres aux activités distinctes d'ACR sur le marché règlementaire de la Californie et sur le marché mondial du carbone volontaire (American Carbon Registry 2019). La provenance des crédits carbone sur le marché volontaire n'est pas mentionnée. Il faut s'inscrire au registre pour s'informer sur les projets. Les échanges entre les parties prenantes pour l'achat de crédits compensatoires se font sur le site de l'organisation : https://americancarbonregistry.org/how-it-works/membership.

4.1.4 Nations Unies - Mécanisme de Développement Propre

Le Mécanisme de Développement Propre (MDP) permet aux projets de réduction des émissions dans les pays en développement d'obtenir des crédits de réduction certifiée des émissions (RCE). Ces RCE peuvent être échangés, vendus et utilisés par les pays industrialisés pour atteindre une partie de leurs objectifs de réduction des émissions dans le cadre du Protocole de Kyoto.

Le MDP est la principale source de revenus du Fonds d'adaptation de la Convention-cadre des Nations unies sur les changements climatiques (CCNUCC), qui a été créée pour financer des projets et programmes d'adaptation dans les pays en développement faisant partie du Protocole de Kyoto qui sont particulièrement vulnérables aux effets négatifs des changements climatiques. Le Fonds d'adaptation est financé par un prélèvement de 2% sur les RCE émises par le MDP (UNFCCC 2019). Les projets de réduction sont principalement en Amérique du Sud, en Afrique et en Asie.

La liste des crédits compensatoires est disponible à l'adresse suivante : https://cdm.unfccc.int/Registry/vcnotices/notices_list.

4.1.5 Gold Standard

Gold Standard a été créé en 2003 pour s'assurer que les projets de réduction des émissions de carbone dans le cadre du MDP de l'Organisation des Nations Unies contribuent également au développement durable. La mission de Gold Standard se concentre principalement sur l'élaboration et l'évolution d'une méta-norme flexible qui établit la référence pour les interventions en matière de climat et de développement et fait également la promotion d'une plus grande ambition dans les marchés et les cadres politiques. L'objectif des stratégies de cette organisation est de réduire les coûts et la complexité ainsi que d'augmenter la valeur et la crédibilité des certifications. Les crédits compensatoires affichant cette norme ont une valeur ajoutée en termes de développement durable (Gold Standard 2019). Comme pour le CDM, les projets de réduction sont principalement en Amérique du Sud, en Afrique et en Asie. On peut voir et acheter des crédits compensatoires « Gold Standard » dérivés de projets de réduction et d'absorption à l'adresse suivante : https://www.goldstandard.org/get-involved/make-an-impact.

4.1.6 CSA - GES ÉcoProjets®

GES ÉcoProjets® est un registre permettant de déclarer et de présenter les réductions ou les absorptions des GES. Le mandat du registre des GES ÉcoProjets® est d'inscrire et de soustraire les projets de réduction et d'absorption vérifiés de la liste. GES ÉcoProjets® attribue un numéro de série unique à chaque tonne de réduction ou d'absorption vérifiée et les renseignements affichés dans ce registre servent de cadre pour la gestion du risque pour les initiatives volontaires, les marchés des GES et la déclaration de conformité règlementaire. GES ÉcoProjets® suit les normes ISO 14064 portant sur l'inventaire, les projets de réduction et leur vérification (CSA 2019a). Les projets de réduction se situent principalement au Canada, mais le registre couvre également d'autres pays. On peut voir la liste des projets à l'adresse suivante : https://www.csaregistries.ca/cleanprojects/masterprojects_f.cfm.

4.1.7 Alberta Carbon Registry

Les crédits de réduction des émissions (CRÉ) du Alberta Carbon Registry sont gérés par le Groupe CSA en partenariat avec le gouvernement de l'Alberta. Ces crédits ne sont disponibles que pour les organisations en Alberta et les projets sont réalisés en Alberta (CSA 2019b). Ce marché du carbone est règlementaire et est similaire à celui du Québec. On peut voir la liste des projets à l'adresse suivante : https://www.csaregistries.ca/albertacarbonregistries/eor_listing.cfm.

4.2 Synthèse des registres pour les principaux protocoles de réduction des GES

Le tableau 14 présente les principaux protocoles de réduction classifiés par catégorie et par registre. Une liste complète et détaillée des protocoles est présentée à l'annexe 2.1.

Tableau 14. Protocoles de réduction et d'absorption classifié par type de registre et par catégorie.

Catégories	Registres	Protocoles
Agriculture	***Alberta Carbon Registry***	Agricultural Nitrous Oxide Emission Reductions
		Conservation Cropping
		Compost Additions to Grazed Grasslands
		Reduced Use of Nitrogen Fertilizer on Agricultural Crops
		Rice Management Systems
	Climate Action Reserve	Nitrogen Management
		Rice Cultivation
	The VCS Program	VM0017 Adoption of Sustainable Agricultural Land Management, v1.014
		VM0021 Soil Carbon Quantification Methodology, v1.014
		VM0022 Quantifying N2O Emissions Reductions in Agricultural Crops through Nitrogen Fertilizer Rate Reduction, v1.114
		VM0026 Methodology for Sustainable Grassland Management (SGM), v1.014
		VM0032 Methodology for the Adoption of Sustainable Grasslands through Adjustment of Fire and Grazing, v1.0
Bétail et fumier	***Alberta Carbon Registry***	Emissions Reductions from Dairy Cattle
		Reduced Age at Harvest of Beef Cattle
		Reducing Greenhouse Gas Emissions from Fed Cattle
		Selection for Low Residual Feed Intake Markers in Beef Cattle
		Grazing Land and Livestock Management
		Methane Recovery in Animal Manure Management Systems
	Climate Action Reserve	Mexico Livestock
		U.S. Livestock
	Mécanisme de Développement Propre	GHG emission reductions from manure management systems --- Version 8.0
	The VCS Program	VMR0003 Revisions to AMS-III.Y to Include Use of Organic Bedding Material, v1.0

Catégories	Registres	Protocoles
	SPEDE	Protocole 1 – Recouvrement d'une fosse à lisier – Destruction du CH_4;
Captation et stockage	***Alberta Carbon Registry***	CO_2 Capture and Permanent Storage in Deep Saline Aquifers
	American Carbon Registry	Carbon Capture and Storage Projects
Déchets	***Alberta Carbon Registry***	Greenhouse Gas Emission Reductions from Pneumatic Devices
		Landfill Gas Capture and Combustion
	American Carbon Registry	Landfill Gas Destruction and Beneficial Use Projects
		Recycling of Transformer Oil
		Re-refining Used Lubricating Oils
	Climate Action Reserve	Aerobic Composting
		Aerobic Landfill Bioreactor
		Mexico Landfill
		Organic Waste Composting
		Organic Waste Digestion
		U.S Landfill
	Mécanisme de Développement Propre	Alternative waste treatment processes --- Version 2.0
		Treatment of wastewater --- Version 7.0
	The VCS Program	Flaring or use of landfill gas --- Version 18.1
	SPEDE	Protocole 2 – Lieux d'enfouissement – Destruction ou traitement du CH_4;
Énergie	***Alberta Carbon Registry***	Biofuel Production and Usage
		Distributed Renewable Energy Generation
		Energy Efficiency Projects
		Energy Generation from the Combustion of Biomass Waste
		Low-Retention, Water-Powered Electricity Generation as Run-of-the-River or an Existing Reservoir
		Solar Electricity Generation
		Waste Heat Recovery
		Wind-Powered Electricity Generation
	Climate Action Reserve	Mexico Boiler Efficiency
	Mécanisme de Développement Propre	Co-firing of biomass residues for heat generation and/or electricity generation in grid connected power plants --- Version 1.0.0
		Construction and operation of new grid connected fossil fuel fired power plants using a less GHG intensive technology --- Version 5.0.0
		Construction of a new natural gas power plant --- Version 2.0
		Conversion from single cycle to combined cycle power generation --- Version 6.1.0
		Electricity and heat generation from biomass --- Version 14.0
		Electricity generation from biomass in power-only plants --- Version 4.0
		Fossil fuel based cogeneration for identified recipient facility(ies) --- Version 2.0
		Fuel switching from coal and/or petroleum fuels to natural gas in existing power plants for electricity generation --- Version 3.0
		Fuel switching from coal or petroleum fuel to natural gas --- Version 5.0
		Grid-connected electricity generation from renewable sources
		Introduction of an efficiency improvement technology in a boiler --- Version 1.0
		Natural gas substitution by biogenic methane produced from the anaerobic digestion of organic waste --- Version 1.0
		Production of biofuel --- Version 3.1
		Waste energy recovery --- Version 6.0
	The VCS Program	Grid-connected electricity generation from renewable sources --- Version 19.0

Catégories	Registres	Protocoles
		VM0001 Infrared Automatic Refrigerant Leak Detection Efficiency Project Methodology, v1.111
		VM0002 New Cogeneration Facilities Supplying Less Carbon Intensive Electricity to Grid and/or Hot Water to One or More Grid Customers, v1.01
		VM0008 Weatherization of Single Family and Multi-Family Buildings, v1.13
		VM0013 Calculating Emission Reductions from Jet Engine Washing, v1.03
		VM0014 Interception and Destruction of Fugitive Methane from Coal Bed Methane (CBM) Seeps, v1.01
		VM0018 Energy Efficiency and Solid Waste Diversion Activities within a Sustainable Community, v1.03
		VM0025 Campus Clean Energy and Energy Efficiency, v1.01
		VMR0005 Methodology for Installation of Low-Flow Water Devices, v1.0
Foresterie	***American Carbon Registry***	Afforestation and Reforestation of Degraded Lands
		Forest
		Improved Forest Management (IFM) for Non-Federal U.S. Forestlands
	Climate Action Reserve	Mexico Forest
		Urban Forest Management
		Urban Tree Planting
	The VCS Program	VM0003 Methodology for Improved Forest Management through Extension of Rotation Age, v1.214
		VM0004 Methodology for Conservation Projects that Avoid Planned Land Use Conversion in Peat Swamp Forests, v1.014
		VM0005 Methodology for Conversion of Low-productive Forest to High-productive Forest, v1.214
		VM0006 Methodology for Carbon Accounting for Mosaic and Landscape-scale REDD Projects, v2.214
		VM0007 REDD+ Methodology Framework (REDD-MF), v1.514
		VM0009 Methodology for Avoided Ecosystem Conversion, v3.014
		VM0010 Methodology for Improved Forest Management: Conversion from Logged to Protected Forest, v1.314
		VM0011 Methodology for Calculating GHG Benefits from Preventing Planned Degradation, v1.014
		VM0012 Improved Forest Management in Temperate and Boreal Forests (LtPF), v1.214
		VM0015 Methodology for Avoided Unplanned Deforestation, v1.114
		VM0021 Soil Carbon Quantification Methodology, v1.014
		VM0029 Methodology for Avoided Forest Degradation through Fire Management, v1.014
		VM0034 British Columbia Forest Carbon Offset Methodology, v1.014
		VM0035 Methodology for Improved Forest Management through Reduced Impact Logging v1.014
		VM0037 Methodology for Implementation of REDD+ Activities in Landscapes Affected by Mosaic Deforestation and Degradation, v1.0
Milieu humide	***American Carbon Registry***	Restoration of California Deltaic and Coastal Wetlands
		Restoration of Degraded Wetlands of the Mississippi Delta
		Restoration of Pocosin Wetlands
	The VCS Program	VM0004 Methodology for Conservation Projects that Avoid Planned Land Use Conversion in Peat Swamp Forests, v1.014
		VM0024 Methodology for Coastal Wetland Creation, v1.014
		VM0026 Methodology for Sustainable Grassland Management (SGM), v1.014
		VM0027 Methodology for Rewetting Drained Tropical Peatlands, v1.014
		VM0032 Methodology for the Adoption of Sustainable Grasslands through Adjustment of Fire and Grazing, v1.014

Catégories	Registres	Protocoles
		VM0033 Methodology for Tidal Wetland and Seagrass Restoration, v1.014
		VM0036 Methodology for Rewetting Drained Temperate Peatlands v1.0
Mine	***American Carbon Registry***	Coal Mine Methane
	Mécanisme de Développement Propre	Abatement of methane from coal mines --- Version 8.0
	The VCS Program	VMR0001 Revisions to ACM0008 to Include Pre-drainage of Methane from an Active Open Cast Mine as a Methane Emission Reduction Activity, v1.08
		VMR0002 Revisions to ACM0008 to Include Methane Capture and Destruction from Abandoned Coal Mines, v1.0
	SPEDE	Protocole 4 - Mines de charbon en exploitation – Destruction du CH_4 provenant du système de dégazage;
		Protocole 5 - Mines de charbon souterraines en exploitation – Destruction du CH_4 de ventilation.
Prairie	***American Carbon Registry***	Avoided Conversion of Grasslands and Shrublands to Crop Production
	Climate Action Reserve	Grassland
	The VCS Program	VM0026 Methodology for Sustainable Grassland Management (SGM), v1.014
		VM0032 Methodology for the Adoption of Sustainable Grasslands through Adjustment of Fire and Grazing, v1.0
Procédé industriel	***American Carbon Registry***	Advanced Refrigeration Systems
		Certified Reclaimed HFC Refrigerants
		Destruction of Ozone Depleting Substances and High-GWP Foam
		Replacement of SF_6 with Alternate Cover Gas in the Magnesium Industry
		Transition to Advanced Formulation Blowing Agents in Foam Manufacturing and Use
	Climate Action Reserve	Mexico Ozone Depleting Substances
		Nitric Acid Production
		Ozone Depleting Substances
	Mécanisme de Développement Propre	Emission reductions from raw material switch in clinker production --- Version 4.0
		Increasing the blend in cement production --- Version 7.1.0
		N_2O abatement from nitric acid production --- Version 4.0
		Partial substitution of fossil fuels in cement or quicklime manufacture --- Version 8.0
		Reduction of emissions from charcoal production by improved kiln design and/or abatement of methane --- Version 1.0.0
	The VCS Program	VM0016 Recovery and Destruction of Ozone-Depleting Substances (ODS) from Products, v1.111
		VM0019 Fuel Switch from Gasoline to Ethanol in Flex-Fuel Vehicle Fleets, v1.01
		VM0020 Transport Energy Efficiency from Lightweight Pallets, v1.03
		VM0023 Reduction of GHG Emissions in Propylene Oxide Production, v1.05
		VM0030 Methodology for Pavement Application using Sulphur Substitute, v1.04
		VM0031 Methodology for Precast Concrete Production using Sulphur Substitute, v1.0
	SPEDE	Protocole 3 – Destruction des substances appauvrissant la couche d’ozone (SACO) contenues dans des mousses isolantes ou utilisées en tant que réfrigérant provenant d’appareils de réfrigération, de congélation et de climatisation
Transport	***Alberta Carbon Registry***	Engine Fuel Management and Vent Gas Capture
		Mass Rapid Transit Projects --- Version 4.0

Catégories	Registres	Protocoles
	Mécanisme de Développement Propre	Truck Stop Electrification
	The VCS Program	VM0028 Methodology for Carpooling, v1.07
		VM0030 Methodology for Pavement Application using Sulphur Substitute, v1.04
		VM0038 Methodology for Electric Vehicle Charging Systems, v1.01
		VMR0003 Revisions to AMS-III.Y to Include Use of Organic Bedding Material, v1.0
		VMR0004 Revisions to AMS-III.BC to Include Mobile Machinery, v1.03

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Annexe 2.1 – Registres pour les principaux protocoles de réduction des GES

Tableau A1. Liste détaillée de protocoles applicables pour des projets de réduction de GES.

Item	Registres	Protocoles de réduction de GES
1	The VCS Program	VM0002 New Cogeneration Facilities Supplying Less Carbon Intensive Electricity to Grid and/or Hot Water to One or More Grid Customers, v1.01
2	The VCS Program	VM0008 Weatherization of Single Family and Multi-Family Buildings, v1.13
3	The VCS Program	VM0013 Calculating Emission Reductions from Jet Engine Washing, v1.03
4	The VCS Program	VM0018 Energy Efficiency and Solid Waste Diversion Activities within a Sustainable Community, v1.03
5	The VCS Program	VM0025 Campus Clean Energy and Energy Efficiency, v1.01
6	The VCS Program	VMR0005 Methodology for Installation of Low-Flow Water Devices, v1.0
7	The VCS Program	VM0001 Infrared Automatic Refrigerant Leak Detection Efficiency Project Methodology, v1.111
8	The VCS Program	VM0014 Interception and Destruction of Fugitive Methane from Coal Bed Methane (CBM) Seeps, v1.01
9	The VCS Program	VM0016 Recovery and Destruction of Ozone-Depleting Substances (ODS) from Products, v1.111
10	The VCS Program	VM0023 Reduction of GHG Emissions in Propylene Oxide Production, v1.05
11	The VCS Program	VM0030 Methodology for Pavement Application using Sulphur Substitute, v1.04
12	The VCS Program	VM0031 Methodology for Precast Concrete Production using Sulphur Substitute, v1.0
13	The VCS Program	VM0019 Fuel Switch from Gasoline to Ethanol in Flex-Fuel Vehicle Fleets, v1.01
14	The VCS Program	VM0020 Transport Energy Efficiency from Lightweight Pallets, v1.03
15	The VCS Program	VM0028 Methodology for Carpooling, v1.07
16	The VCS Program	VM0030 Methodology for Pavement Application using Sulphur Substitute, v1.04
17	The VCS Program	VM0038 Methodology for Electric Vehicle Charging Systems, v1.01
18	The VCS Program	VMR0004 Revisions to AMS-III.BC to Include Mobile Machinery, v1.03
19	The VCS Program	VMR0003 Revisions to AMS-III.Y to Include Use of Organic Bedding Material, v1.0
20	The VCS Program	VM0005 Methodology for Conversion of Low-productive Forest to High-productive Forest, v1.214
21	The VCS Program	VM0017 Adoption of Sustainable Agricultural Land Management, v1.014
22	The VCS Program	VM0021 Soil Carbon Quantification Methodology, v1.014
23	The VCS Program	VM0022 Quantifying N2O Emissions Reductions in Agricultural Crops through Nitrogen Fertilizer Rate Reduction, v1.114
24	The VCS Program	VM0026 Methodology for Sustainable Grassland Management (SGM), v1.014
25	The VCS Program	VM0032 Methodology for the Adoption of Sustainable Grasslands through Adjustment of Fire and Grazing, v1.0
26	The VCS Program	VMR0001 Revisions to ACM0008 to Include Pre-drainage of Methane from an Active Open Cast Mine as a Methane Emission Reduction Activity, v1.08
27	The VCS Program	VMR0002 Revisions to ACM0008 to Include Methane Capture and Destruction from Abandoned Coal Mines, v1.0
28	The VCS Program	VM0003 Methodology for Improved Forest Management through Extension of Rotation Age, v1.214

Item	Registres	Protocoles de réduction de GES
29	The VCS Program	VM0004 Methodology for Conservation Projects that Avoid Planned Land Use Conversion in Peat Swamp Forests, v1.014
30	The VCS Program	VM0006 Methodology for Carbon Accounting for Mosaic and Landscape-scale REDD Projects, v2.214
31	The VCS Program	VM0007 REDD+ Methodology Framework (REDD-MF), v1.514
32	The VCS Program	VM0009 Methodology for Avoided Ecosystem Conversion, v3.014
33	The VCS Program	VM0010 Methodology for Improved Forest Management: Conversion from Logged to Protected Forest, v1.314
34	The VCS Program	VM0011 Methodology for Calculating GHG Benefits from Preventing Planned Degradation, v1.014
35	The VCS Program	VM0012 Improved Forest Management in Temperate and Boreal Forests (LtPF), v1.214
36	The VCS Program	VM0015 Methodology for Avoided Unplanned Deforestation, v1.114
37	The VCS Program	VM0029 Methodology for Avoided Forest Degradation through Fire Management, v1.014
38	The VCS Program	VM0034 British Columbia Forest Carbon Offset Methodology, v1.014
39	The VCS Program	VM0035 Methodology for Improved Forest Management through Reduced Impact Logging v1.014
40	The VCS Program	VM0037 Methodology for Implementation of REDD+ Activities in Landscapes Affected by Mosaic Deforestation and Degradation, v1.0
41	The VCS Program	VM0009 Methodology for Avoided Ecosystem Conversion, v3.014
42	The VCS Program	VM0021 Soil Carbon Quantification Methodology, v1.014
43	The VCS Program	VM0026 Methodology for Sustainable Grassland Management (SGM), v1.014
44	The VCS Program	VM0032 Methodology for the Adoption of Sustainable Grasslands through Adjustment of Fire and Grazing, v1.0
45	The VCS Program	VM0004 Methodology for Conservation Projects that Avoid Planned Land Use Conversion in Peat Swamp Forests, v1.014
46	The VCS Program	VM0024 Methodology for Coastal Wetland Creation, v1.014
47	The VCS Program	VM0027 Methodology for Rewetting Drained Tropical Peatlands, v1.014
48	The VCS Program	VM0033 Methodology for Tidal Wetland and Seagrass Restoration, v1.014
49	The VCS Program	VM0036 Methodology for Rewetting Drained Temperate Peatlands v1.0
50	The VCS Program	VM0026 Methodology for Sustainable Grassland Management (SGM), v1.014
51	The VCS Program	VM0032 Methodology for the Adoption of Sustainable Grasslands through Adjustment of Fire and Grazing, v1.014
52	The VCS Program	VMR0003 Revisions to AMS-III.Y to Include Use of Organic Bedding Material, v1.0
53	The VCS Program	Flaring or use of landfill gas --- Version 18.1
54	The VCS Program	Grid-connected electricity generation from renewable sources --- Version 19.0
55	Mécanisme du Développement Propre	Partial substitution of fossil fuels in cement or quicklime manufacture --- Version 8.0
56	Mécanisme du Développement Propre	Increasing the blend in cement production --- Version 7.1.0
57	Mécanisme du Développement Propre	Electricity and heat generation from biomass --- Version 14.0

Item	Registres	Protocoles de réduction de GES
58	Mécanisme du Développement Propre	Conversion from single cycle to combined cycle power generation --- Version 6.1.0
59	Mécanisme du Développement Propre	Abatement of methane from coal mines --- Version 8.0
60	Mécanisme du Développement Propre	Fuel switching from coal or petroleum fuel to natural gas --- Version 5.0
61	Mécanisme du Développement Propre	GHG emission reductions from manure management systems --- Version 8.0
62	Mécanisme du Développement Propre	Fuel switching from coal and/or petroleum fuels to natural gas in existing power plants for electricity generation --- Version 3.0
63	Mécanisme du Développement Propre	Waste energy recovery --- Version 6.0
64	Mécanisme du Développement Propre	Construction and operation of new grid connected fossil fuel fired power plants using a less GHG intensive technology --- Version 5.0.0
65	Mécanisme du Développement Propre	Treatment of wastewater --- Version 7.0
66	Mécanisme du Développement Propre	Emission reductions from raw material switch in clinker production --- Version 4.0
67	Mécanisme du Développement Propre	Mass Rapid Transit Projects --- Version 4.0
68	Mécanisme du Développement Propre	Production of biofuel --- Version 3.1
69	Mécanisme du Développement Propre	Electricity generation from biomass in power-only plants --- Version 4.0
70	Mécanisme du Développement Propre	N2O abatement from nitric acid production --- Version 4.0
71	Mécanisme du Développement Propre	Co-firing of biomass residues for heat generation and/or electricity generation in grid connected power plants --- Version 1.0.0
72	Mécanisme du Développement Propre	Reduction of emissions from charcoal production by improved kiln design and/or abatement of methane --- Version 1.0.0
73	Mécanisme du Développement Propre	Alternative waste treatment processes --- Version 2.0
74	Mécanisme du Développement Propre	Introduction of an efficiency improvement technology in a boiler --- Version 1.0
75	Mécanisme du Développement Propre	Natural gas substitution by biogenic methane produced from the anaerobic digestion of organic waste --- Version 1.0

Item	Registres	Protocoles de réduction de GES
76	Mécanisme du Développement Propre	Construction of a new natural gas power plant --- Version 2.0
77	Mécanisme du Développement Propre	Fossil fuel based cogeneration for identified recipient facility(ies) --- Version 2.0
78	Mécanisme du Développement Propre	Grid-connected electricity generation from renewable sources
79	Mécanisme du Développement Propre	Truck Stop Electrification
80	American Carbon Registry	Advanced Refrigeration Systems
81	American Carbon Registry	Certified Reclaimed HFC Refrigerants
82	American Carbon Registry	Destruction of Ozone Depleting Substances and High-GWP Foam
83	American Carbon Registry	Replacement of SF6 with Alternate Cover Gas in the Magnesium Industry
84	American Carbon Registry	Transition to Advanced Formulation Blowing Agents in Foam Manufacturing and Use
85	American Carbon Registry	Afforestation and Reforestation of Degraded Lands
86	American Carbon Registry	Avoided Conversion of Grasslands and Shrublands to Crop Production
87	American Carbon Registry	Compost Additions to Grazed Grasslands
88	American Carbon Registry	Improved Forest Management (IFM) for Non-Federal U.S. Forestlands
89	American Carbon Registry	Restoration of California Deltaic and Coastal Wetlands
90	American Carbon Registry	Restoration of Degraded Wetlands of the Mississippi Delta
91	American Carbon Registry	Restoration of Pocosin Wetlands
92	American Carbon Registry	Rice Management Systems
93	American Carbon Registry	Carbon Capture and Storage Projects
94	American Carbon Registry	Grazing Land and Livestock Management
95	American Carbon Registry	Methane Recovery in Animal Manure Management Systems
96	American Carbon Registry	Reduced Use of Nitrogen Fertilizer on Agricultural Crops
97	American Carbon Registry	Landfill Gas Destruction and Beneficial Use Projects
98	American Carbon Registry	Re-refining Used Lubricating Oils
99	American Carbon Registry	Recycling of Transformer Oil
100	American Carbon Registry	Coal Mine Methane
101	American Carbon Registry	Forest
102	Climate Action Reserve	Grassland
103	Climate Action Reserve	Mexico Boiler Efficiency
104	Climate Action Reserve	Mexico Forest
105	Climate Action Reserve	Mexico Landfill
106	Climate Action Reserve	Mexico Livestock
107	Climate Action Reserve	Mexico Ozone Depleting Substances

Item	Registres	Protocoles de réduction de GES
108	Climate Action Reserve	Nitric Acid Production
109	Climate Action Reserve	Nitrogen Management
110	Climate Action Reserve	Organic Waste Composting
111	Climate Action Reserve	Organic Waste Digestion
112	Climate Action Reserve	Ozone Depleting Substances
113	Climate Action Reserve	Rice Cultivation
114	Climate Action Reserve	Urban Forest Management
115	Climate Action Reserve	Urban Tree Planting
116	Climate Action Reserve	U.S Landfill
117	Climate Action Reserve	U.S. Livestock
118	Climate Action Reserve	Aerobic Composting
119	Climate Action Reserve	Aerobic Landfill Bioreactor
120	Alberta Caborn Registry	Agricultural Nitrous Oxide Emission Reductions
121	Alberta Caborn Registry	Biofuel Production and Usage
122	Alberta Caborn Registry	CO2 Capture and Permanent Storage in Deep Saline Aquifers
123	Alberta Caborn Registry	Conservation Cropping
124	Alberta Caborn Registry	Distributed Renewable Energy Generation
125	Alberta Caborn Registry	Emissions Reductions from Dairy Cattle
126	Alberta Caborn Registry	Energy Efficiency Projects
127	Alberta Caborn Registry	Energy Generation from the Combustion of Biomass Waste
128	Alberta Caborn Registry	Engine Fuel Management and Vent Gas Capture
129	Alberta Caborn Registry	Greenhouse Gas Emission Reductions from Pneumatic Devices
130	Alberta Caborn Registry	Landfill Gas Capture and Combustion
131	Alberta Caborn Registry	Low-Retention, Water-Powered Electricity Generation as Run-of-the-River or an Existing Reservoir
132	Alberta Caborn Registry	Reduced Age at Harvest of Beef Cattle
133	Alberta Caborn Registry	Reducing Greenhouse Gas Emissions from Fed Cattle
134	Alberta Caborn Registry	Selection for Low Residual Feed Intake Markers in Beef Cattle
135	Alberta Caborn Registry	Solar Electricity Generation
136	Alberta Caborn Registry	Waste Heat Recovery
137	Alberta Caborn Registry	Wind-Powered Electricity Generation

Tableau A2. Liste détaillée de projets de réduction de GES.

Item	Registre	Protocoles de projets de réduction de GES
1	EcoProjet CSA	Title: Aéroport de Montréal's Energy Efficiency Measures for GHG Emission Reductions Project Project Identifier: 9337-2554
2	EcoProjet CSA	Title: Afforestation in the South of the province of Quebec Project Identifier: 9082-7111
3	EcoProjet CSA	Title: Afforestation/Reforestation Project on Solifor Maurice S.E.C. Private Lands in the province of Québec Project Identifier: 7100-8264
4	EcoProjet CSA	Title: Afforestation/Reforestation Project on Solifor Perthuis S.E.C. Private Lands in the province of Québec Project Identifier: 5084-5566
5	EcoProjet CSA	Title: AIM composting activities performed at Hamilton's Central Composting Facility for greenhouse gas emission reductions Project Identifier: 5218-7014
6	EcoProjet CSA	Title: Amaizeingly Green Products Facility Project Project Identifier: 9737-8689
7	EcoProjet CSA	Title: ARMOUR TRANSPORTATION SYSTEMS - Intermodal Rail and Ship Greenhouse Gas Emission Reductions Project Project Identifier: 5556-1738
8	EcoProjet CSA	Title: Avoidance of methane production from decay of biomass through composting Project Identifier: 9524-8578
9	EcoProjet CSA	Title: Avoidance of methane production from decay of biomass through controlled mechanical treatment Project Identifier: 3978-8926
10	EcoProjet CSA	Title: Avoidance of methane production from decay of biomass through pelletisation and switch from fossil fuel to wood waste biomass at bois énergétique recyclé Lauzon recycled wood energy Project Identifier: 2742-7663
11	EcoProjet CSA	Title: Belize and Nicaragua Logs Recovery Project Project Identifier: 9251-0905
12	EcoProjet CSA	Title: Bonduelle North America Biomass Valorization for GHG Emissions Reduction ProjectProject Identifier: 3919-9302
13	EcoProjet CSA	Title: Bonduelle North America Energy Efficiency Measures for GHG Emission Reductions Project Project Identifier: 0369-1824
14	EcoProjet CSA	Title: Brokenlande Biogas Project Project Identifier: 4952-8046
15	EcoProjet CSA	Title: C & B Farms Biomass Heating Project Project Identifier: 2349-9529
16	EcoProjet CSA	Title: Canadian Recycled Plastics Project Project Identifier: 0804-3910
17	EcoProjet CSA	Title: Captage et combustion du biogaz au site d'enfouissement sanitaire de Red Pine Project Identifier: 8170-8846
18	EcoProjet CSA	Title: Carbon Neutral Technology Corporation - IT Asset Reuse Project for STS EducationProject Identifier: 3251-6981
19	EcoProjet CSA	Title: Carbon Neutral Technology Corporation IT Asset Reuse Project for 2nd Gear Project Identifier: 4874-3827
20	EcoProjet CSA	Title: Carbon Neutral Technology Corporation IT Asset Reuse Project for CDI Computer Dealers Inc. Project Identifier: 8771-2215
21	EcoProjet CSA	Title: Carbon Neutral Technology Corporation IT Asset Reuse Project for Comsale Project Identifier: 2178-7707
22	EcoProjet CSA	Title: Cattleland Feedyards Ltd. Beef Lifecycle Project #1 Project Identifier: 3744-2465
23	EcoProjet CSA	Title: Central Alberta Beef Lifecycle Project Project Identifier: 3651-9481
24	EcoProjet CSA	Title: Chaudiere Generating Facility Project Identifier: 5807-0620

Item	Registre	Protocoles de projets de réduction de GES
25	EcoProjet CSA	Title: Chauffage urbain de la TOHU par la centrale de cogénération Gazmont à Montréal Project Identifier: 2658-1805
26	EcoProjet CSA	Title: City of Toronto's Municipal Solid Waste Diversion From Landfill to Biodigestion at the Dufferin Organics Processing Facility Project Identifier: 2571-2547
27	EcoProjet CSA	Title: Clean energy technologies for heating of greenhouses by Productions Horticoles Demers Inc. Project Identifier: 3230-1042
28	EcoProjet CSA	Title: Climate protection by small scale biogas in Switzerland Project Identifier: 6864-5017
29	EcoProjet CSA	Title: Climatisation et Chauffage Urbains de Montréal (CCUM) fuel switching measures for GHG emissions reduction project Project Identifier: 2645-0267
30	EcoProjet CSA	Title: Coast Environmental Chemainus Composting Facility Offset Project Project Identifier: 8204-1336
31	EcoProjet CSA	Title: Commission Scolaire Marguerite-Bourgeoys' (CSMB) energy efficiency measures for GHG Emission Reductions Project Project Identifier: 4765-7933
32	EcoProjet CSA	Title: Community Distribution of High-Efficiency Light Bulbs, a collaborative effort by the University of Florida, Gainesville Regional Utilities, Publix and Earth Givers Project Identifier: 0160-0006
33	EcoProjet CSA	Title: Community Ecosystem Restoration Project Project Identifier: 9251-6893
34	EcoProjet CSA	Title: Composting of Source Separated Organics from the Waterloo Region at the Guelph Facility Project Identifier: 6809-9103
35	EcoProjet CSA	Title: Construction GFL, concrete Recycling Project Project Identifier: 0290-6314
36	EcoProjet CSA	Title: Destruction of ozone depleting substances used as refrigerants removed from refrigeration, freezer and air-conditioning appliances Project Identifier: 4061-9686
37	EcoProjet CSA	Title: East Landfill - Landfill Gas Recovery and Utilization Project Project Identifier: 8047-8047
38	EcoProjet CSA	Title: Educational institutions' GHG emission reductions from energy conservation grouped project at schools of Commission Scolaire des Patriotes Project Identifier: 3020-9875
39	EcoProjet CSA	Title: Emission reductions of the truck fleet at SGT 2000 Inc. Project Identifier: 3364-6900
40	EcoProjet CSA	Title: Energy efficiency grouped project at district heating plant and connected buildings in Chicoutimi Project Identifier: 2615-3299
41	EcoProjet CSA	Title: Energy efficiency improvements at Labatt Breweries of Canada Project Identifier: 8347-7421
42	EcoProjet CSA	Title: Energy Efficiency Project for the Museum of Fine Arts of Montreal Project Identifier: 8068-4332
43	EcoProjet CSA	Title: Energy efficiency Projects at Centre de Sante et de Services Sociaux du Nord de Lanaudiere Project Identifier: 5998-7278
44	EcoProjet CSA	Title: Energy efficiency projects at Jewish General Hospital Project Identifier: 6549-4006
45	EcoProjet CSA	Title: Enersol GHG Emission Reductions via Solar Pool Heating Project Identifier: 9457-3402
46	EcoProjet CSA	Title: Envire Industries, GHG Emission Reductions Project Project Identifier: 8928-3035
47	EcoProjet CSA	Title: Enviroval Inc.'s GHG emission reductions Project Identifier: 5084-7388
48	EcoProjet CSA	Title: Essex-Windsor Regional Landfill Gas Capture and Destruction Project Project Identifier: 2474-6209
49	EcoProjet CSA	Title: Extraction et combustion des biogaz - CESA Project Identifier: 8180-7777

Item	Registre	Protocoles de projets de réduction de GES
50	EcoProjet CSA	Title: Extraction et combustion des biogaz - LES Roland-Thibault Inc. Project Identifier: 8079-1059
51	EcoProjet CSA	Title: Extraction et combustion des biogaz - RDL Project Identifier: 9370-7483
52	EcoProjet CSA	Title: Extraction et combustion des biogaz - RIRT Project Identifier: 0883-0920
53	EcoProjet CSA	Title: Extraction et combustion des biogaz au site d'enfouissement sanitaire de LaterrièreProject Identifier: 6146-3306
54	EcoProjet CSA	Title: Ferti-Val and Agrior Greenhouse Gas Emission Reductions Composting Project Project Identifier: 7910-0498
55	EcoProjet CSA	Title: Fuel switch and biomass energy project at Centre de santé et de services sociaux Domaine-du-Roy Project Identifier: 6651-1747
56	EcoProjet CSA	Title: Gaudreau Environnement renewable solid waste management activities GHG emission reductions report Project Identifier: 8852-4478
57	EcoProjet CSA	Title: Green Roof Technology Project Identifier: 1451-4954
58	EcoProjet CSA	Title: Green4Good IT Asset Reuse Project Project Identifier: 5121-7301
59	EcoProjet CSA	Title: Greenhouse Gas Reductions for Wheeled Vehicles (Pneumatic Tires) Project Identifier: 2992-8321
60	EcoProjet CSA	Title: Greenhouse heat generation from biomass boilers at Les Serres Stéphane Bertrand Mirabel Project Identifier: 3692-8490
61	EcoProjet CSA	Title: Groupe Robert inc. fuel efficiency strategies in freight transport GHG Emissions Reduction Project Project Identifier: 4952-5509
62	EcoProjet CSA	Title: Heffley Creek Biomass Gasification Project Project Identifier: 3048-9943
63	EcoProjet CSA	Title: Highway 101 Landfill Gas Capture Project Project Identifier: 5047-3414
64	EcoProjet CSA	Title: HVAC for Elk Island Schools Commercial and Institutional Buildings Energy Efficiency Project Project Identifier: 7990-3012
65	EcoProjet CSA	Title: IMAFLEX GHG emission reductions/Plastic Recycling Project Project Identifier: 3574-1666
66	EcoProjet CSA	Title: Implantation d'un réseau de captage et de destruction du biogaz au lieu d'enfouissement sanitaire de La Lièvre Project Identifier: 3168-5278
67	EcoProjet CSA	Title: Implantation d'un réseau de captage et de destruction du biogaz au lieu d'enfouissement sanitaire de Saint-Raymond Project Identifier: 9851-6244
68	EcoProjet CSA	Title: Implantation d'un réseau de captage et de destruction du biogaz au lieu d'enfouissement sanitaire de Ville de Rivière Rouge Project Identifier: 7393-3044
69	EcoProjet CSA	Title: Implantation d'un réseau de captage et de destruction du biogaz au lieu d'enfouissement sanitaire Saint-Lambert-de-Lauzon Project Identifier: 7514-3762
70	EcoProjet CSA	Title: Implantation de mesures d'efficacité énergétique et de remplacement de combustibles fossiles en serres agricoles Project Identifier: 1797-3086
71	EcoProjet CSA	Title: Implementation of energy efficiency measures and fuel switching for GHG emissions reduction Project Identifier: 9746-2120
72	EcoProjet CSA	Title: Implementation of energy efficiency measures, fuel switching and geothermal energy for GHG emission reductions Project Identifier: 9925-2975

Item	Registre	Protocoles de projets de réduction de GES
73	EcoProjet CSA	Title: Intermodal Transportation Project Project Identifier: 1840-6051
74	EcoProjet CSA	Title: Landfill gas capture and destruction Project Identifier: 2461-5037
75	EcoProjet CSA	Title: Leading by Example: Energy Efficiency Retrofits of City of Toronto Facilities Project Identifier: 3219-7130
76	EcoProjet CSA	Title: Les Entreprises Environnementales Pierrefonds (LEEP) biogas capture and destruction GHG Emissions Reductions Project Project Identifier: 9340-7745
77	EcoProjet CSA	Title: Les produits Polychem Canada Inc. Plastic Recycling GHG Emission Reductions ProjectProject Identifier: 2181-2911
78	EcoProjet CSA	Title: McGill University Health Centre's Energy Efficiency Measures for GHG Emission Reductions Projects Project Identifier: 3274-8695
79	EcoProjet CSA	Title: Merom Farms Biomass Project Project Identifier: 4022-1180
80	EcoProjet CSA	Title: Minas Basin GHG emission reductions Project Identifier: 2690-5813
81	EcoProjet CSA	Title: Mobile Greenhouse Gas Reduction - Engine and Fuel Treatment Project Identifier: 6893-4564
82	EcoProjet CSA	Title: Mobile Greenhouse Gas Reduction - Engine Treatment Project Identifier: 9198-0478
83	EcoProjet CSA	Title: Mobile Greenhouse Gas Reductions Project Identifier: 2860-6503
84	EcoProjet CSA	Title: MotorSilk Engine Treatment in Canadian Tire Fleet Project Identifier: 8965-9079
85	EcoProjet CSA	Title: Municipal Solid Waste to Power Technology Project Identifier: 4918-2962
86	EcoProjet CSA	Title: Nakkawita, Pantak, and Gurulawana Small Scale Hydropower Projects Project Identifier: 3547-4902
87	EcoProjet CSA	Title: Natural Gas Combined Cycled Power Generation Plant Project Identifier: 7732-0939
88	EcoProjet CSA	Title: Net Zero Waste Abbotsford Composting Facility Offset Project Project Identifier: 6089-9126
89	EcoProjet CSA	Title: Newfoundland Climate and Ecosystems Conservancy Project (NCECP) Project Identifier: 3294-4326
90	EcoProjet CSA	Title: Niagara Escarpment forest carbon project (NEFCP) - Preserving forest integrity in the Niagara escarpment region Project Identifier: 5008-9954
91	EcoProjet CSA	Title: Ontario Biodiversity Afforestation Project (OBAP) Project Identifier: 1901-3383
92	EcoProjet CSA	Title: Orgaworld Canada Ltd. Composting Facility, London, ON GHG Emissions Reduction Project Project Identifier: 3839-3242
93	EcoProjet CSA	Title: PerfectPleat Extended Surface Pleated Filter Project Project Identifier: 5859-2714
94	EcoProjet CSA	Title: Perlite Insulation for an Industrial Medium Heat Environment Project Identifier: 2473-3680
95	EcoProjet CSA	Title: Post-Industrial Plastic Recycling Project Identifier: 6717-8308
96	EcoProjet CSA	Title: Prism Farms Biomass Heating Project Project Identifier: 3717-3949
97	EcoProjet CSA	Title: Projet d'implantation de mesures d'efficacité énergétique pour la réduction des gaz à effet de serre (GES) de l'Office municipal d'habitation de Montréal (OMHM) Project Identifier: 9091-1884
98	EcoProjet CSA	Title: Pyramid Farms Biomass Heating Project Project Identifier: 4650-2502
99	EcoProjet CSA	Title: Quantification of CO2 eq emission reductions from slag-based recycling operations by Les Matériaux Harsco Project Identifier: 3876-3354
100	EcoProjet CSA	Title: Quantification of CO2eq emissions reductions from slag-based recycling operations by Excell Minerais Project Identifier: 1741-2605

Item	Registre	Protocoles de projets de réduction de GES
101	EcoProjet CSA	Title: Quantification of net CO2e emission reductions for the manufacturing of pallets made from 100% recycled plastic by Solplast Inc. (2002-2006) Project Identifier: 8316-1152
102	EcoProjet CSA	Title: Quantification of net CO2e emission reductions from plastic and rubber recycling operations by Solplast Inc. Project Identifier: 9181-5474
103	EcoProjet CSA	Title: Quantification of net CO2e emission reductions from polyethylene terephtalate and polypropylene recycling operations by Plastrec Inc. (2002-2006) Project Identifier: 6060-2548
104	EcoProjet CSA	Title: Quik's Farm Biomass Boiler Project Identifier: 9547-3252
105	EcoProjet CSA	Title: Recovery of Manure/Recovered manure for compost Project Identifier: 8810-1861
106	EcoProjet CSA	Title: Recovery of Manure/Recovered manure for compost Project Identifier: 0384-1153
107	EcoProjet CSA	Title: Recovery of Manure/Recovered manure for cow bedding Project Identifier: 3442-0876
108	EcoProjet CSA	Title: Recovery of Manure/Recovered manure for cow bedding Project Identifier: 3470-5272
109	EcoProjet CSA	Title: Recovery of Manure/Recovered manure for cow bedding Project Identifier: 8291-2312
110	EcoProjet CSA	Title: Recovery of Manure/Recovered manure for cow bedding Project Identifier: 9790-6601
111	EcoProjet CSA	Title: Recovery of Manure/Recovered manure for cow bedding and compost Project Identifier: 2986-5204
112	EcoProjet CSA	Title: Recovery of Manure/Recovered manure for cow bedding and fertilizer Project Identifier: 4491-4407
113	EcoProjet CSA	Title: Recovery of Manure/Recovered manure for cow bedding and fertilizer Project Identifier: 8532-2612
114	EcoProjet CSA	Title: Recovery of Manure/Recovered manure for cow bedding and fertilizer Project Identifier: 5338-3502
115	EcoProjet CSA	Title: Recyc RPM GHG Emission Reductions Recycling Project Project Identifier: 9818-8372
116	EcoProjet CSA	Title: Recyclage Granutech Inc.- Rubber Recovery Process Project Project Identifier: 1985-5627
117	EcoProjet CSA	Title: Recycled/Transformed foodstuffs intended for the animals process by Prorec inc. Project Identifier: 1538-2445
118	EcoProjet CSA	Title: Regional District of Nanaimo (RDN) Landfill Gas (LFG) Capture and Combustion Greenhouse Gas (GHG) Emission Reductions Project Project Identifier: 9236-1218
119	EcoProjet CSA	Title: Ride Green® with Tire-Gard® with Nitrogen Tire Inflation Project Identifier: 3185-9581
120	EcoProjet CSA	Title: Royal Mat Inc. - Recycling of tires/Manufacturing of mats with recycled tires Project Identifier: 4825-6129
121	EcoProjet CSA	Title: Rubber Recycling Project Project Identifier: 0456-8986
122	EcoProjet CSA	Title: St. Felicien Biomass Cogeneration Project Project Identifier: 4920-6272
123	EcoProjet CSA	Title: T.M.R. Landfill Greenhouse Gas Emission Avoidance Project Identifier: 0944-6186
124	EcoProjet CSA	Title: Terra Grains Fuel Ethanol Plant Project Identifier: 7317-9468
125	EcoProjet CSA	Title: The Egyptian Brick Factory Fuel-Switch Project Project Identifier: 0561-8286
126	EcoProjet CSA	Title: Thermo-12 Gold Insulation for an Industrial High Heat Environment Project Identifier: 0149-2374
127	EcoProjet CSA	Title: Thermo-12 Gold Insulation vs. Perlite for an Industrial Environment Project Identifier: 8667-3101
128	EcoProjet CSA	Title: Toronto District School Board Energy Efficiency Project Project Identifier: 6393-7288
129	EcoProjet CSA	Title: University of Alberta Energy Efficient Lighting Project Project Identifier: 5024-9900
130	EcoProjet CSA	Title: Wey Ganga Small Scale Hydropower Project Project Identifier: 2903-8783
131	EcoProjet CSA	Title: White Roof Technology Project Identifier: 6869-0631

Item	Registre	Protocoles de projets de réduction de GES
132	Mécanisme du Développement Propre	Decomposition of fluoroform (HFC-23) waste streams --- Version 6.0.0
133	Mécanisme du Développement Propre	Analysis of the least-cost fuel option for seasonally-operating biomass cogeneration plants --- Version 1.0
134	Mécanisme du Développement Propre	Recovery and utilization of gas from oil fields that would otherwise be flared or vented --- Version 7.0
135	Mécanisme du Développement Propre	Steam system efficiency improvements by replacing steam traps and returning condensate --- Version 2.0
136	Mécanisme du Développement Propre	Baseline methodology for steam optimization systems --- Version 4.0
137	Mécanisme du Développement Propre	Renewable energy projects replacing part of the electricity production of one single fossil fuel fired power plant that stands alone or supplies to a grid, excluding biomass projects --- Version 2.0
138	Mécanisme du Développement Propre	Baseline methodology for water pumping efficiency improvements --- Version 2.0
139	Mécanisme du Développement Propre	Baseline Methodology for decomposition of N2O from existing adipic acid production plants --- Version 3.0
140	Mécanisme du Développement Propre	Leak detection and repair in gas production, processing, transmission, storage and distribution systems and in refinery facilities --- Version 4.0.0
141	Mécanisme du Développement Propre	Methodology for zero-emissions grid-connected electricity generation from renewable sources in Chile or in countries with merit order based dispatch grid --- Version 3.0
142	Mécanisme du Développement Propre	Substitution of CO2 from fossil or mineral origin by CO2 from renewable sources in the production of inorganic compounds --- Version 2.1
143	Mécanisme du Développement Propre	N2O destruction in the tail gas of Caprolactam production plants --- Version 6.0
144	Mécanisme du Développement Propre	PFC emission reductions from anode effect mitigation at primary aluminium smelting facilities --- Version 4.0.0
145	Mécanisme du Développement Propre	Bus rapid transit projects --- Version 6.0
146	Mécanisme du Développement Propre	SF6 emission reductions in electrical grids --- Version 2.0.0
147	Mécanisme du Développement Propre	Fuel switch from fossil fuels to biomass residues in heat generation equipment --- Version 5.0
148	Mécanisme du Développement Propre	Flare (or vent) reduction and utilization of gas from oil wells as a feedstock --- Version 3.0
149	Mécanisme du Développement Propre	Methodology for improved electrical energy efficiency of an existing submerged electric arc furnace used for the production of silicon and ferro alloys --- Version 3.0.0

Item	Registre	Protocoles de projets de réduction de GES
150	Mécanisme du Développement Propre	Leak reduction from a natural gas distribution grid by replacing old cast iron pipes or steel pipes without cathodic protection with polyethylene pipes --- Version 2.0
151	Mécanisme du Développement Propre	Energy efficiency improvement projects - boiler rehabilitation or replacement in industrial and district heating sectors --- Version 2.0.0
152	Mécanisme du Développement Propre	Grid connection of isolated electricity systems --- Version 3.0
153	Mécanisme du Développement Propre	Distribution of efficient light bulbs to households --- Version 2.0
154	Mécanisme du Développement Propre	New cogeneration project activities supplying electricity and heat to multiple customers --- Version 5.0
155	Mécanisme du Développement Propre	Methodology for gas based energy generation in an industrial facility --- Version 3.0
156	Mécanisme du Développement Propre	Feed switch in integrated Ammonia-urea manufacturing industry --- Version 3.0.0
157	Mécanisme du Développement Propre	Increased electricity generation from existing hydropower stations through Decision Support System optimization --- Version 3.0
158	Mécanisme du Développement Propre	Biogenic methane injection to a natural gas distribution grid --- Version 4.0.0
159	Mécanisme du Développement Propre	Recovery and utilization of waste gas in refinery or gas plant --- Version 2.1.0
160	Mécanisme du Développement Propre	Efficiency improvement by boiler replacement or rehabilitation and optional fuel switch in fossil fuel-fired steam boiler systems --- Version 1.0
161	Mécanisme du Développement Propre	Avoided emissions from biomass wastes through use as feed stock in pulp and paper, cardboard, fibreboard or bio-oil production --- Version 3.0.1
162	Mécanisme du Développement Propre	Introduction of a district heating system --- Version 5.0
163	Mécanisme du Développement Propre	Reduction in GHGs emission from primary aluminium smelters --- Version 2.0
164	Mécanisme du Développement Propre	Power saving through replacement by energy efficient chillers --- Version 2.0
165	Mécanisme du Développement Propre	Methodology for rehabilitation and/or energy efficiency improvement in existing power plants --- Version 2.1
166	Mécanisme du Développement Propre	Energy efficiency improvements of a power plant through retrofitting turbines --- Version 2.0
167	Mécanisme du Développement Propre	Recovery of CO2 from tail gas in industrial facilities to substitute the use of fossil fuels for production of CO2 --- Version 1.2.0

Item	Registre	Protocoles de projets de réduction de GES
168	Mécanisme du Développement Propre	Capture and utilisation or destruction of mine methane (excluding coal mines) or non mine methane --- Version 3.0.0
169	Mécanisme du Développement Propre	Replacement of SF6 with alternate cover gas in the magnesium industry --- Version 2.1
170	Mécanisme du Développement Propre	GHG emission reductions through waste heat utilisation for pre-heating of raw materials in sponge iron manufacturing process --- Version 2.0
171	Mécanisme du Développement Propre	Methodology for installation of energy efficient transformers in a power distribution grid --- Version 2.0
172	Mécanisme du Développement Propre	Methodology for improved energy efficiency by modifying ferroalloy production facility --- Version 1.0
173	Mécanisme du Développement Propre	Biogenic methane use as feedstock and fuel for town gas production --- Version 2.0
174	Mécanisme du Développement Propre	Manufacturing of energy efficient domestic refrigerators --- Version 3.1.0
175	Mécanisme du Développement Propre	Manufacturing and servicing of domestic refrigeration appliances using a low GWP refrigerant --- Version 2.0
176	Mécanisme du Développement Propre	Fossil Fuel Displacement by Geothermal Resources for Space Heating --- Version 3.0
177	Mécanisme du Développement Propre	GHG emission reductions through multi-site manure collection and treatment in a central plant --- Version 1.0
178	Mécanisme du Développement Propre	Methodology for new grid connected power plants using permeate gas previously flared and/or vented --- Version 3.0.0
179	Mécanisme du Développement Propre	Methodology for collection, processing and supply of biogas to end-users for production of heat --- Version 1.0
180	Mécanisme du Développement Propre	Implementation of fossil fuel trigeneration systems in existing industrial facilities --- Version 2.0
181	Mécanisme du Développement Propre	Recovery of gas from oil wells that would otherwise be vented or flared and its delivery to specific end-users --- Version 1.0
182	Mécanisme du Développement Propre	Point of Use Abatement Device to Reduce SF6 emissions in LCD Manufacturing Operations --- Version 2.0.0
183	Mécanisme du Développement Propre	Recovery of SF6 from Gas insulated electrical equipment in testing facilities --- Version 2.0
184	Mécanisme du Développement Propre	Mitigation of greenhouse gases emissions with treatment of wastewater in aerobic wastewater treatment plants --- Version 1.0
185	Mécanisme du Développement Propre	Flare or vent reduction at coke plants through the conversion of their waste gas into dimethyl ether for use as a fuel --- Version 1.0

Item	Registre	Protocoles de projets de réduction de GES
186	Mécanisme du Développement Propre	Use of charcoal from planted renewable biomass in a new iron ore reduction system --- Version 2.0
187	Mécanisme du Développement Propre	Avoidance of landfill gas emissions by in-situ aeration of landfills --- Version 1.0.1
188	Mécanisme du Développement Propre	Installation of cogeneration system supplying electricity and chilled water to new and existing consumers --- Version 3.0
189	Mécanisme du Développement Propre	Distribution of low greenhouse gas emitting water purification systems for safe drinking water --- Version 5.0
190	Mécanisme du Développement Propre	Air separation using cryogenic energy recovered from the vaporization of LNG --- Version 1.0
191	Mécanisme du Développement Propre	Production of diesel using a mixed feedstock of gasoil and vegetable oil --- Version 2.0
192	Mécanisme du Développement Propre	Modal shift in transportation of cargo from road transportation to water or rail transportation --- Version 1.1.0
193	Mécanisme du Développement Propre	Energy efficiency technologies and fuel switching in new and existing buildings --- Version 4.0
194	Mécanisme du Développement Propre	Substitution of PFC gases for cleaning Chemical Vapour Deposition (CVD) reactors in the semiconductor industry --- Version 2.0.0
195	Mécanisme du Développement Propre	Avoidance of landfill gas emissions by passive aeration of landfills --- Version 1.0.1
196	Mécanisme du Développement Propre	Distribution of biomass based stove and/or heater for household or institutional use --- Version 2.0.0
197	Mécanisme du Développement Propre	Waste gas based combined cycle power plant in a Greenfield iron and steel plant --- Version 1.0.0
198	Mécanisme du Développement Propre	CF4 emission reduction from installation of an abatement system in a semiconductor manufacturing facility --- Version 1.0.0
199	Mécanisme du Développement Propre	Installation of high voltage direct current power transmission line --- Version 1.0.0
200	Mécanisme du Développement Propre	Utilization of ammonia-plant off gas for steam generation --- Version 1.0.0
201	Mécanisme du Développement Propre	Installation of a new natural gas fired gas turbine to an existing CHP plant --- Version 1.0.0
202	Mécanisme du Développement Propre	Integrated Solar Combined Cycle (ISCC) projects --- Version 1.0.0
203	Mécanisme du Développement Propre	High speed passenger rail systems --- Version 2.0

Item	Registre	Protocoles de projets de réduction de GES
204	Mécanisme du Développement Propre	Renewable energy power generation in isolated grids --- Version 3.0
205	Mécanisme du Développement Propre	Interconnection of electricity grids in countries with economic merit order dispatch --- Version 2.0.0
206	Mécanisme du Développement Propre	Energy efficiency in data centres through dynamic power management --- Version 1.0.0
207	Mécanisme du Développement Propre	Energy efficiency improvements of a lime production facility through installation of new kilns --- Version 2.0.0
208	Mécanisme du Développement Propre	New natural gas based cogeneration plant --- Version 4.0
209	Mécanisme du Développement Propre	Interconnection between electricity systems for energy exchange --- Version 1.0.0
210	Mécanisme du Développement Propre	Introduction of hot supply of Direct Reduced Iron in Electric Arc Furnaces --- Version 1.0.0
211	Mécanisme du Développement Propre	Modal shift in transportation of liquid fuels --- Version 2.0
212	Mécanisme du Développement Propre	Abatement of fluorinated greenhouse gases in semiconductor manufacturing --- Version 1.0.0
213	Mécanisme du Développement Propre	Less carbon intensive power generation through continuous reductive distillation of waste --- Version 1.0
214	Mécanisme du Développement Propre	Distribution of compact fluorescent lamps (CFL) and light-emitting diode (LED) lamps to households --- Version 1.0
215	Mécanisme du Développement Propre	Shift from electrolytic to catalytic process for recycling of chlorine from hydrogen chloride gas in isocyanate plants --- Version 1.0
216	Mécanisme du Développement Propre	Recovery and utilization of coke oven gas from coke plants for LNG production --- Version 1.0
217	Mécanisme du Développement Propre	Electric taxiing systems for airplanes --- Version 2.0
218	Mécanisme du Développement Propre	Introduction of a new district cooling system --- Version 1.0
219	Mécanisme du Développement Propre	Introduction of low resistivity power transmission line --- Version 2.0
220	Mécanisme du Développement Propre	SF6 emission reductions in gas insulated metal enclosed switchgear --- Version 1.0
221	Mécanisme du Développement Propre	Energy-efficient refrigerators and air-conditioners --- Version 1.0

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222	Climate Reserve Registry	A-Gas 2018-3
223	Climate Reserve Registry	A-Gas 2018-4
224	Climate Reserve Registry	A-Gas 2018-5
225	Climate Reserve Registry	A-Gas 2018-7
226	Climate Reserve Registry	A-Gas 2018-8
227	Climate Reserve Registry	A-Gas 2018-9
228	Climate Reserve Registry	A-Gas 2019-1
229	Climate Reserve Registry	A-Gas 2019-4
230	Climate Reserve Registry	A-GAS Americas 2015-1
231	Climate Reserve Registry	A-Gas Americas 2016-2
232	Climate Reserve Registry	A-Gas Americas 2017-1
233	Climate Reserve Registry	A-Gas Americas 2017-2
234	Climate Reserve Registry	A-Gas Americas 2017-3
235	Climate Reserve Registry	A-Gas Americas 2017-4
236	Climate Reserve Registry	A-Gas Americas 2017-6
237	Climate Reserve Registry	A-Gas Americas 2017-8
238	Climate Reserve Registry	A-Gas Americas 2018-1
239	Climate Reserve Registry	A-Gas Americas 2018-2
240	Climate Reserve Registry	A-Gas O'Hare
241	Climate Reserve Registry	A-GAS RemTec 2013-1
242	Climate Reserve Registry	A-GAS RemTec 2013-4
243	Climate Reserve Registry	A-GAS RemTec 2013-5
244	Climate Reserve Registry	A-GAS RemTec 2014-1
245	Climate Reserve Registry	A-GAS RemTec 2014-2
246	Climate Reserve Registry	A-GAS RemTec 2014-3
247	Climate Reserve Registry	A-GAS RemTec 2015-2
248	Climate Reserve Registry	ABEC New Hope LLC
249	Climate Reserve Registry	Adirondack Farms
250	Climate Reserve Registry	Albion
251	Climate Reserve Registry	Alcoa Landfill Gas Destruction Project
252	Climate Reserve Registry	Alder Stream Preserve
253	Climate Reserve Registry	Alliance Dairies
254	Climate Reserve Registry	American Environmental Landfill (AEL)
255	Climate Reserve Registry	Angelina County Landfill
256	Climate Reserve Registry	Anson County Landfill

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257	Climate Reserve Registry	AR-Joy Farm Dairy Digester
258	Climate Reserve Registry	Arcata City Forest Barnum Tract
259	Climate Reserve Registry	Arcata Sunnybrae Tract
260	Climate Reserve Registry	Ashford III
261	Climate Reserve Registry	Athens-Clarke County Landfill Project
262	Climate Reserve Registry	Aurora Ridge
263	Climate Reserve Registry	Aurora Ridge Dairy
264	Climate Reserve Registry	Backbone
265	Climate Reserve Registry	Bartow Landfill
266	Climate Reserve Registry	Berkeley County Landfill Gas Project
267	Climate Reserve Registry	Berkshire Cow Power
268	Climate Reserve Registry	Beulah Municipal Landfill (Dorchester County, MD)
269	Climate Reserve Registry	Bi-County Landfill Gas Destruction Project
270	Climate Reserve Registry	Big Bend
271	Climate Reserve Registry	Big River / Salmon Creek Forests
272	Climate Reserve Registry	Big River / Salmon Creek Forests - ARB
273	Climate Reserve Registry	Big Run Landfill Gas Destruction Project
274	Climate Reserve Registry	Big Valley
275	Climate Reserve Registry	Billings Regional Landfill
276	Climate Reserve Registry	Black Warrior Solid Waste Facility
277	Climate Reserve Registry	Blue Mountain Biogas
278	Climate Reserve Registry	Blue Ridge Landfill
279	Climate Reserve Registry	Blue Source - Alligator River Avoided Conversion
280	Climate Reserve Registry	Blue Source - Bishop Improved Forest Management Project
281	Climate Reserve Registry	Blue Source - Corkscrew Improved Forest Management Project
282	Climate Reserve Registry	Blue Source - Francis Beidler Improved Forest Management Project
283	Climate Reserve Registry	Blue Source - Noles North Avoided Conversion Forest Project
284	Climate Reserve Registry	Blue Source - Pocosin Lakes Forest Conservation Project
285	Climate Reserve Registry	Blue Source - Pungo River Forest Conservation Project
286	Climate Reserve Registry	Blue Source -Noles South Avoided Conversion Forest Project
287	Climate Reserve Registry	Blue Source- Goodwood Improved Forest Management Project
288	Climate Reserve Registry	Blue Source- Stonewall Improved Forest Management Project
289	Climate Reserve Registry	Blue Source- Sylvan Improved Forest Management Project
290	Climate Reserve Registry	Blue Source-Montrose Improved Forest Management Project
291	Climate Reserve Registry	Blue Source-Silver Bluff Improved Forest Management Project

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292	Climate Reserve Registry	Blue Source-Snowshoe Improved Forest Management Project
293	Climate Reserve Registry	Blue Source-Westervelt Atlantic Coast Improved Forest Management Project
294	Climate Reserve Registry	Blue Source-Westervelt Gulf Coast Improved Forest Management Project
295	Climate Reserve Registry	Blue Source-Westervelt Piedmont Improved Forest Management Project
296	Climate Reserve Registry	Blue Source-Winchendon Improved Forest Management Project
297	Climate Reserve Registry	Blue Source-Wolf River Improved Forest Management Project
298	Climate Reserve Registry	Bluesource - Carroll Avoided Grassland Conversion Project
299	Climate Reserve Registry	Bluff Road Landfill
300	Climate Reserve Registry	BNW Ranch
301	Climate Reserve Registry	BNW West
302	Climate Reserve Registry	Bos Dairy
303	Climate Reserve Registry	Bowman Lake
304	Climate Reserve Registry	Bridgewater Dairy LLC
305	Climate Reserve Registry	Bridgewater Dairy, LLC
306	Climate Reserve Registry	Brook View Dairy
307	Climate Reserve Registry	Brook View Dairy Methane Reduction Project
308	Climate Reserve Registry	Brushy Mountain
309	Climate Reserve Registry	Buck Mountain ARB002
310	Climate Reserve Registry	Buckeye Forest Project
311	Climate Reserve Registry	Bull Creek
312	Climate Reserve Registry	Buncombe County Landfill
313	Climate Reserve Registry	Butler County Landfill Pipeline Project
314	Climate Reserve Registry	CalBio ORRD
315	Climate Reserve Registry	CalBio ORRD Project
316	Climate Reserve Registry	Camelot Landfill
317	Climate Reserve Registry	Canadian Valley Landfill
318	Climate Reserve Registry	Captura de Carbono en San Juan Lachao, Oaxaca
319	Climate Reserve Registry	Captura de carbono en San Rafael Ixtapalucan
320	Climate Reserve Registry	Captura de Carbono Forestal Ejido San Lucas
321	Climate Reserve Registry	Captura de Carbono San Bartolo O2
322	Climate Reserve Registry	CE&S Dairy
323	Climate Reserve Registry	Cedar Grove - Maple Valley OWC Composting Project
324	Climate Reserve Registry	Cedar Grove Composting
325	Climate Reserve Registry	Cedar Rapids Linn County Solid Waste Agency Landfill Gas Project
326	Climate Reserve Registry	Central LFG to Energy Project

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327	Climate Reserve Registry	Central Sands Dairy LLC
328	Climate Reserve Registry	Central Sands Dairy, LLC
329	Climate Reserve Registry	Central Sanitary Landfill
330	Climate Reserve Registry	Chaput Family Farms
331	Climate Reserve Registry	Charleston Landfill Gas Utilization Project
332	Climate Reserve Registry	Charlotte County Zemel Road Landfill Gas Capture Project
333	Climate Reserve Registry	Chautauqua County
334	Climate Reserve Registry	Chugach Alaska Forest Carbon Project
335	Climate Reserve Registry	Citrus County, Florida Landfill Gas Flare Project
336	Climate Reserve Registry	City of Garland Landfill Carbon Project
337	Climate Reserve Registry	City of Lee's Summit Resource Recovery Park
338	Climate Reserve Registry	City of Thomasville MSW Landfill
339	Climate Reserve Registry	Clayton County Landfill Gas Project
340	Climate Reserve Registry	ClimeCo ODS Destruction 16 and 17
341	Climate Reserve Registry	ClimeCo ODS Destruction 18 and 19
342	Climate Reserve Registry	ClimeCo ODS Destruction 20
343	Climate Reserve Registry	ClimeCo ODS Destruction 21
344	Climate Reserve Registry	ClimeCo ODS Destruction 22
345	Climate Reserve Registry	ClimeCo ODS Destruction 23
346	Climate Reserve Registry	ClimeCo ODS Destruction 24
347	Climate Reserve Registry	ClimeCo ODS Destruction 25
348	Climate Reserve Registry	ClimeCo ODS Destruction 26
349	Climate Reserve Registry	ClimeCo ODS Destruction 27
350	Climate Reserve Registry	ClimeCo ODS Destruction 28
351	Climate Reserve Registry	ClimeCo ODS Destruction 29
352	Climate Reserve Registry	ClimeCo ODS Destruction 30
353	Climate Reserve Registry	ClimeCo ODS Destruction 31
354	Climate Reserve Registry	Clinton County Landfill Methane Destruction Project
355	Climate Reserve Registry	CMW Landfill Methane Reduction Project
356	Climate Reserve Registry	Coffee County Sanitary Landfill Gas Collection System
357	Climate Reserve Registry	Coffeyville NAP2
358	Climate Reserve Registry	Colebrook Landfill
359	Climate Reserve Registry	Conservación y Captura de Carbono Co2ltzingo
360	Climate Reserve Registry	Coolgas 2015-3
361	Climate Reserve Registry	Coolgas 2016-1

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362	Climate Reserve Registry	Coolgas 2016-3
363	Climate Reserve Registry	Coolgas 2016-4
364	Climate Reserve Registry	Coolgas 2017-5
365	Climate Reserve Registry	Coolgas 2017-7
366	Climate Reserve Registry	Coolgas 2018-6
367	Climate Reserve Registry	Coolgas 2019-2
368	Climate Reserve Registry	Coolgas India ODS Project 1
369	Climate Reserve Registry	Coolgas India ODS project 2
370	Climate Reserve Registry	Coolgas ODS 2013 Project #1
371	Climate Reserve Registry	Coolgas US ODS Project 1
372	Climate Reserve Registry	Coolgas US ODS Project 2
373	Climate Reserve Registry	Cottonwood Dairy Livestock Gas Capture Project
374	Climate Reserve Registry	Cottonwood Dairy Livestock Gas Capture Project
375	Climate Reserve Registry	Cottonwood Dairy Organic Waste Digestion Project
376	Climate Reserve Registry	Coyne Farms
377	Climate Reserve Registry	Crane Valley
378	Climate Reserve Registry	Crow Wing County Landfill Gas Collection System
379	Climate Reserve Registry	CSE Arizona Facility
380	Climate Reserve Registry	CSE AZ Facility I
381	Climate Reserve Registry	Dairy Dreams
382	Climate Reserve Registry	Dairy Dreams Methane Reduction Project
383	Climate Reserve Registry	Dairyland Digester
384	Climate Reserve Registry	Dalton-Whitfield Landfill Project
385	Climate Reserve Registry	Davidson County Landfill Gas Destruction Project
386	Climate Reserve Registry	Davis Landfill Gas Offset Project
387	Climate Reserve Registry	Deer Run Digester
388	Climate Reserve Registry	Development Authority of the North Country (DANC) Landfill Gas Destruction Project
389	Climate Reserve Registry	District 45 Dairy
390	Climate Reserve Registry	District 45 Dairy
391	Climate Reserve Registry	Double A Dairy
392	Climate Reserve Registry	DPC Domestic ODS Destruction Project #10
393	Climate Reserve Registry	DPC Domestic ODS Destruction Project #11
394	Climate Reserve Registry	DPC Domestic ODS Destruction Project #13
395	Climate Reserve Registry	DPC Domestic ODS Destruction Project #14
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413	Climate Reserve Registry	Dubuque Metropolitan Sanitary Landfill
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415	Climate Reserve Registry	Eagle Point Landfill
416	Climate Reserve Registry	East Central Sanitary Landfill Voluntary GCCS
417	Climate Reserve Registry	ECC ODS Destruction 11-2013
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419	Climate Reserve Registry	ECC-ODS-CA-002
420	Climate Reserve Registry	ECC-ODS-PA-001
421	Climate Reserve Registry	ECC-PA-ODS-003
422	Climate Reserve Registry	Edaleen Cow Power, LLC
423	Climate Reserve Registry	El Dorado Nitrogen, LP - Nitrous Oxide Abatement Project
424	Climate Reserve Registry	Elk Creek
425	Climate Reserve Registry	Elk Creek Coal Mine Methane Destruction & Utilization Project
426	Climate Reserve Registry	EOS 2013 Domestic
427	Climate Reserve Registry	EOS ARB ODS 2013-1
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444	Climate Reserve Registry	Fall River
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454	Climate Reserve Registry	Finite Carbon - Berry Summit
455	Climate Reserve Registry	Finite Carbon - Boone Parklands IFM
456	Climate Reserve Registry	Finite Carbon - Brosnan Forest
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458	Climate Reserve Registry	Finite Carbon - Farm Cove Community Forest Project
459	Climate Reserve Registry	Finite Carbon - JTO Champion Property IFM
460	Climate Reserve Registry	Finite Carbon - Lyme Cross City IFM
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464	Climate Reserve Registry	Finite Carbon - Molpus Ataya Kentucky IFM
465	Climate Reserve Registry	Finite Carbon - MWF Adirondacks IFM
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509	Climate Reserve Registry	Green Assets - Middleton Avoided Conversion Project
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523	Climate Reserve Registry	Hardin County Landfill
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643	Climate Reserve Registry	RES Ag - DM4-3 LLC
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645	Climate Reserve Registry	Ridgecrest Dairy
646	Climate Reserve Registry	Rio Grande Valley Landfill
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718	Climate Reserve Registry	Trinity Timberlands University Hill Improved Forest Management Project
719	Climate Reserve Registry	TRR Landfill
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Annexe 2.2 – Recueil de publications portant sur des moyens de réduction de GES

Cette annexe présente un recueil de publications portant sur des moyens de réduction de GES. Les publications sont accompagnées des résumés et certaines ont été citées dans cette revue de littérature alors que les autres sont présentées à titre d'information supplémentaire.

Table des matières

AGRICULTURE - GÉNÉRAL

Enabling a sustainable and prosperous future through science and innovation in the bioeconomy at Agriculture and Agri-Food Canada
Type Article de revue
Auteur S.F. Sarkar
Auteur J.S. Poon
Auteur E. Lepage
Auteur L. Bilecki
Auteur B. Girard
Volume 40
Pages 70-75
Publication New Biotechnology
Date 2018
DOI 10.1016/j.nbt.2017.04.001
Résumé Science and innovation are important components underpinning the agricultural and agri-food system in Canada. Canada's vast geographical area presents diverse, regionally specific requirements in addition to the 21st century agricultural challenges facing the overall sector. As the broader needs of the agricultural landscape have evolved and will continue to do so in the next few decades, there is a trend in place to transition towards a sustainable bioeconomy, contributing to reducing greenhouse gas emission and our dependency on non-renewable resources. We highlight some of the key policy drivers on an overarching national scale and those specific to agricultural research and innovation that are critical to fostering a supportive environment for innovation and a sustainable bioeconomy. As well, we delineate some major challenges and opportunities facing agriculture in Canada, including climate change, sustainable agriculture, clean technologies, and agricultural productivity, and some scientific initiatives currently underway to tackle these challenges. The use of various technologies and scientific efforts, such as Next Generation Sequencing, metagenomics analysis, satellite image analysis and mapping of soil moisture, and value-added bioproduct development will accelerate scientific development and innovation and its contribution to a sustainable and prosperous bioeconomy. © 2017

Costs and benefits of shelterbelts: A review of producers'perceptions and mind map analyses for Saskatchewan, Canada
Type Article de revue
Auteur J.C. Rempel
Auteur S.N. Kulshreshtha
Auteur B.Y. Amichev
Auteur K.C.J. Van Rees
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-85028700625&doi=10.1139%2fcjss-2016-0100&partnerID=40&
md5=12a9457ce93dd8c9cb5c0770bb154b59
Volume 97
Numéro 3
Pages 341-352
Publication Canadian Journal of Soil Science
Date 2016
DOI 10.1139/cjss-2016-0100

Résumé The role of shelterbelts within prairie agriculture is changing. In the past, shelterbelts have been promoted and adopted to reduce soil erosion and to protect farmsteads and livestock from harsh prairie climates. Production techniques used today have been changed from when shelterbelts were first introduced as a management practice to reduce erosion. Advances in production technology accompanied with increase in farm size and changes to policy have all contributed to a shift in how shelterbelts are considered within management plans. The objective of this research is to identify the private costs and benefits from adoption and retention of shelterbelts. In the summer of 2013, a survey was conducted of producers and land owners chiefly from Saskatchewan, Canada. It was found that many of the benefits of shelterbelts can be classified as noneconomic and, therefore, are more difficult for producers and land owners to recognize or include within their operations management decisions. Conversely, the costs to producers were easily identified and heavily influenced management decisions. As greenhouse gas management and policy become more of a focus, shelterbelts have the potential to play a major role in climate change mitigation by sequestering significant amounts of atmospheric carbon dioxide (CO_2) into the soil and as biomass carbon in above- and belowground parts of planted shelterbelt trees or shrubs. However, most producers do not recognize such benefits within their management decisions, as they are not currently compensated for the benefits that they provide to society.

Biologically derived fertilizer: A multifaceted bio-tool in methane mitigation

Type Article de revue
Auteur J.S. Singh
Auteur P.J. Strong
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-84946567237&doi=10.1016%2fj.ecoenv.2015.10.018&partnerID=40&md5=2a37af78ede29c03395c5bb8a33814bf
Volume 124
Pages 267-276
Publication Ecotoxicology and Environmental Safety
Date 2016
DOI 10.1016/j.ecoenv.2015.10.018

Résumé Methane emissions are affected by agricultural practices. Agriculture has increased in scale and intensity because of greater food, feed and energy demands. The application of chemical fertilizers in agriculture, particularly in paddy fields, has contributed to increased atmospheric methane emissions. Using organic fertilizers may improve crop yields and the methane sink potential within agricultural systems, which may be further improved when combined with beneficial microbes (i.e. biofertilizers) that improve the activity of methane oxidizing bacteria such as methanotrophs. Biofertilizers may be an effective tool for agriculture that is environmentally beneficial compared to conventional inorganic fertilizers. This review highlights and discusses the interplay between ammonia and methane oxidizing bacteria, the potential interactions of microbial communities with microbially-enriched organic amendments and the possible role of these biofertilizers in augmenting the methane sink potential of soils. It is suggested that biofertilizer applications
should not only be investigated in terms of sustainable agriculture productivity and environmental management, but also in terms of their effects on methanogen and methanotroph populations.

Biomass production on trace element-contaminated land: A review

Type Article de revue
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Auteur H.M. Conesa
Auteur B.H. Robinson
Auteur R. Schulin
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-84866256434&doi=10.1089%2fees.2011.0428&partnerID=40&md5=720e6c8b07016778b1c17ea7a4987aa8
Volume 29
Numéro 9
Pages 823-839
Publication Environmental Engineering Science
Date 2012
DOI 10.1089/ees.2011.0428
Résumé Biomass production, with its primary goal of producing energy or biochar on fertile agricultural land, is of questionable economic and environmental benefit if it has to compete with agricultural crops and thereby raise the price of food. We investigate the possibility of biomass production on contaminated land (BCL). BCL could improve both the economic and environmental outlook of bioenergy, as it would bring a positive economic return from contaminated land without replacing food crops. Large areas of contaminated land, such as former mining areas, would be more economical than
small, fragmented, or high-value contaminated sites, such as those in former industrial belts of cities. High-biomass, high-value, and deep-rooted energy crops are particularly desirable for the dual benefits of economic return and pollution control through phytostabilization. To avoid contaminant entry into the food chain, plant uptake could be minimized by plant selection and by application of soil conditioners. The latter, however, would involve additional costs, which may reduce the economic feasibility of BCL. Moreover, with respect to the environmental effects of BCL, investigations must address effects of root exudates and decaying leaf litter on contaminant solubility, and effects of deep roots on the creation of macropores that could facilitate contaminant leaching. Detailed assessment of the value of contemporaneous phytostabilization, which occurs during BCL, is necessary to determine whether this technology is the best management option of a given site. © 2012 Mary Ann Liebert, Inc.

Beneficial management practices and mitigation of greenhouse gas emissions in the agriculture of the Canadian Prairie: A review
Type Article de revue
Auteur H. Asgedom
Auteur E. Kebreab
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-80054828835&doi=10.1007%2fs13593-011-0016-2&partnerID=40&md5=7364be06e851ec222d7f0120ac92932c
Volume 31
Numéro 3
Pages 433-451
Publication Agronomy for Sustainable Development
Date 2011
DOI 10.1007/s13593-011-0016-2
Résumé Climate change is one of the main global issues of modern time. Ever increasing demand for food/feed and the need for higher environmental standards require shaping of the agricultural activities toward ecological and more sustainable efficient systems. One of the principal ways of attaining higher productivity and environmental standards is identification and adoption of beneficial management

practices (BMP) by reviewing the conventional agricultural activities. The BMP are agricultural practices that promote sustainable land stewardship and maintain/increase profitability of farms. The BMP
are from both crop and animal production systems and tradeoffs between the two systems could provide several opportunities in reducing, removing and/or avoiding of greenhouse gases (GHG) emissions. Despite that, few reviews have presented them together. This review covers GHG emissions related to the BMP in the crop and animal production systems of farms relevant to Canadian Prairie. These BMP include: (1) use of inorganic N fertilizers, (2) livestock and feed management, (3) manure management, (4) cropping systems, (5) tillage practices and (6) improved pasture and grazing management. In addition,
sources of variations, quantification methods and adoptability are discussed. Quantified GHG emissions from direct and indirect measurements of researches from Canada and other part of the world are included. Since most experiments are conducted under multiple biophysical scenarios while adopting various methodologies, summarizing the findings was difficult. The effect of BMP on GHG is determined by ecological processes. Such determinants are discussed and knowledge gaps are identified. Integration of crop and livestock production systems could further lead toward higher energy and resource use efficiency; hence less GHG emissions. © The Author(s) 2011.

Biomass-based chemical looping technologies: the good, the bad and the future
Type Article de revue
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Auteur Hui Zhou
Auteur Vineet Singh Sikarwar
Auteur Ming Zhao
Auteur Ah-Hyung A. Park
Auteur Paul S. Fennell
Auteur Laihong Shen
Auteur Liang-Shih Fan
Volume 10
Numéro 9
Pages 1885-1910
Publication Energy & Environmental Science
ISSN 1754-5692
Date SEP 1 2017
Extra WOS:000410594300002
DOI 10.1039/c6ee03718f
Résumé Biomass is a promising renewable energy resource despite its low energy density, high moisture content and complex ash components. The use of biomass in energy production is considered to be approximately carbon neutral, and if it is combined with carbon capture technology, the overall energy conversion may even be negative in terms of net CO2 emission, which is known as BECCS (bioenergy with carbon capture and storage). The initial development of BECCS technologies often proposes the installation of a CO2 capture unit downstream of the conventional thermochemical conversion processes, which
comprise combustion, pyrolysis or gasification. Although these approaches would benefit from the adaptation of already well developed energy conversion processes and CO2 capture technologies, they are limited in terms of materials and energy integration as well as systems engineering, which could lead to truly disruptive technologies for BECCS. Recently, a new generation of transformative energy conversion technologies including chemical looping have been developed. In particular, chemical looping employs solid looping materials and it uniquely allows inherent capture of CO2 during the conversion of

fuels. In this review, the benefits, challenges, and prospects of biomass-based chemical looping technologies in various configurations have been discussed in-depth to provide important insight into the development of innovative BECCS technologies based on chemical looping.

ECONOMIC INSTRUMENTS FOR REDUCTION OF GREENHOUSE GAS EMISSION IN AGRICULTURE AND FORESTRY

Type Article de revue
Auteur Radmilo Pesic
Auteur Marko Ivanis
Auteur Radivoj Prodanovic
Volume 65
Numéro 1
Pages 269-291
Publication Ekonomika Poljoprivreda-Economics of Agriculture
ISSN 0352-3462
Date 2018
Extra WOS:000433225700018
DOI 10.5937/ekoPolj1801269P
Résumé A significant reduction of greenhouse gas emissions in agriculture and forestry can be achieved with adequate economic instruments. There are also other measures on disposal, such as good agricultural practice and organic production that involve the use of agronomic and biotechnological knowledge and skills with the purpose to produce healthy and safe food, with the preserving the environment and production resources. In the paper we analyze the previous experience in the application of economic instruments for the reduction of greenhouse effect in Agriculture and Forestry, in the broad and narrow sense, both in the domestic and international context. Special attention is given to the experiences in the implementation of the so-called flexibility mechanisms under the Kyoto Protocol. As a result of these experiences, in the period after 2012, new instruments have been created, mainly on a voluntary basis, which does not inspire confidence in their effectiveness. It has been noted that the system of economic instruments for the promotion of agricultural
production in Serbia is in contradiction with the objectives of the climate protection policy. Changes are proposed in terms of abolishing direct benefits per hectare and the livestock units, as well as introduction of incentives for energy efficiency, renewable energy sources, and specifically for the organic production. Punitive measures must, once and for all, stop the harmful and dangerous practice of burning crop residues on fields.

The progressive routes for carbon capture and sequestration

Type Article de revue
Auteur Sonil Nanda
Auteur Sivamohan N. Reddy
Auteur Sushanta K. Mitra
Auteur Janusz A. Kozinski
Volume 4
Numéro 2
Pages 99-122
Publication Energy Science & Engineering
ISSN 2050-0505
Date MAR 2016

Extra WOS:000374441700001
DOI 10.1002/ese3.117
Résumé The global warming is directly related to the increased greenhouse gas emissions from both natural and anthropogenic origins. There has been a drastic rise in the concentration of CO2 and other greenhouse gases since the industrial revolution primarily due to the intensifying consumption of fossil fuels. With the need to reduce carbon emissions and mitigate global warming certain strategies relating to carbon capturing and sequestration are indispensable. This paper comprehensively describes several physicochemical, biological and geological routes for carbon capture and sequestration. The trend of the increase in greenhouse gases over the years is illustrated along with the global statistics for fossil fuels usage and biofuels production. The physicochemical carbon capturing technologies discussed include absorption, adsorption, membrane separation and cryogenic distillation. The algal and bacterial systems, dedicated energy crops and coalbed methanogenesis have been vividly explained as the biological routes for carbon sequestration. The geological carbon sequestering route centers on biochar application and oceanic carbon storage. A systematic survey has been made on the origin and impact of greenhouse gases along with the potential for sequestration based on some fast-track and long-term sequestration technologies.

Beyond Technology: Demand-Side Solutions for Climate Change Mitigation

Type Chapitre de livre
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Auteur Blanca Fernandez
Auteur Helmut Haberl
Auteur Radhika Khosla
Auteur Yacob Mulugetta
Auteur Karen C. Seto
Éditeur A. Gadgil
Éditeur T. P. Gadgil
Volume 41
Lieu Palo Alto
Éditeur Annual Reviews
Pages 173-198
ISBN 978-0-8243-2341-7
Date 2016
Extra WOS:000398214100007
Résumé The assessment literature on climate change solutions to date has emphasized technologies and options based on cost-effectiveness analysis. However, many solutions to climate change mitigation misalign with such analytical frameworks. Here, we examine demand-side solutions, a crucial class of mitigation options that go beyond technological specification and cost-benefit analysis. To do so, we synthesize demand-side mitigation options in the urban, building, transport, and agricultural sectors. We also highlight the specific nature of demand-side solutions in the context of development. We then
discuss key analytical considerations to integrate demand-side options into overarching assessments on mitigation. Such a framework would include infrastructure solutions that interact with endogenous preference formation. Both hard infrastructures, such as the built environment, and soft infrastructures, such as habits and norms, shape behavior and as a consequence offer significant potential for reducing overall energy demand and greenhouse gas emissions. We conclude that systemic infrastructural and behavioral change will likely be a necessary component of a transition to a low-carbon society.
Titre du livre Annual Review of Environment and Resources, Vol 41

A review of technology and policy deep decarbonization pathway options for making energy-intensive industry production consistent with the Paris Agreement

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Auteur O. Sartor
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Volume 187
Pages 960-973
Publication Journal of Cleaner Production
Date 2018
DOI 10.1016/j.jclepro.2018.03.107
Résumé The production of commodities by energy-intensive industry is responsible for 1/3 of annual global greenhouse gas (GHG) emissions. The climate goal of the Paris Agreement, to hold the increase in the global average temperature to well below 2 °C above pre-industrial levels while pursuing efforts to limit the temperature increase to 1.5 °C, requires global GHG emissions reach net-zero and probably negative by 2055–2080. Given the average economic lifetime of industrial facilities is 20 years or more, this indicates all new investment must be net-zero emitting by 2035–2060 or be compensated by negative emissions to guarantee GHG-neutrality. We argue, based on a sample portfolio of emerging and near-commercial technologies for each sector (largely based on zero carbon electricity & heat sources, biomass and carbon capture, and catalogued in an accompanying database), that reducing energyintensive industrial GHG emissions to Paris Agreement compatible levels may not only be technically possible, but can be achieved with sufficient prioritization and policy effort. We then review policy options to drive innovation and investment in these technologies. From this we synthesize a preliminary integrated strategy for a managed transition with minimum stranded assets, unemployment, and social trauma that recognizes the competitive and globally traded nature of commodity production. The strategy includes: an initial policy commitment followed by a national and sectoral stakeholder driven pathway process to build commitment and identify opportunities based on local zero carbon resources; penetration of near-commercial technologies through increasing valuation of GHG material intensity through GHG pricing or tradable performance based regulations with protection for competitiveness and against carbon leakage; research and demand support for the output of pilot plants, including some combination of guaranteed abovemarket prices that decline with output and an increasing requirement for low carbon inputs in government procurement; and finally, key supporting institutions.

AGRICULTURE - BIOCHAR

Pyrogenic carbon capture and storage
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Volume 11
Numéro 4
Pages 573-591
Publication GCB Bioenergy
Date 2019
DOI 10.1111/gcbb.12553
Résumé The growth of biomass is considered the most efficient method currently available to extract carbon dioxide from the atmosphere. However, biomass carbon is easily degraded by microorganisms releasing it in the form of greenhouse gases back to the atmosphere. If biomass is pyrolyzed, the organic carbon is converted into solid (biochar), liquid (bio-oil), and gaseous (permanent pyrogas) carbonaceous products. During the last decade, biochar has been discussed as a promising option to improve soil fertility and sequester carbon, although the carbon efficiency of the thermal conversion of biomass into biochar is in the range of 30%–50% only. So far, the liquid and gaseous pyrolysis products were mainly considered for combustion, though they can equally be processed into recalcitrant forms suitable for carbon sequestration. In this review, we show that pyrolytic carbon capture and storage (PyCCS) can aspire for carbon sequestration efficiencies of >70%, which is shown to be an important threshold to allow PyCCS to become a relevant negative emission technology. Prolonged residence times of pyrogenic carbon can be generated (a) within the terrestrial biosphere including the agricultural use of
biochar; (b) within advanced bio-based materials as long as they are not oxidized (biochar, bio-oil); and (c) within suitable geological deposits (bio-oil and CO 2 from permanent pyrogas oxidation). While pathway (c) would need major carbon taxes or similar governmental incentives to become a realistic option, pathways (a) and (b) create added economic value and could at least partly be implemented without other financial incentives. Pyrolysis technology is already well established, biochar sequestration and bio-oil sequestration in soils, respectively biomaterials, do not present ecological hazards, and global scale-up appears feasible within a time frame of 10–30 years. Thus, PyCCS could evolve into a decisive tool for global carbon governance, serving climate change mitigation and the sustainable development goals simultaneously. © 2018 John Wiley & Sons Ltd

Dans cette revue, nous montrons que la capture et le stockage pyrolytiques de carbone (PyCCS) peuvent aspirer à des rendements de séquestration du carbone supérieurs à 70%, ce qui s’avère être un seuil important pour permettre à PyCCS de devenir une technologie pertinente en matière d’émissions négatives.

La technologie de pyrolyse est déjà bien établie, la séquestration du biocharbon et la séquestration de la bio-huile dans les sols, respectivement les biomatériaux, ne présentent pas de risques écologiques et l'extension à l'échelle mondiale semble possible dans un délai de 10 à 30 ans.

Data challenges in optimizing biochar-based carbon sequestration
Type Article de revue
Auteur R.R. Tan
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-85060230782&doi=10.1016%2fj.rser.2019.01.032&partnerID=40&md5=c3a6846ad0938a65666c50da43fb4632
Pages 174-177
Publication Renewable and Sustainable Energy Reviews
Date 2019
DOI 10.1016/j.rser.2019.01.032
Résumé Biochar-based carbon management networks (CMNs) offer a means of achieving negative net greenhouse gas (GHG) emissions. Such systems rely on relatively mature technologies for biochar production, distribution and application by tillage; thus, the prospects for near-term scale-up, especially in developing countries with agriculture-intensive economies, are promising. The main technological gap lies in the capability to predict, optimize and monitor the actual climate change mitigation benefits. Computer-aided planning of biochar-based CMNs will be needed to maximize GHG reductions
while minimizing any potential adverse environmental impacts. Such models can help decision-makers to understand and optimize the cost/benefit aspects of such systems to accelerate their commercial deployment. This paper gives a brief review of the available scientific literature, and discusses prospective areas for further research to facilitate the large-scale use of biochar as a negative emissions technology (NET). © 2019 Elsevier Ltd

Ce document passe brièvement en revue la littérature scientifique disponible et examine les domaines dans lesquels des recherches futures pourraient être entreprises pour faciliter l'utilisation à grande échelle du biochar en tant que technologie à émissions négatives (NET).
La principale lacune technologique réside dans la capacité de prévoir, d'optimiser et de surveiller les avantages réels de l'atténuation du changement climatique.
Une planification assistée par ordinateur des CMN basés sur le biocharbon sera nécessaire pour maximiser les réductions de GES tout en minimisant les éventuels effets négatifs sur l'environnement

Benefits and limitations of biochar amendment in agricultural soils: A review
Type Article de revue
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Auteur S.S. Lee
Auteur S.K. Pandey
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URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-85053083041&doi=10.1016%2fj.jenvman.2018.08.082&partnerID=40&md5=b443753b8dc4a7df92128d916fe2d56f
Volume 227

Pages 146-154
Publication Journal of Environmental Management
Date 2018
DOI 10.1016/j.jenvman.2018.08.082
Résumé Current agriculture faces multiple challenges due to rapid increases in food demand and environmental concerns. Recently, biochar application in agricultural soils has attracted a good deal of attention. According to literature findings, biochar has proven to play various beneficial roles with respect to the enhancement of crop yield as a fertilizer and soil quality as a soil conditioner. It can further be used to remediate soil pollution as an adsorbent, while
supporting the mitigation of greenhouse gases (GHGs) through the expansion of the soil carbon pool. The efficacy of biochar application on agricultural environments is found to be controlled by various factors such as pyrolysis temperature, feed stock, soil type, and biotic interactions. The combined effects of these factors may thus exert a decisive control on the overall outcome. Furthermore, the biochar application can also be proven to be detrimental in some scenarios. This review evaluates both the potential benefits and limitations of biochar application in agriculture soils. © 2018 Elsevier Ltd

Potential commercialisation of biocoke production in Malaysia—A best evidence review
Type Article de revue
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Auteur W.S. Ho
Volume 90
Pages 636-649
Publication Renewable and Sustainable Energy Reviews
Date 2018
DOI 10.1016/j.rser.2018.03.008
Résumé Global depletion of fossil fuels, growing awareness on the effects of carbon emissions and greenhouse gases and, the need for renewable energy, has increased the attention towards biocoke research and active engagement with various research groups and industrial players. Biocoke production and utilisation is crucial as it contributes to the efficient management of agricultural residue and municipal solid waste. The technologies involved in the biocoke production and the viability of Malaysia's agricultural waste as a feedstock was described in this paper. In addition, the paper provided background information about the biocoke characteristics and the feedstocks that dictate quality. Comparisons of commercial coal coke and biocoke production technologies that may be applicable to Malaysia were also addressed. Moreover, the paper demonstrated the challenges towards Malaysia's biocoke commercialisation despite its viability from biomass feedstocks characteristics, availability, and evidence of calorific value estimations. © 2018 Elsevier

Recent developments in biochar utilization as an additive in organic solid waste composting: A review
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Volume 246
Pages 203-213
Publication Bioresource Technology
Date 2017
DOI 10.1016/j.biortech.2017.07.090
Résumé In recent years, considerable studies have been devoted to investigating the effect of biochar application on organic solid waste composting. This review provides an up-to-date overview of biochar amendment on composting processes and compost quality. Biochar production, characteristics, and its application coupled with the basic concepts of composting are briefly introduced before detailing the effects of biochar addition on composting. According to recent studies, biochar has exhibited great potential for enhancing composting. It is evident that biochar addition in composting can: (1) improve compost mixture physicochemical properties, (2) enhance microbial activities and promote organic matter decomposition, (3) reduce ammonia (NH3) and greenhouse gas (GHG) emissions, and (4) upgrade compost quality by increasing the total/available nutrient content, enhancing maturity, and decreasing phytotoxicity. Despite that, further research is needed to explore the mechanism of biochar addition on composting and to evaluate the agricultural and environmental performances of co-composted biochar compost. © 2017 Elsevier Ltd

Biochar boosts tropical but not temperate crop yields
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Auteur B.A. Hungate
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Volume 12
Numéro 5
Publication Environmental Research Letters
Date 2017
DOI 10.1088/1748-9326/aa67bd
Résumé Applying biochar to soil is thought to have multiple benefits, from helping mitigate climate change [1, 2], to managing waste [3] to conserving soil [4]. Biochar is also widely assumed to boost crop yield [5, 6], but there is controversy regarding the extent and cause of any yield benefit [7]. Here we use a global-scale meta-analysis to show that biochar has, on average, no effect on crop yield in temperate latitudes, yet elicits a 25% average increase in yield in

the tropics. In the tropics, biochar increased yield through liming and fertilization, consistent with the low soil pH, low fertility, and low fertilizer inputs typical of arable tropical soils. We also found that, in tropical soils, high-nutrient biochar inputs stimulated yield substantially more than low-nutrient biochar, further supporting the role of nutrient fertilization in the observed yield stimulation. In contrast, arable soils in temperate regions are moderate in
pH, higher in fertility, and generally receive higher fertilizer inputs, leaving little room for additional benefits from biochar. Our findings demonstrate that the yield-stimulating effects of biochar are not universal, but may especially benefit agriculture in low-nutrient, acidic soils in the tropics. Biochar management in temperate zones should focus on potential non-yield benefits such as lime and fertilizer cost savings, greenhouse gas emissions control, and other ecosystem services. © 2017 IOP Publishing Ltd.

Biochar as a tool to reduce the agricultural greenhouse-gas burden–knowns, unknowns and future research needs
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Volume 25
Numéro 2
Pages 114-139
Publication Journal of Environmental Engineering and Landscape Management
Date 2017
DOI 10.3846/16486897.2017.1319375
Résumé Agriculture and land use change has significantly increased atmospheric emissions of the non-CO2 green-house gases (GHG) nitrous oxide (N2O) and methane (CH4). Since human nutritional and bioenergy needs continue to increase, at a shrinking global land area for production, novel land management strategies are required that reduce the GHG footprint per unit of yield. Here we review the potential of biochar to reduce N2O and CH4 emissions from agricultural practices including potential mechanisms behind observed effects. Furthermore, we investigate alternative uses of biochar in agricultural land management that may significantly reduce the GHG-emissions-per-unit-of-product footprint, such as (i) pyrolysis of manures as hygienic alternative to direct soil application, (ii) using biochar as fertilizer carrier matrix for underfoot fertilization, biochar use (iii) as composting additive or (iv) as feed additive in animal

husbandry or for manure treatment. We conclude that the largest future research needs lay in conducting life-cycle GHG assessments
when using biochar as an on-farm management tool for nutrient-rich biomass waste streams.

Biochar properties and eco-friendly applications for climate change mitigation, waste management, and wastewater treatment: A review

Type Article de revue
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URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-85019370629&doi=10.1016%2fj.rser.2017.05.057&partnerID=40&md5=25566b1a8d3b80e11b735c25da2bd021
Volume 79
Pages 255-273
Publication Renewable and Sustainable Energy Reviews
Date 2017
DOI 10.1016/j.rser.2017.05.057
Résumé Pyrolysis is one of the most promising technologies for the conversion of biomass into high-value products such as bio-oil, syngas, and biochar in the absence of oxygen. High yield biochar can be produced through torrefaction or slow pyrolysis. The efficiency of biochar production from biomass is highly dependent on the pyrolysis temperature, heating rate, type and composition of feedstock, particle size, and reactor conditions. Application of biochar to agriculture may have a significant effect on reducing global warming through the reduction of greenhouse gas (GHG) emissions and the
sequestering of atmospheric carbon into soil. At the same time, biochar can help improve soil health and fertility, and enhance agricultural production. Livestock manure, along with waste-feed residues and bedding materials, is a potential source of biochar. This waste emits significant amounts of GHGs adding to global warming and threatening the environment in other ways. The environmental challenges caused by agricultural and animal-waste disposal can be reduced by recycling the waste using pyrolysis, into biochar, energy, and value-added products. Biochar can act as a sorbent for organic and
inorganic contaminants and can efficiently remove these materials from affected waters. Contaminant removal is mainly based on the presence of functional groups and charges on the surface of the biochar. Thus, biochar can help to improve food security by contributing to sustainable production systems and maintaining an eco-friendly environment. This review details the principles and concepts involved in biochar production, the factors that affect biochar quality, as well as the applications of biochar.

Biochar systems in the water-energy-food nexus: the emerging role of process systems engineering

Type Article de revue
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Auteur M.F.D. Benjamin
Auteur R.R. Tan
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-85029175548&doi=10.1016%2fj.coche.2017.08.005&partnerID=40&

md5=9c4fe83bf547560372db2c3a78fa44a8
Volume 18
Pages 32-37
Publication Current Opinion in Chemical Engineering
Date 2017
DOI 10.1016/j.coche.2017.08.005
Résumé Biochar application to soil is a potentially scalable carbon management strategy with the capability of achieving negative greenhouse gas emissions. In addition, biochar is also linked to the water-energy-food nexus (WEFN) through its potential to modify soil properties to improve agricultural productivity. Potential benefits include increased yield and reduced demand for water, fertilizers and other inputs. However, the current literature on biochar is highly fragmented, with a significant research gap in system-level analysis to synchronize production, logistics and application into a sustainable carbon management strategy. Process systems engineering (PSE) can provide a framework to allow the potential benefits of biochar systems to be optimized. This article gives an overview of biochar as a strategy to address carbon management and WEFN issues, reviews relevant scientific literature, analyzes bibliometric trends, and maps potential areas for the application of PSE to the planning of large-scale biochar systems.

Biochar as potential sustainable precursors for activated carbon production: Multiple applications in environmental protection and energy storage

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md5=17387749d28ec27e47f080dc21884713
Volume 227
Pages 359-372
Publication Bioresource Technology
Date 2017
DOI 10.1016/j.biortech.2016.12.083
Résumé There is a growing interest of the scientific community on production of activated carbon using biochar as potential sustainable precursors pyrolyzed from biomass wastes. Physical activation and chemical activation are the main methods applied in the activation process. These methods could have significantly beneficial effects on biochar chemical/physical properties, which make it suitable for multiple applications including water pollution treatment, CO_2capture, and energy storage. The feedstock with different compositions, pyrolysis conditions and activation parameters of biochar have significant influences on the properties of resultant activated carbon. Compared with traditional activated carbon, activated biochar appears to be a new potential cost-effective and environmentally-friendly carbon materials with great application prospect in many fields. This review not only summarizes information

from the current analysis of activated biochar and their multiple applications for further optimization and understanding, but also offers new
directions for development of activated biochar. © 2016 Elsevier Ltd

Soil biochar amendment as a climate change mitigation tool: Key parameters and mechanisms involved
Type Article de revue
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URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-84978194238&doi=10.1016%2fj.jenvman.2016.06.063&partnerID=40&md5=9928a684f29fb6b8d5d8377f63ef31c2
Volume 181
Pages 484-497
Publication Journal of Environmental Management
Date 2016
DOI 10.1016/j.jenvman.2016.06.063
Résumé Biochar, a solid porous material obtained from the carbonization of biomass under low or no oxygen conditions, has been proposed as a climate change mitigation tool because it is expected to sequester carbon (C) for centuries and to reduce greenhouse gas (GHG) emissions from soils. This review aimed to identify key biochar properties and production parameters that have an effect on these specific applications of the biochar. Moreover, mechanisms involved in interactions between biochar and soils were highlighted. Following a compilation and comparison of the characteristics of 76 biochars from 40 research studies, biochars with a lower N content, and consequently a higher C/N ratio (>30), were found to be more suitable for mitigation of N2O emissions from soils. Moreover, biochars produced at a higher pyrolysis temperature, and with O/C ratio <0.2, H/Corg ratio <0.4 and volatile matter below 80% may have high C sequestration potential. Based on these observations, biochar production and application to the field can be used as a tool to mitigate climate change. However, it is important to determine the pyrolysis conditions and feedstock needed to produce a biochar with the desired properties for a specific application. More research studies are needed to identify the exact mechanisms involved following biochar amendment to soil. © 2016 Elsevier

Agronomic and remedial benefits and risks of applying biochar to soil: Current knowledge and future research directions
Type Article de revue
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Auteur P. Thavamani
Auteur M. Megharaj
Auteur K. Venkateswarlu
Auteur R. Naidu
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-84948188386&doi=10.1016%2fj.envint.2015.10.018&partnerID=40&md5=2ffb4f5557c50c680ba463a72a1a75b3
Volume 87
Pages 1-12
Publication Environment International

Date 2016
DOI 10.1016/j.envint.2015.10.018
Résumé 'Biochar' represents an emerging technology that is increasingly being recognized for its potential role in carbon sequestration, reducing greenhouse gas emissions, waste management, renewable energy, soil improvement, crop productivity enhancement and environmental remediation. Published reviews have so far focused mainly on the above listed agronomic and environmental benefits of applying biochar, yet paid little or no attention to its harmful effects on the ecological system. This review highlights a balanced overview of the advantages and disadvantages of the pyrolysis process of biochar production, end-product quality and the benefits versus drawbacks of biochar on: (a) soil geochemistry and albedo, (b) microflora and fauna, (c) agrochemicals, (d) greenhouse gas efflux, (e) nutrients, (f) crop yield, and (g) contaminants (organic and inorganic). Future research should focus more on the unintended long-term consequences of biochar on biological organisms and their processes in the soil. © 2015 Elsevier Ltd.

Biochar-based bioenergy and its environmental impact in Northwestern Ontario Canada: A review

Type Article de revue
Auteur K. Homagain
Auteur C. Shahi
Auteur N. Luckai
Auteur M. Sharma
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-84919880624&doi=10.1007%2fs11676-014-0522-6&partnerID=40&
md5=2dc8b5dbd6b4e7a569213dec22afb362
Volume 25
Numéro 4
Pages 737-748
Publication Journal of Forestry Research
Date 2014
DOI 10.1007/s11676-014-0522-6
Résumé Biochar is normally produced as a by-product of bioenergy. However, if biochar is produced as a co-product with bioenergy from sustainably managed forests and used for soil amendment, it could provide a carbon neutral or even carbon negative solution for current environmental degradation problems. In this paper, we present a comprehensive review of biochar production as a co-product of bioenergy and its implications. We focus on biochar production with reference to biomass availability and sustainability and on biochar utilization for its soil amendment and greenhouse gas emissions reduction properties. Past studies confirm that northwestern Ontario has a sustainable and sufficient supply of biomass feedstock that can be used to produce bioenergy, with biochar as a co-product that can replace fossil fuel consumption, increase soil productivity and sequester carbon in the long run. For the next step, we recommend that comprehensive life cycle assessment of biochar-based bioenergy production, from raw material collection to biochar application, with an extensive economic assessment is necessary for making this technology commercially viable in northwestern Ontario. © 2014, Northeast Forestry University and Springer-Verlag Berlin Heidelberg.

Biochar: Carbon sequestration, land remediation, and impacts on soil microbiology

Type Article de revue
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Auteur T.K. Ralebitso-Senior
Auteur E. Senior
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-84868249768&doi=10.1080%2f10643389.2011.574115&partnerID=40&md5=dc6081c67ccf35c1506e38e56743e951
Volume 42
Numéro 22
Pages 2311-2364
Publication Critical Reviews in Environmental Science and Technology
Date 2012
DOI 10.1080/10643389.2011.574115
Résumé Biocharcharcoal used to amend land and sequester carbonis attracting considerable interest. Its distinctive physical/chemical/biological properties, including high water-holding capacity, large surface area, cation exchange capacity, elemental composition, and pore size/volume/distribution, effect its recognized impacts, especially on microbial communities. These are explored in the context of agriculture, composting, and land remediation/restoration.
Considerable focus is given to mycorrhizal associations, which are central to exploitation in environmental technologies involving biochar. The characteristics of biochar, its availability for nutrient cycling, including the beneficial and potentially negative/inhibitory impacts, and the requisite multidisciplinary analysis (physicochemical, microbiological, and molecular) to study these in detail, are explored. © 2012 Taylor & Francis Group, LLC.

Impacts of biochar application on upland agriculture: A review
Type Article de revue
Auteur Kumuduni Niroshika Palansooriya
Auteur Yong Sik Ok
Auteur Yasser Mahmoud Awad
Auteur Sang Soo Lee
Auteur Jwa-Kyung Sung
Auteur Agamemnon Koutsospyros
Auteur Deok Hyun Moon
Volume 234
Pages 52-64
Publication Journal of Environmental Management
ISSN 0301-4797
Date MAR 15 2019
Extra WOS:000460195000007
DOI 10.1016/j.jenvman.2018.12.085
Résumé Soil degradation has become an emerging global problem limiting sustainable upland crop production. Soil erosion, soil acidity, low fertility, inorganic/organic contamination, and salinization challenge food security and lead to severe economic constraints. Therefore, a new research agenda to develop cost-beneficial amendments for improving upland soil quality and productivity is urgently required. Biochar has been used in recent years to mitigate the problems mentioned above. Application of biochar improves the upland soil quality through significant changes in soil physicochemical and

biological properties, thereby substantially increasing crop yield. This review article aims to discuss the effects of biochar on upland soil quality and productivity based on biochar-soil interactions. The yield of various upland crops can be enhanced by biochar-induced increases of nutrient availability and topsoil retention/recovery. Furthermore, biochar can assist in controlling unsuitable soil acidity/alkalinity/salinity and remediating a contaminated soil while increasing the retention of soil organic carbon, water content, and thereby high crop yield. Biochar is strongly recommended as one of the best management practices to meet the challenges of upland agriculture. However, the properties of biochar and soil type should be considered carefully prior to application.
Notes :
Cet article de synthèse a pour objectif de discuter des effets du biocharbon sur la qualité et la productivité des sols des hautes terres, en fonction des interactions biocharbon-sol. Le rendement de diverses cultures de montagne peut être amélioré par des augmentations de la disponibilité en éléments nutritifs et de la rétention / récupération de la couche arable induites par le biochar. De plus, le biochar peut aider à contrôler l’acidité, l’alcalinité et la salinité du sol, ainsi que la dépollution d’un sol contaminé, tout en augmentant la rétention du carbone organique du sol et de sa teneur en eau, et par conséquent un rendement élevé. Le biocharbon est l’une des meilleures pratiques de gestion pour relever les défis de l’agriculture en altitude. Cependant, les propriétés du biochar et du type de sol doivent être soigneusement examinées avant l'application.

Impact of biochar application on yield-scaled greenhouse gas intensity: A meta-analysis

Type Article de revue
Auteur Xiang Liu
Auteur Peini Mao
Auteur Lanhai Li
Auteur Jie Ma
Volume 656
Pages 969-976
Publication Science of the Total Environment
ISSN 0048-9697
Date MAR 15 2019
Extra WOS:000455039600094
DOI 10.1016/j.scitotenv.2018.11.396
Résumé The application of biochar to agricultural ecosystems is a potential solution to mitigate climate change and guarantee food security. However, the impacts of biochar on greenhouse gas emissions and crop yield are usually evaluated separately and the results are contradictory in individual studies. In this study, a meta-analysis was conducted based on data from 28 peer-reviewed studies to quantify the impacts of biochar application on greenhouse gas emissions and crop yield using yield-scaled greenhouse gas intensity (GHGI). Potential factors (experimental conditions and properties of soil and biochar) influencing the effect of biochar on yield-scaled GHGI were explored. The results showed that overall, biochar significantly reduced yield-scaled GHGI by 29%. The reductions in yield-scaled GHGI induced by biochar varied with different experimental conditions and properties of soil and biochar. However, the difference was only significant between the two cropping systems, with significantly greater reduction being observed in dry lands (-41%) than in paddy fields (-17%). Therefore, it is suggested that biochar amendment in dry lands may bring more environmental and agronomic benefits than that in paddy fields. The response of crop yield to biochar application further implied that biochar made from crop residue, biochar produced at low pyrolysis temperatures (<= 400 degrees C), and biochar with high pH (>9.0) might contribute to save the production cost of biochar while promoting crop yield in agricultural ecosystems. Long-term field trials are required to elucidate the persistence of the impact of biochar on reducing yield-scaled GHGI and to clarify the underlying mechanisms. The balance between the price of biochar production and the benefits brought by biochar should also be focused in further studies.
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Marqueurs :
Biochar
Notes : une méta-analyse a été réalisée sur la base des données de 28 études examinées par des pairs afin de quantifier les effets de l’application de biocharbon sur les émissions de gaz à effet de serre et le rendement des cultures à l’aide de l’intensité des gaz à effet de serre (GHG). Les résultats ont montré que, globalement, le biochar réduisait de manière significative les émissions de GHGI à échelle de rendement de 29%. Les réductions des émissions de GES associées au biochar à l'échelle de rendement ont varié selon les conditions expérimentales et les propriétés du sol et du biochar
Cependant, la différence n'était significative qu’entre les deux systèmes de culture, une réduction significativement plus importante étant observée sur les terres arides (-41%) par rapport aux rizières (-17%). Par conséquent, il est suggéré que l’amendement du biochar dans les terres arides pourrait apporter plus d’avantages environnementaux et agronomiques que dans les rizières. La réponse du rendement de la culture à l’application du biocharbon impliquait en outre que le biochar composé de résidus de culture,

produit à des températures de pyrolyse basses (≤400 ° C) et d’un biochar avec un pH élevé (> 9,0) pourrait contribuer à réduire les coûts de rendement des cultures dans les écosystèmes agricoles.
Des essais sur le terrain à long terme sont nécessaires pour élucider la persistance de l'impact du biochar sur la réduction des GHGI à échelle de rendement et pour clarifier les mécanismes sous-jacents. L'équilibre entre le prix de la production de biocharbon et les bénéfices apportés par le biochar devrait également faire l'objet d'une étude ultérieure.

Biochar and Water Quality

Type Article de revue
Auteur Humberto Blanco-Canqui
Volume 48
Numéro 1
Pages 2-15
Publication Journal of Environmental Quality
ISSN 0047-2425
Date JAN-FEB 2019
Extra WOS:000454419100002
DOI 10.2134/jeq2018.06.0248
Résumé Biochar application is considered to be an emerging strategy to improve soil ecosystem services. However, implications of such application on water quality parameters have not been widely discussed. This paper synthesizes the state-of-the-art research on biochar effects on water erosion, nitrate leaching, and other sources of water pollution. Literature indicates that in general, biochar application reduces runoff by 5 to 50% and soil loss by 11 to
78%, suggesting that it can be effective at reducing water erosion, but the magnitude of erosion reduction is highly variable. Co-application of biochar with other organic amendments (i.e., animal manure, compost) appears to be more effective at reducing water erosion than biochar alone. A main mechanism by which biochar can reduce water erosion is by improving soil properties (i.e., organic C, hydraulic conductivity, aggregate stability), which affect soil
erodibility. This review also indicates that biochar reduces nitrate leaching, in most cases by 2 to 88%, but has mixed effect on phosphate and dissolved C leaching. Additionally, biochar effectively filters urban runoff, adsorbs pollutants, and reduces pesticides losses. Biochar feedstock, pyrolysis temperature, application amount, time after application, and co-application with other amendments affect biochar impacts on water quality. Biochar erosion and potential reduction in nutrient and pesticide use efficiency due to the strong adsorption are concerns that deserve consideration. Overall, biochar application has the potential to reduce water erosion, nitrate leaching, pesticide losses, and other pollutant losses, but more field-scale data are needed to better discern the extent to which biochar can improve water quality.

Properties and Beneficial Uses of (Bio) Chars, with Special Attention to Products from Sewage Sludge Pyrolysis
Type Article de revue
Auteur Arianna Callegari
Auteur Andrea Giuseppe Capodaglio
Volume 7
Numéro 1
Pages 20
Publication Resources-Basel
Date MAR 2018
Extra WOS:000428564300019
DOI 10.3390/resources7010020
Résumé Residual sludge disposal costs may constitute up to, and sometimes above, 50% of the total cost of operation of a Wastewater Treatment Plant (WWTP) and contribute approximately 40% of the total greenhouse gas (GHG) emissions associated with its operation. Traditionally, wastewater sludges are processed for: (a) reduction of total weight and volume to facilitate their transfer and subsequent treatments; (b) stabilization of contained organic material and destruction of pathogenic microorganisms, elimination of noxious odors, and reduction of putrefaction potential and, at an increasing degree; (c) value addition by developing economically viable recovery of energy and residual constituents. Among several other processes, pyrolysis of sludge biomass is being experimented with by some researchers. From the process, oil with composition not dissimilar to that of biodiesels, syngas, and a solid residue can be obtained. While the advantage of obtaining sludge-derived liquid and gaseous fuels is obvious to most, the solid residue from the process, or char (also
indicated as biochar by many), may also have several useful, initially unexpected applications. Recently, the char fraction is getting attention from the scientific community due to its potential to improve agricultural soils' productivity, remediate contaminated soils, and supposed, possible mitigation effects on climate change. This paper first discusses sludge-pyrolysis-derived char production fundamentals (including relationships between char, bio-oil, and syngas fractions in different process operating conditions, general char properties, and possible beneficial uses). Then, based on current authors' experiments with microwave-assisted sludge pyrolysis aimed at maximization of liquid fuel extraction, evaluate specific produced char characteristics and production to define its properties and most appropriate beneficial use applications in this type of setting.

Biochar for composting improvement and contaminants reduction. A review
Type Article de revue
Auteur Paulina Godlewska
Auteur Hans Peter Schmidt
Auteur Yong Sik Ok
Auteur Patryk Oleszczuk
Volume 246
Pages 193-202
Publication Bioresource Technology
ISSN 0960-8524
Date DEC 2017
Extra WOS:000415640100022
DOI 10.1016/j.biortech.2017.07.095

Résumé Biochar is characterised by a large specific surface area, porosity, and a large amount of functional groups. All of those features cause that biochar can be a potentially good material in the optimisation of the process of composting and final compost quality. The objective of this study was to compile the current knowledge on the possibility of biochar application in the process of composting and on the effect of biochar on compost properties and on the content of contaminants in compost. The paper presents the effect of biochar on compost maturity indices, composting temperature and moisture, and also on the content and bioavailability of nutrients and of organic and inorganic contaminants. In the paper note is also taken of the effect of biochar added to composted material on plants, microorganisms and soil invertebrates.

Environmental building policy by the use of microalgae and decreasing of risks for Canadian oil sand sector development

Type Article de revue
Auteur Armen B. Avagyan
Volume 24
Numéro 25
Pages 20241-20253
Publication Environmental Science and Pollution Research
ISSN 0944-1344
Date SEP 2017
Extra WOS:000408698700009
DOI 10.1007/s11356-017-9864-x
Résumé Environmental building recommendations aimed towards new environmental policies and management-changing decisions which as example
demonstrated in consideration of the problems of Canadian oil sands operators. For the implementation of the circular economic strategy, we use an in-depth analysis of reported environmental after-consequence on all stages of the production process. The study addressed the promotion of innovative solutions for greenhouse gas emission, waste mitigation, and risk of falling in oil prices for operators of oil sands with creating market opportunities. They include the addition of microalgae biomass in tailings ponds for improvement of the microbial balance for the water speedily cleaning, recycling, and reusing with mitigation of GHG emissions. The use of food scraps for the nutrition of microalgae will reduce greenhouse gas emission minimally, on 0.33 MtCO(2)eq for Alberta and 2.63 MtCO(2)eq/year for Canada. Microalgae-derived biofuel can reduce this emission for Alberta on 11.9-17.9 MtCO(2)eq and for Canada on 71-106 MtCO(2)eq/year, and the manufacturing of other products will adsorb up to 135.6 MtCO(2) and produce 99.2 MtO(2). The development of the Live Conserve Industry and principal step from non-efficient protection of the environment to its cultivation in a large scale with mitigation of GHG emission and waste as well as generating of O-2 and value-added products by the use of microalgae opens an important shift towards a new design and building of a biological system.

Biochar-based water treatment systems as a potential low-cost and sustainable technology for clean water provision
Type Article de revue
Auteur Willis Gwenzi
Auteur Nhamo Chaukura
Auteur Chicgoua Noubactep
Auteur Fungai N. D. Mukome
Volume 197
Pages 732-749
Publication Journal of Environmental Management
ISSN 0301-4797
Date JUL 15 2017
Extra WOS:000401880100069
DOI 10.1016/j.jenvman.2017.03.087
Résumé Approximately 600 million people lack access to safe drinking water, hence achieving Sustainable Development Goal 6 (Ensure availability and sustainable management of water and sanitation for all by 2030) calls for rapid translation of recent research into practical and frugal solutions within the remaining 13 years. Biochars, with excellent capacity to remove several contaminants from aqueous solutions, constitute an untapped technology for drinking water treatment. Biochar water treatment has several potential merits compared to existing low-cost methods (i.e., sand filtration, boiling, solar
disinfection, chlorination): (1) biochar is a low-cost and renewable adsorbent made using readily available biomaterials and skills, making it appropriate for low-income communities; (2) existing methods predominantly remove pathogens, but biochars remove chemical, biological and physical contaminants;(3) biochars maintain organoleptic properties of water, while existing methods generate carcinogenic by-products (e.g., chlorination) and/or increase concentrations of chemical contaminants (e.g., boiling). Biochars have co-benefits including provision of clean energy for household heating and cooking, and soil application of spent biochar improves soil quality and crop yields. Integrating biochar into the water and sanitation system transforms linear material flows into looped material cycles, consistent with terra preta sanitation. Lack of design information on biochar water treatment, and environmental and public health risks constrain the biochar technology. Seven hypotheses for future research are highlighted under three themes: (1) design and optimization of biochar water treatment; (2) ecotoxicology and human health risks associated with contaminant transfer along the biochar-soil-food-human pathway, and (3) life cycle analyses of carbon and energy footprints of biochar water treatment systems.

Polycyclic aromatic hydrocarbons and volatile organic compounds in biochar and biochar-amended soil: a review
Type Article de revue
Auteur Tanushree Dutta
Auteur Eilhann Kwon
Auteur Satya Sundar Bhattacharya
Auteur Byong Hun Jeon
Auteur Akash Deep
Auteur Minori Uchimiya
Auteur Ki-Hyun Kim
Volume 9
Numéro 6
Pages 990-1004

Publication Global Change Biology Bioenergy
ISSN 1757-1693
Date JUN 2017
Extra WOS:000402743500001
DOI 10.1111/gcbb.12363
Résumé Residual pollutants including polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), and carbon (aceous) nanoparticles are inevitably generated during the pyrolysis of waste biomass and remain on the solid coproduct called biochar. Such pollutants could have adverse effects on the plant growth as well as microbial community in soil. Although biochar has been proposed as a 'carbon negative strategy' to mitigate the greenhouse gas emissions, the impacts of its application with respect to long-term persistence and bioavailability of hazardous components are not clear. Moreover, the co-occurrence of low molecular weight VOCs with PAHs in biochar may exert further phytotoxic effects. This review describes the basic need to unravel key mechanisms driving the storage vs. emission of these organics and the dynamics between the sorbent (biochar) and soil microbes. Moreover, there is an urgent need for standardized methods for quantitative analysis of PAHs and VOCs in biochar under environmentally relevant conditions. This review is
also extended to cover current research gaps including the influence of biochar application on the short- and long-term fate of PAHs and VOCs and the proper control tactics for biochar quality and associated risk.

Potential Environmental Benefits from Blending Biosolids with Other Organic Amendments before Application to Land

Type Article de revue
Auteur Dharini Paramashivam
Auteur Nicholas M. Dickinson
Auteur Timothy J. Clough
Auteur Jacqui Horswell
Auteur Brett H. Robinson
Volume 46
Numéro 3
Pages 481-489
Publication Journal of Environmental Quality
ISSN 0047-2425
Date MAY-JUN 2017
Extra WOS:000404385100001
DOI 10.2134/jeq2016.10.0421
Résumé Biosolids disposal to landfill or through incineration is wasteful of a resource that is rich in organic matter and plant nutrients. Land application can improve soil fertility and enhance crop production but may result in excessive nitrate N (NO3--N) leaching and residual contamination from pathogens, heavy metals, and xenobiotics. This paper evaluates evidence that these concerns can be reduced significantly by blending biosolids with organic materials to reduce the environmental impact of biosolids application to soils. It appears feasible to combine organic waste streams for use as a resource to build or amend degraded soils. Sawdust and partially pyrolyzed biochars provide an opportunity to reduce the environmental impact of biosolids application, with studies showing reductions of NO3--N leaching of 40 to 80%. However, other organic amendments including lignite coal waste may result in excessive NO3--N leaching. Field trials combining biosolids and biochars for rehabilitation of degraded forest and ecological restoration are recommended.

Biochar-Rhizosphere Interactions - a Review
Type Article de revue
Auteur Slawomir Gluszek
Auteur Lidia Sas-Paszt
Auteur Beata Sumorok
Auteur Ryszard Kozera
Volume 66
Numéro 2
Pages 151-161
Publication Polish Journal of Microbiology
ISSN 1733-1331
Date 2017
Extra WOS:000405058700001
Résumé Biochar is a solid material of biological origin obtained from biomass carbonization, designed as a mean to reduce greenhouse gases emission and carbon sequestration in soils for a long time. Biochar has a wide spectrum of practical utilization and is applied as a promising soil improver or fertilizer in agriculture, or as a medium for soil or water remediation. Preparations of biochar increase plant growth and yielding when applied into soil and also improve plant growth conditions, mainly bio, physical and chemical properties of soil. Its physical and chemical properties have an influence on bacteria, fungi and invertebrates, both in field and laboratory conditions. Such effects on rhizosphere organisms are positive or negative depending on biochar raw material origin, charring conditions, frequency of applications, applications method and doses, but long term effects are generally positive and are associated mainly with increased soil biota activity However, a risk assessment of biochar applications is necessary to protect food production and the soil environment. This should be accomplished by biochar production and characterization, land use implementation, economic analysis, including life cycle assessment, and environmental impact assessment.

Recent developments in biochar as an effective tool for agricultural soil management: a review
Type Article de revue
Auteur Mahmood Laghari
Auteur Ravi Naidu
Auteur Bo Xiao
Auteur Zhiquan Hu
Auteur Muhammad Saffar Mirjat
Auteur Mian Hu
Auteur Muhammad Nawaz Kandhro
Auteur Zhihua Chen
Auteur Dabin Guo
Auteur Qamardudin Jogi
Auteur Zaidun Naji Abudi
Auteur Saima Fazal
Volume 96
Numéro 15
Pages 4840-4849
Publication Journal of the Science of Food and Agriculture
ISSN 0022-5142
Date DEC 2016

Extra WOS:000387351200002
DOI 10.1002/jsfa.7753
Résumé In recent years biochar has been demonstrated to be a useful amendment to sequester carbon and reduce greenhouse gas emission from the soil to the atmosphere. Hence it can help to mitigate global environment change. Some studies have shown that biochar addition to agricultural soils increases crop production. The mechanisms involved are: increased soil aeration and water-holding capacity, enhanced microbial activity and plant nutrient status in soil, and alteration of some important soil chemical properties. This review provides an in-depth consideration of the production, characterization and agricultural use of different biochars. Biochar is a complex organic material and its characteristics vary with production conditions and the feedstock used. The agronomic benefits of biochar solely depend upon the use of particular types of biochar with proper field application rate under appropriate soil types and conditions. (C) 2016 Society of Chemical Industry

Biochar stability in soil: meta-analysis of decomposition and priming effects

Type Article de revue
Auteur Jinyang Wang
Auteur Zhengqin Xiong
Auteur Yakov Kuzyakov
Volume 8
Numéro 3
Pages 512-523
Publication Global Change Biology Bioenergy
ISSN 1757-1693
Date MAY 2016
Extra WOS:000374060500001
DOI 10.1111/gcbb.12266
Résumé The stability and decomposition of biochar are fundamental to understand its persistence in soil, its contribution to carbon (C) sequestration, and thus its role in the global C cycle. Our current knowledge about the degradability of biochar, however, is limited. Using 128 observations of biochar-derived CO2 from 24 studies with stable (C-13) and radioactive (C-14) carbon isotopes, we meta-analyzed the biochar decomposition in soil and estimated its mean
residence time (MRT). The decomposed amount of biochar increased logarithmically with experimental duration, and the decomposition rate decreased with time. The biochar decomposition rate varied significantly with experimental duration, feedstock, pyrolysis temperature, and soil clay content. The MRTs of labile and recalcitrant biochar C pools were estimated to be about 108days and 556years with pool sizes of 3% and 97%, respectively. These results show that only a small part of biochar is bioavailable and that the remaining 97% contribute directly to long-term C sequestration in soil. The
second database (116 observations from 21 studies) was used to evaluate the priming effects after biochar addition. Biochar slightly retarded the mineralization of soil organic matter (SOM; overall mean: -3.8%, 95% CI=-8.1-0.8%) compared to the soil without biochar addition. Significant negative priming was common for studies with a duration shorter than half a year (-8.6%), crop-derived biochar (-20.3%), fast pyrolysis (-18.9%), the lowest pyrolysis temperature (-18.5%), and small application amounts (-11.9%). In contrast, biochar addition to sandy soils strongly stimulated SOM mineralization by 20.8%. This indicates that biochar stimulates microbial activities especially in soils with low fertility. Furthermore, abiotic and biotic processes, as well as the characteristics of biochar and soils, affecting biochar decomposition are

discussed. We conclude that biochar can persist in soils on a centennial scale and that it has a positive effect on SOM dynamics and thus on C sequestration.

Agronomic and remedial benefits and risks of applying biochar to soil: Current knowledge and future research directions

Type Article de revue
Auteur Saranya Kuppusamy
Auteur Palanisami Thavamani
Auteur Mallavarapu Megharaj
Auteur Kadiyala Venkateswarlu
Auteur Ravi Naidu
Volume 87
Pages 1-12
Publication Environment International
ISSN 0160-4120
Date FEB 2016
Extra WOS:000368951700001
DOI 10.1016/j.envint.2015.10.018
Résumé 'Biochar' represents an emerging technology that is increasingly being recognized for its potential role in carbon sequestration, reducing greenhouse gas emissions, waste management, renewable energy, soil improvement, crop productivity enhancement and environmental remediation. Published reviews have so far focused mainly on the above listed agronomic and environmental benefits of applying biochar, yet paid little or no attention to its harmful effects on the ecological system. This review highlights a balanced overview of the advantages and disadvantages of the pyrolysis process of biochar
production, end-product quality and the benefits versus drawbacks of biochar on: (a) soil geochemistry and albedo, (b) microflora and fauna, (c) agrochemicals, (d) greenhouse gas efflux, (e) nutrients, (f) crop yield, and (g) contaminants (organic and inorganic). Future research should focus more on the unintended long-term consequences of biochar on biological organisms and their processes in the soil.
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Mechanisms of biochar-mediated alleviation of toxicity of trace elements in plants: a critical review
Type Article de revue
Auteur Muhammad Rizwan
Auteur Shafaqat Ali
Auteur Muhammad Farooq Qayyum
Auteur Muhammad Ibrahim
Auteur Muhammad Zia-ur-Rehman
Auteur Tahir Abbas
Auteur Yong Sik Ok
Volume 23
Numéro 3
Pages 2230-2248
Publication Environmental Science and Pollution Research
ISSN 0944-1344
Date FEB 2016
Extra WOS:000368376800026
DOI 10.1007/s11356-015-5697-7
Résumé Trace elements (TEs) contamination is one of the main abiotic stresses which limit plant growth and deteriorate the food quality by their entry into food chain. In recent, biochar (BC) soil amendment has been widely reported for the reduction of TE(s) uptake and toxicity in plants. This review summarizes the role of BC in enhancing TE(s) tolerance in plants. Under TE(s) stress, BC application increased plant growth, biomass, photosynthetic pigments, grain
yield, and quality. The key mechanisms evoked are immobilization of TE(s) in the soil, increase in soil pH, alteration of TE(s) redox state in the soil, and improvement in soil physical and biological properties under TE(s) stress. However, these mechanisms vary with plant species, genotypes, growth conditions, duration of stress imposed, BC type, and preparation methods. This review highlights the potential for improving plant resistance to TE(s) stress by BC application and provides a theoretical basis for application of BC in TE(s) contaminated soils worldwide.

Review of the Effects of Biochar Amendment on Soil Properties and Carbon Sequestration
Type Article de revue
Auteur Tao Xie
Auteur Bala Yamini Sadasivam
Auteur Krishna R. Reddy
Auteur Chengwen Wang
Auteur Kurt Spokas
Volume 20
Numéro 1
Pages UNSP 04015013
Publication Journal of Hazardous Toxic and Radioactive Waste
ISSN 2153-5493
Date JAN 2016
Extra WOS:000404961200015
DOI 10.1061/(ASCE)HZ.2153-5515.0000293
Résumé Biochar is one of a series of materials referred to as black carbon because it is produced by thermochemical transformation of the original biomass material under a variety of conditions. The objectives of this paper are to summarize the characteristics of biochar created from different feedstocks

and identify the potential of biochar to maintain soil quality and sequester carbon. Biochar properties were analyzed in context to the biochar sources using indicators of their elemental compositions, pH, surface area, and cation exchange capacity. Application effects were also compared to evaluate the potential of biochar as a soil amendment and carbon capture agent on the basis of pot and field study results. Biochar performed well in terms of the improvement of soil pH and organic carbon, the stability of soil fertilizer generated from its large surface areas and cation exchange capacities. In general, the use of biochar
proved to be an appropriate strategy for carbon neutralization resulting from carbon storage by itself and the decrease of total greenhouse gas emissions, including CO 2, CH 4, and N2O, although the effects of biochar on each gas differed significantly. Overall, biochar exhibits great potential for expanded use in environmental fields; however, additional long term field studies that would assess biochar application rates are recommended. (C) 2015 American Society of Civil Engineers.

Designing advanced biochar products for maximizing greenhouse gas mitigation potential

Type Article de revue
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Auteur Binoy Sarkar
Auteur Nanthi Bolan
Auteur Jeff Novak
Auteur Yong Sik Ok
Auteur Lukas Van Zwieten
Auteur Bhupinder Pal Singh
Auteur M. B. Kirkham
Auteur Girish Choppala
Auteur Kurt Spokas
Auteur Ravi Naidu
Volume 46
Numéro 17
Pages 1367-1401
Publication Critical Reviews in Environmental Science and Technology
ISSN 1064-3389
Date 2016
Extra WOS:000389819800001
DOI 10.1080/10643389.2016.1239975
Résumé Greenhouse gas (GHG) emissions from agricultural operations continue to increase. Carbon (C)-enriched char materials like biochar have been described as a mitigation strategy. Utilization of biochar material as a soil amendment has been demonstrated to provide potentially greater soil GHG suppression due to its interactions in the soil system. However, these effects are variable and the duration of the impact remains uncertain. Various (nano)materials can
be used to modify chars to obtain surface functionality to mitigate GHG emissions. This review critically focusses on the innovative methodologies for improving char efficiency, underpinning GHG mitigation and C sequestration.

BIOCHAR: PYROGENIC CARBON FOR AGRICULTURAL USE - A CRITICAL REVIEW

Type Article de revue

Auteur Etelvino Henrique Novotny
Auteur Claudia Maria Branco de Freitas Maia
Auteur Marcia Thais de Melo Carvalho
Auteur Beata Emoeke Madari

Volume 39
Numéro 2
Pages 321-344
Publication Revista Brasileira De Ciencia Do Solo
ISSN 0100-0683
Date MAR-APR 2015
Extra WOS:000358443300001
DOI 10.1590/01000683rbcs20140818

Résumé Biochar (carbonized biomass for agricultural use) has been used worldwide as soil amendment and is a technology of particular interest for Brazil, since its "inspiration" is from the historical Terra Preta de Indios (Amazon Dark Earth), and also because Brazil is the world's largest charcoal producer, generating enormous residue quantities in form of fine charcoal and due to the availability of different residual biomasses, mainly from agroindustry (e.g., sugar-cane
bagasse; wood and paper-mill wastes; residues from biofuel industries; sewage sludge etc), that can be used for biochar production, making Brazil a key actor in the international scenario in terms of biochar research and utilization). In the last decade, numerous studies on biochar have been carried out and now a vast literature, and excellent reviews, are available. The objective of this paper is therefore to deliver a critical review with some highlights on biochar research, rather than an exhaustive bibliographic review. To this end, some key points considered critical and relevant were selected and the pertinent literature "condensed", with a view to guide future research, rather than analyze trends of the past.

MICROALGUES

Zero-waste algal biorefinery for bioenergy and biochar: A green leap towards achieving energy and environmental sustainability

Type Article de revue
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Auteur A.K. Sarmah
Auteur R. Sen
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-85054333131&doi=10.1016%2fj.scitotenv.2018.10.002&partnerID=40&md5=a806593c2a7f66264fb4560b8e5816ab
Volume 650
Pages 2467-2482
Publication Science of the Total Environment
Date 2019
DOI 10.1016/j.scitotenv.2018.10.002

Résumé In spite of tremendous efforts and huge investments on resources, biodiesel from oleaginous microalgae has not yet become a commercially viable and sustainable alternative to petro-diesel. This is mainly because of the technological and economic challenges hovering around large scale cultivation and downstream processing of algae, water and land usage, stabilized production technology, market forces and government policies on alternative energy and carbon credits. This review attempts to capture and analyse the global trends and developments in the areas of biofuel and bio-product of microalgae and proposes possible strategies that can be adopted to produce biofuel, biochar and bio-products utilizing wastewater in a bio-refinery model. The strategies include “Zero waste discharge” concept with process integration, wherein microalgae is grown strategically using different wastewater combined with flue gas in cultivation system for simultaneous production of ‘high-value-low-volume’ product and ‘low-value-high-volume’ product with sharing of the
remnant biomass to produce biochar. In addition, the CO 2 present in the atmosphere is captured and sequestered long term in the form of biochar would help to attain carbon negativity, while remediating wastewater and balancing energy requirements. Therefore, “Zero waste discharge” concept holds the potential to make the process a sustainable one, while gaining on the carbon credits. © 2018 Elsevier B.V.

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Marqueurs :
Microalgues bioproduits de microalgues

Cette revue tente de capturer et d’analyser les tendances et les évolutions mondiales dans les domaines des biocarburants et des bioproduits de microalgues et propose des stratégies pouvant être adoptées pour produire des biocarburants, des biocharbon et des bioproduits utilisant les eaux usées dans un modèle de bioraffinage. Les stratégies incluent le concept de «rejet zéro déchet» avec intégration de processus, dans lequel une micro-algue est cultivée de manière stratégique en utilisant différentes eaux usées combinées à des gaz de combustion dans un système de culture pour la production simultanée de produits «à haute valeur ajoutée et à faible volume» et de «déchets à faible valeur ajoutée». volume 'produit avec partage de la biomasse restante pour produire du biochar. De plus, le CO 2 présent dans l’atmosphère est capté et séquestré à long terme sous forme de biochar, ce qui aiderait à atteindre la négativité du carbone, tout en assainissant les eaux usées et en équilibrant les besoins énergétiques. Par conséquent, le concept de «rejet zéro déchet» a le potentiel de rendre le processus durable, tout en bénéficiant des crédits de carbone.

The promising future of microalgae: Current status, challenges, and optimization of a sustainable and renewable industry for biofuels, feed,and other products

Type Article de revue
Auteur M.I. Khan
Auteur J.H. Shin
Auteur J.D. Kim
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-85043337437&doi=10.1186%2fs12934-018-0879-x&partnerID=40&md5=94c0bb158bf74fe9aa5b4cb5a3a2c5ec
Volume 17
Numéro 1
Publication Microbial Cell Factories
Date 2018
DOI 10.1186/s12934-018-0879-x
Résumé Microalgae have recently attracted considerable interest worldwide, due to their extensive application potential in the renewable energy, biopharmaceutical, and nutraceutical industries. Microalgae are renewable, sustainable, and economical sources of biofuels, bioactive medicinal products, and food ingredients. Several microalgae species have been investigated for their potential as value-added products with remarkable pharmacological and biological qualities. As biofuels, they are a perfect substitute to liquid fossil fuels with respect to cost, renewability, and environmental concerns. Microalgae have a significant ability to convert atmospheric CO 2 to useful products such as carbohydrates, lipids, and other bioactive metabolites. Although microalgae are feasible sources for bioenergy and biopharmaceuticals in general, some limitations and challenges remain, which must be overcome to upgrade the technology from pilot-phase to industrial level. The most challenging and crucial issues are enhancing microalgae growth rate and product synthesis, dewatering algae culture for biomass production, pretreating biomass, and optimizing the fermentation process in case of algal bioethanol production. The present review describes the advantages of microalgae for the production of biofuels and various bioactive compounds and discusses culturing parameters. © 2018 The Author(s).

COP21: The algae opportunity?

Type Article de revue
Auteur J.C.M. Pires
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-85019849097&doi=10.1016%2fj.rser.2017.05.197&partnerID=40&md5=9d8ebd6d0b25761e55369f290b90e9e0
Volume 79
Pages 867-877
Publication Renewable and Sustainable Energy Reviews
Date 2017
DOI 10.1016/j.rser.2017.05.197
Résumé Climate change is one of the main threats of the modern society. This phenomenon is associated with the increase of the greenhouse gases (GHGs, mainly carbon dioxide – CO2) emissions due to anthropogenic activities. Main causes are the burning of fossil fuels and land use change (deforestation). Climate change impacts are associated with risks to basic needs (health, food security and clean water) as

well as risks to development (jobs, economic growth and the cost of living). Taking into account this phenomenon, several countries participated in the last United Nations Climate Change Conference in Paris (21st Conference of the Parties – COP21) and agreed to reduce their GHG emissions to limit the rise in global temperature to less than 2 °C. Main commitments and actions are focused in energy efficiency, renewable energy deployment and forest protection (increasing the CO2 natural sinks). In this context, biofuels (from non-edible feedstocks) have the potential to replace fossil based fuels in the transport sector, being a carbon-neutral fuel. In particular, algae–based biofuel can play a dual role in this scenario: as photosynthetic organisms, algae can capture CO2 from industrial emissions or from atmosphere and the resulting biomass can be used to produce a wide range of materials including biofuels. Therefore, this paper reviews the research advances of algae cultures with focus on the applications (CO2 capture and bioenergy production) related to the targets of COP21 agreement. Main recent advances in algal research studies and projects are also presented. © 2017 Elsevier Ltd

Microalgae: An emerging source of energy based bio-products and a solution for environmental issues

Type Article de revue
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Auteur B.R. Gurjar
Auteur S. Biswas
Auteur V. Pruthi
Auteur N. Kumar
Auteur P. Kumar
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-85003914706&doi=10.1016%2fj.rser.2016.10.028&partnerID=40&md5=a665172a4d6f1a4cbc176c0738187972
Volume 72
Pages 1083-1093
Publication Renewable and Sustainable Energy Reviews
Date 2017
DOI 10.1016/j.rser.2016.10.028
Résumé The microalgae biomass is emerging as a potential source of energy and bioproducts with several advantages over conventional crops in terms of its ability to produce ~300-times more renewable oil. Microalgae also have a high photosynthetic response, product accumulation rate and biomass production rate compared with other energy crops. Microalgae have the ability to grow on nonagricultural soil using wastewater instead of drinking water. Furthermore, microalgae have high capability to fix carbon dioxide from the environment. Microalgae-based bioproducts have different applications in pharmaceuticals, food and feed industries, and agricultural and transportation sectors. The key objectives covered in this review pertain to the role of microalgae to (i) maintain food chain, (ii) conservation of land and water resources in the environment with sequestration of CO2, (iii) production of energy in the form of biodiesel with zero waste, and (iv) simultaneous release of higher oxygen to the environment compared with other energy crops. © 2016 Elsevier Ltd

Carbon dioxide capture from flue gases using microalgae: Engineering aspects and biorefinery concept

Type Article de revue
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Auteur M. Simões

URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-84858713627&doi=10.1016%2fj.rser.2012.02.055&partnerID=40&md5=0780778344df66d29b0dc5e85b489f7b
Volume 16
Numéro 5
Pages 3043-3053
Publication Renewable and Sustainable Energy Reviews
Date 2012
DOI 10.1016/j.rser.2012.02.055
Résumé Carbon dioxide (CO 2) is one of the most important contributors for the increase of the greenhouse effect. CO 2 concentrations are increasing in the last decades mainly due to the increase of anthropogenic emissions. To reduce the effects caused by this environmental problem, several technologies were studied to capture CO 2 from large emission source points: (i) absorption; (ii) adsorption; (iii) gas-separation membranes; and (iv) cryogenic distillation.
The resulting streams with high CO 2 concentrations are transported and stored in geological formations. However, these methodologies, known as carbon capture and storage (CCS) technologies, are considered as short-term solutions, as there are still concerns about the environmental sustainability of these processes. A promising technology is the biological capture of CO 2 using microalgae. These microorganisms can fix CO 2 using solar energy with efficiency ten times greater than terrestrial plants. Moreover, the capture process using microalgae has the following advantages: (i) being an environmental sustainable method; (ii) using directly the solar energy; and (iii) co-producing high added value materials based on biomass, such as human food, animal feed mainly for aquaculture, cosmetics, medical drugs, fertilizers, biomolecules for specific applications and biofuels. Approaches for making CO 2 fixation by microalgae economically competitive in comparison with CCS methodologies are discussed, which includes the type of bioreactors, the key process parameters, the gaseous effluents and wastewater treatment, the harvesting methods and the products extracted by microalgal biomass.

Overview of Carbon Capture Technology: Microalgal Biorefinery Concept and State-of-the-Art

Type Article de revue

Auteur Jyoti Singh

Auteur Dolly Wattal Dhar

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Publication Frontiers in Marine Science

Date FEB 5 2019

Extra WOS:000457829100001

DOI 10.3389/fmars.2019.00029

Résumé The impending danger of climate change and pollution can now be seen on the world panorama. The concentration of CO2, the most important Green House Gas (GHG), has reached to formidable levels. Although carbon capture and storage (CCS) methods have been largely worked upon, they are cumbersome in terms of economy and their long term environmental safety raises a concern. Alternatively, bio-sequestration of CO2 using microalgal cell factories has emerged as a promising way of recycling CO2 into biomass via photosynthesis which in turn could be used for the production of bioenergy and other value-added products. Despite enormous potential, the production of microalgae for low-value bulk products and bulk products such as biofuels, is heretofore, not feasible. To achieve economic viability and sustainability, major hurdles in both, the upstream and downstream processes have to be overcome. Recent technoeconomic analyses and life-cycle assessments of microalgae-based production systems have suggested that the only possible way for scaling up the production is to completely use the biomass in an integrated biorefinery set-up wherein every valuable component is extracted, processed
and valorized. This article provides a brief yet comprehensive review of the present carbon sequestration and utilization technologies, focusing primarily on biological CO2 capture by microalgae in the context of bio-refinery. The paper discusses various products of microalgal biorefinery and aims to assess the opportunities, challenges and current state-of-the-art of microalgae-based CO2 bioconversion, which are essential to the sustainability of this approach in terms of the environment as well as the economy.

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Marqueurs :

Microalgues, Bioraffinage

Notes :

Cet article présente une synthèse brève mais complète des technologies actuelles de séquestration et d'utilisation du carbone, en se concentrant principalement sur le captage biologique du CO2 par les microalgues dans le contexte du bioraffinage.

Le document discute de divers produits de la bioraffinerie de microalgues et vise à évaluer les opportunités, les défis et l'état actuel de la bioconversion au CO2 à partir de microalgues, qui sont essentiels à la durabilité de cette approche en termes d'environnement et d'économie.

From post-combustion carbon capture to sorption-enhanced hydrogen production: A state-of-the-art review of carbonate looping process feasibility
Type Article de revue
Auteur Dawid P. Hanak
Auteur Sebastian Michalski
Auteur Vasilije Manovic
Volume 177
Pages 428-452
Publication Energy Conversion and Management
ISSN 0196-8904
Date DEC 1 2018
Extra WOS:000451356300036
DOI 10.1016/j.enconman.2018.09.058
Résumé Carbon capture and storage is expected to play a pivotal role in achieving the emission reduction targets established by the Paris Agreement. However, the most mature technologies have been shown to reduce the net efficiency of fossil fuel-fired power plants by at least 7% points, increasing the electricity cost. Carbonate looping is a technology that may reduce these efficiency and economic penalties. Its maturity has increased significantly over the past twenty years, mostly due to development of novel process configurations and sorbents for improved process performance. This review provides a comprehensive overview of the calcium looping concepts and statistically evaluates their techno-economic feasibility. It has been shown that the most commonly reported figures for the efficiency penalty associated with calcium looping retrofits were between 6 and 8% points. Furthermore, the calciumlooping-based coal-fired power plants and sorption-enhanced hydrogen production systems integrated with combined cycles and/or fuel cells have been shown to achieve net efficiencies as high as 40% and 50-60%, respectively. Importantly, the performance of both retrofit and greenfield scenarios can be further improved by increasing the degree of heat integration, as well as using advanced power cycles and enhanced sorbents. The assessment of the economic feasibility of calcium looping concepts has indicated that the cost of carbon dioxide avoided will be between 10 and 30 (sic) per tonne of carbon dioxide and 10-50 (sic) per tonne of carbon dioxide in the retrofit and greenfield scenarios, respectively. However, limited economic data have been presented in the current literature for the thermodynamic performance of calcium looping concepts.

Effectiveness of amino acid salt solutions in capturing CO2: A review
Type Article de revue
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Auteur Yifu Li
Auteur Wenxiang Zhang
Auteur Junlei Wang
Auteur Mohamad Reza Soltanian
Auteur Abdul Ghani Olabi
Volume 98
Pages 179-188
Publication Renewable & Sustainable Energy Reviews
ISSN 1364-0321
Date DEC 2018
Extra WOS:000450559100014
DOI 10.1016/j.rser.2018.09.019

Résumé Carbon capture and storage (CCS) is now known to be an effective way to reduce greenhouse gas emissions especially CO2 to the atmosphere. Amino acid salt (AAS) solutions are regarded as promising CO2 absorbents compared to traditional amine solutions, as they are environmentally being with lower evaporation as well as fewer degradation issues. This paper is intended to review recent developments in CO2 capture using AASs. The thermodynamics and kinetics of CO2 and different AASs are illustrated in detail. We will also discuss the blended solutions containing AASs in terms of applications and
absorption or regeneration performance. Additionally, we will present specific directions for future research on CO2-AAS systems. This paper could provide a guideline for effective carbon capture by new absorbents.

Technology Evolution in Membrane-Based CCS

Type Article de revue
Auteur Jose Luis Miguez
Auteur Jacobo Porteiro
Auteur Raquel Perez-Orozco
Auteur Miguel Angel Gomez
Volume 11
Numéro 11
Pages 3153
Publication Energies
ISSN 1996-1073
Date NOV 2018
Extra WOS:000451814000291
DOI 10.3390/en11113153
Résumé In recent years, many CO2 capture technologies have been developed due to growing awareness about the importance of reducing greenhouse gas emissions. In this paper, publications from the last decade addressing this topic were analyzed, paying special attention to patent status to provide useful information for policymakers, industry, and businesses and to help determine the direction of future research. To show the most current patent activity related to carbon capture using membrane technology, we collected 2749 patent documents and 572 scientific papers. The results demonstrated that membranes are a developing field, with the number of applications growing at a steady pace, exceeding 100 applications per year in 2013 and 2014. North American assignees were the main contributors, with the greatest number of patents owned by companies such as UOP LLC, Kilimanjaro Energy Inc., and Membrane Technology and Research Inc., making up 26% of the total number of published patents. Asian countries (China, Japan, and Korea) and international offices were also important knowledge sources, providing 29% and 24% of the documents, respectively. Furthermore, this paper highlights 10 more valuable patents regarding their degree of innovation and citations, classified as Y02C 10/10 according to the Cooperative Patent lassification

Gas fermentation of C1 feedstocks: commercialization status and future prospects
Type Article de revue
Auteur Leonardo V. Teixeira
Auteur Liza F. Moutinho
Auteur Aline S. Romao-Dumaresq
Volume 12
Numéro 6
Pages 1103-1117
Publication Biofuels Bioproducts & Biorefining-Biofpr
ISSN 1932-104X
Date NOV-DEC 2018
Extra WOS:000450612100014
DOI 10.1002/bbb.1912
Résumé The increasing emissions of carbon dioxide, methane and carbon oxide (collectively referred as C1 compounds) are likely to configure a major contribution to global warming and other environmental issues. The implementation of carbon capture and storage (CCS) is considered a crucial strategy to prevent global warming, but the overall costs of currently available CCS technologies are still prohibitive for its large-scale deployment. Using microorganisms capable of assimilating C1 compounds for producing value-added products could be an important driver for mitigating emissions and
minimizing their deleterious consequences, while simultaneously deriving additional economic benefits from these compounds. This review summarizes the main microorganisms and metabolic routes being investigated, with special focus on both the products targeted and the current industrial initiatives. There are a number of companies investing in these routes and in some instances commercial deployment was identified. Despite the variety of commercially-appealing products, genetic manipulation of microorganisms to maximize yields and the design of technologies capable of efficiently using
the gaseous feedstocks are major challenges yet to be overcome to fully unlock the potential of C1 microbiological routes. (c) 2018 Society of Chemical Industry and John Wiley & Sons, Ltd

Utilization of algae for biofuel, bio-products and bio-remediation
Type Article de revue
Auteur Thangavel Mathimani
Auteur Arivalagan Pugazhendhi
Volume 17
Pages 326-330
Publication Biocatalysis and Agricultural Biotechnology
ISSN 1878-8181
Date JAN 2019
Extra WOS:000458427900042
DOI 10.1016/j.bcab.2018.12.007
Résumé Algae are considered as a promising source for biofuel and bio-products. Algae contain carbohydrates, lipids, proteins and their photosynthetic and lipid accumulating potential makes them a suitable candidate for bioenergy. Algal biomass is used in the production of biofuels like biodiesel, bioethanol, biobutanol, and biohydrogen etc. Therefore, this review provides an overview on the usage of algal biomass in multiple applications like fuel, food and environment. Initially, evolution of first and second generation biofuel feedstocks and their limitations have been described. Later, advantages of third generation biofuel feedstock i.e., algae over first and second generation feedstock were discussed comprehensively. Apart from bioenergy production from algae, industrially important co-products or

value added products extracted from microalgae were addressed. Various microalgae utilized for the extraction of omega-3 fatty acids were listed. Eventually, environmental application of microalgae namely wastewater treatment and CO2 sequestration were presented.
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Marqueurs :
Microalgues, Algues
Notes :
Cette revue donne donc un aperçu de l'utilisation de la biomasse d'algues dans de multiples applications telles que les carburants, l'alimentation et l'environnement. Initialement, l'évolution des matières premières de biocarburants de première et deuxième générations et leurs limites ont été décrites.

Tailoring Microalgae for Efficient Biofuel Production
Type Article de revue
Auteur Prabin Kumar Sharma
Auteur Manalisha Saharia
Auteur Richa Srivstava
Auteur Sanjeev Kumar
Auteur Lingaraj Sahoo
Volume 5
Pages UNSP 382
Publication Frontiers in Marine Science
Date NOV 21 2018
Extra WOS:000457229600001
DOI 10.3389/fmars.2018.00382
Résumé Depleting fossil fuel, soaring prices, growing demand, and global climate change concerns have driven the research for finding an alternative source of sustainable fuel. Microalgae have emerged as a potential feedstock for biofuel production as many strains accumulate higher amounts of lipid, with faster biomass growth and higher photosynthetic yield than their land plant counterparts. In addition to this, microalgae can be cultured without needing agricultural land or ecological landscapes and offer opportunities for mitigating global climate change, allowing waste water treatment and carbon dioxide sequestration. Despite these benefits, microalgae pose many challenges, including low lipid yield under limiting growth conditions and slow growth in high lipid content strains. Biotechnological interventions can make major advances in strain improvement for the commercial scale production of biofuel. We discuss various strategies, including efficient transformation toolbox, to increase lipid accumulation and its quality through the regulation of key
enzymes involved in lipid production, by blocking the competing pathways, pyramiding genes, enabling high cell biomass under nutrient-deprived conditions and other environmental stresses, and controlling the upstream regulators of targets, the transcription factors, and microRNAs. We highlight the opportunities emerging from the current progress in the application of genome editing in microalgae for accelerating the strain improvement program.

A review on sustainable microalgae based biofuel and bioenergy production: Recent developments
Type Article de revue
Auteur Abdul Raheem
Auteur Pepijn Prinsen
Auteur Arun K. Vuppaladadiyam
Auteur Ming Zhao

Auteur Rafael Luque
Volume 181
Pages 42-59
Publication Journal of Cleaner Production
ISSN 0959-6526
Date APR 20 2018
Extra WOS:000428483100005
DOI 10.1016/j.jclepro.2018.01.125
Résumé Climate changes induced by anthropogenic greenhouse gas emissions (mainly carbon dioxide) is one of the major threats of the modern era. Primary causes are the high reliance on fossil fuels for power generation, transportation, manufacturing and the intensive land usage (deforestation). The current share of renewable biofuel production in the overall fuel demand has been found insufficient to replace fossil fuels. Microalgae can deliver a sustainable
and complementary biofuel platform with some important advantages. This review aims to offer a state-of-the art review of algal biomass conversion methods into various biofuel products, including biodiesel, syngas, biogas, bioethanol. Emerging more sustainable biofuel/bioenergy production technologies are highlighted. Attention is also paid to sustainable cultivation methods, including wastewater treatment and bioremediation to capture CO2 and fix nitrogen and phosphorus, produced from industrial, agricultural and municipal sources. Finally, a light is shed on the important role of algae
metabolic engineering.

Microalgae to biofuels: 'Promising' alternative and renewable energy, review

Type Article de revue
Auteur Eyasu Shumbulo Shuba
Auteur Demeke Kifle
Volume 81
Pages 743-755
Publication Renewable & Sustainable Energy Reviews
ISSN 1364-0321
Date JAN 2018
Extra WOS:000417070500057
DOI 10.1016/j.rser.2017.08.042
Résumé The rapid growth of human population has led to mounting energy demands, which is projected to increase by 50% or more by 2030. The natural petroleum can not catch-up the current consumption rate, which is already reported to be 105 times faster than nature can create. Besides, the use of fossil fuels is devastating to our environment through greenhouse gas emissions and consequent global warming. Therefore, the search for 'clean' energy has become the most overwhelming challenges. Currently, several alternatives are being studied and implemented. Biofuels, fuels from living organisms,
provide environmental benefits, since their use leads to a decrease in the harmful emissions of CO2 and hydrocarbons and, to the elimination of Sox emissions, with a consequent decrease in the greenhouse effects. Unfortunately, the present biofuel projections are based on feed stocks that are also food commodities and resources suitable for conventional agriculture. One possibility to overcome the problem is the cultivation of micro-algae and switching to third generation biofuels, which seem to be a promising source since algae are able to efficiently convert sunlight, water, and CO2 into a variety of products suitable for renewable energy applications. Therefore, this review is intended to recapitulate current works on micro-algal biofuel production potential and discuss possible ways to put it into practice. This review starts by highlighting the advantages and various forms of micro-algal biofuels. Some of the micro-

algal species proved to be suitable for biofuel production so far are considered, with particular emphasis on Scenedesmus obliquus. The
recent attempts and achievements in improving the economies of production through genetic and metabolic engineering of micro-algal strains are also addressed. Other potential applications such as wastewater treatment and CO_2 mitigation that can be coupled with biofuel production are described. Finally, the promises and challenges of algae to biofuel industry are uncovered.

Biodiversity impacts of bioenergy production: Microalgae vs. first generation biofuels

Type Article de revue
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Volume 74
Pages 1131-1146
Publication Renewable & Sustainable Energy Reviews
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Date JUL 2017
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DOI 10.1016/j.rser.2017.02.068
Résumé Energy and fuel demands, which are currently met primarily using fossil fuels, are expected to increase substantially in the coming decades. Burning fossil fuels results in the increase of net atmospheric CO_2 and climate change, hence there is widespread interest in identifying sustainable alternative fuel sources. Biofuels are one such alternative involving the production of biodiesel and bioethanol from plants. However, the environmental impacts of
biofuels are not well understood. First generation biofuels (i.e. those derived from edible biomass including crops such as maize and sugarcane) require extensive agricultural areas to produce sufficient quantities to replace fossil fuels, resulting in competition with food production, increased land clearing and pollution associated with agricultural production and harvesting. Microalgal production systems are a promising alternative that suffer from fewer
environmental impacts. Here, we evaluate the potential impacts of microalgal production systems on biodiversity compared to first generation biofuels, through a review of studies and a comparison of environmental pressures that directly or indirectly impact biodiversity. We also compare the cultivation area required to meet gasoline and distillate fuel oil demands globally, accounting for spatial variation in productivity and energy consumption. We conclude that microalgal systems exert fewer pressures on biodiversity per unit of fuel generated compared to first generation biofuels, mainly because of reductions in direct and indirect land-use change, water consumption if water is recycled, and no application of pesticides. Further improvements of technologies and production methods, including optimization of productivities per unit area, colocation with wastewater systems and industrial CO_2 sources, nutrient and water recycling and use of coproducts for internal energy generation, would further increase CO_2 savings. Overall pollution reductions can be achieved through increased energy efficiencies, along with nutrient and water recycling. Microalgal systems provide strong potential for
helping in meeting global energy demands sustainably.

Potential of biofuels from algae: Comparison with fossil fuels, ethanol and biodiesel in Europe and Brazil through life cycle assessment

(LCA)
Type Article de revue
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Volume 73
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Publication Renewable & Sustainable Energy Reviews
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Extra WOS:000401204700049
DOI 10.1016/j.rser.2017.01.152
Résumé Despite a substantial literature using life cycle assessment (LCA) approach, the extent to which second and third generation biofuels are more sustainable than the first generation remains a subject of debate. Although the existence of limitations due to LCA variability and uncertainty, this paper intends to determine global tendencies based on a statistic and critical interpretation of previously published study results, reviewing 61 recent papers addressing an
environmental evaluation of microalgae biofuels. Such information is compared to the same impact indicators for fossil fuels and for ethanol and biodiesel from terrestrial crops in Europe and Brazil. For each case, the system boundaries and the methodological choices were precisely described. The sustainability potential of all biofuels was evaluated by the Global Warming Potential (GWP), the Energy Ratio (ER) and the Land Use (LU), allowing a broad estimation of the biofuels' contribution to climate change mitigation, their net energy efficiency and their competiveness with food production chain.
The results highlight that algae-derived biodiesel is, by far, the most efficient alternative in terms of land use compared to other biofuels, avoiding competition with food crops. Some biodiesel pathways can also satisfactorily perform in terms of greenhouse gases emissions reduction, but some others can be even worst than fossil diesel. Nevertheless, in terms of energy efficiency, algae biofuels cannot compete with other biofuels or fossil fuels. They present very low performances, even demanding more energy for its production then the energy they can deliver. Moreover, no pathway can be conclusively selected as preferable between the two main technologies available for microalgae biodiesel due to high uncertainties. However, open raceway pounds technology seems to be preferable as it looks less GHG intensive, requiring lower energy input and land use. Energetic and GWP performances can be improved if production pathways are carefully chosen and optimized.

Microalgae: Antiquity to era of integrated technology
Type Article de revue
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Volume 71
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Publication Renewable & Sustainable Energy Reviews

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Date MAY 2017
Extra WOS:000394920600041
DOI 10.1016/j.rser.2016.12.081
Résumé Uncontrolled anthropogenic activities and technological revolution increase fossil fuel consumption at higher rate that prompted researchers looking for alternative energy source to cover the current need and future demand of energy. Biomass of terrestrial crops has been studied as a promising source of renewable energy in last few decades however large scale production is still questionable because of lower productivity, indirect use of fossil fuel, lack of land availability and food vs. fuel conflict. These limitations of land based system fetch opportunity to look into untapped potential use of microalgae with high biomass productivity from saline and waste water stream. This unconventional way of feedstock generation can additionally produce value added products apart from clean energy. This review presents current scenario of microalgae applications in biofuel production and micro algae based high value bio-product industries leveraging environmental protection and waste utilization benefits. Microalgae cultivation, harvesting and biomass conversion technologies for biodiesel production have been reviewed based on adapting ancient learning to understand critical factors affecting overall productivity and economic viability. Dedicated efforts from technical experts are still required for economic viability of large scale biodiesel production in spite of positive finding at small scale. Several high value bio-products from microalgae amplified magnetism of trades for investment in this field. Microalgae
cultivation intersects two key concern areas of global warming and water pollution control/water recycling by CO2 sequestration and waste water utilization respectively. Integration of suitable upstream and downstream processing technologies with multiple product portfolio would make the microalgae bio-refinery economical viable.

A Holistic Approach to Managing Microalgae for Biofuel Applications

Type Article de revue
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Auteur Malcolm S. Y. Tang
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Volume 18
Numéro 1
Pages 215
Publication International Journal of Molecular Sciences
ISSN 1422-0067
Date JAN 2017
Extra WOS:000393030600209
DOI 10.3390/ijms18010215
Résumé Microalgae contribute up to 60% of the oxygen content in the Earth's atmosphere by absorbing carbon dioxide and releasing oxygen during photosynthesis. Microalgae are abundantly available in the natural environment, thanks to their ability to survive and grow rapidly under harsh and inhospitable conditions. Microalgal cultivation is environmentally friendly because the microalgal biomass can be utilized for the productions of biofuels, food and feed supplements, pharmaceuticals, nutraceuticals, and cosmetics. The cultivation of microalgal also can complement approaches like carbon dioxide sequestration and bioremediation of wastewaters, thereby addressing the serious environmental concerns. This review focuses on the factors affecting microalgal cultures, techniques adapted to obtain high-density microalgal cultures in photobioreactors, and the conversion of microalgal biomass into biofuels. The applications of microalgae in carbon dioxide sequestration and phycoremediation of wastewater are also discussed.

ÉNERGIE

A comprehensive study of geothermal heating and cooling systems
Type Article de revue
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URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-85056758279&doi=10.1016%2fj.scs.2018.09.036&partnerID=40&md5=56adc5ffd730ab40045cfd2f5177d080
Volume 44
Pages 793-818
Publication Sustainable Cities and Society
Date 2019
DOI 10.1016/j.scs.2018.09.036
Résumé Geothermal heat is an energy source that is local, reliable, resilient, environmentally-friendly, and sustainable. This natural energy is produced from the heat within the earth, and has different applications, such as heating and cooling of buildings, generating electricity, providing warm/cold water for agricultural products in greenhouses, and balneological use. Geothermal energy is not dependent on weather or climate and can supply heat and electricity almost continuously throughout the year. It may even be possible to use geothermal projects as “thermal batteries”, wherein waste or collected heat is stored for future use, even seasonal use, making geothermal energy “renewable” at a time scale of years. Extensive research has been carried out on different technologies and applications of geothermal energy, but comprehensive assessment of geothermal heating and cooling systems is relevant because of changing understanding, scale of application, and technology evolution. This study presents a general overview of geothermal heating and cooling systems. We provide an introduction to energy and the environment as well as the relationship between them; a brief history of geothermal energy; a discussion of district energy systems; a review of geothermal heating and cooling systems; a survey of geothermal energy distribution systems; an overview of ground source heat pumps; and, a discussion of ground heat exchangers. Recognition and accommodation of several factors addressed and discussed in our review will enhance the design and implementation of any geothermal heating or cooling system. © 2018 Elsevier Ltd
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Marqueurs :
Géothermie

Cette étude présente un aperçu général des systèmes de chauffage et de refroidissement géothermiques. La reconnaissance et la prise en compte de plusieurs facteurs abordés et discutés dans notre examen permettront d'améliorer la conception et la mise en oeuvre de tout système de chauffage ou de refroidissement géothermique.

The energy future

Type Article de revue

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Auteur C.A. Bonino

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URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-85049188404&doi=10.1146%2fannurev-chembioeng-060817-084300&partnerID=40&md5=a1743b6c1d31f965d815bf47c272e93a

Volume 9

Pages 153-174

Publication Annual Review of Chemical and Biomolecular Engineering

Date 2018

DOI 10.1146/annurev-chembioeng-060817-084300

Résumé The foreseeable energy future will be driven by economics of known technologies and the desire to reduce CO2 emissions to the atmosphere. Renewable energy options are compared with each other and with the use of fossil fuels with carbon capture and sequestration (CCS). Economic analysis is used to determine the best of several alternatives. One can disagree on the detailed costs, including externalities such as climate change and air and water pollution. But the differences in capital and operating costs between known technologies are so significant that one can draw clear conclusions. Results show that renewable energy cannot compete with fossil fuels on a cost basis alone because energy is intrinsic to the molecule, except for hydroelectricity. However, fossil fuels are implicated in climate change. Using renewable energy exclusively, including transportation and electricity needs, could reduce the standard of living in the United States by 43% to 62%, which would correspond to the level in about 1970. If capture and sequester of CO 2 are
implemented, the cost of using fossil fuels will increase, but they beat renewable energy handily as an economic way to produce clean energy. © 2018 by Annual Reviews. All rights reserved.

Thermal energy storage system integration forms for a sustainable future

Type Article de revue

Auteur G. Li

Auteur X. Zheng

URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-84968854118&doi=10.1016%2fj.rser.2016.04.076&partnerID=40&md5=a8ed44fdafba098e13564b2f8412e2c3

Volume 62

Pages 736-757

Publication Renewable and Sustainable Energy Reviews

Date 2016

DOI 10.1016/j.rser.2016.04.076

Résumé There is an increasing awareness that there are limits to the availability of non-renewable resources, while there is an increasing energy demand throughout the world. This demand is expected to be satisfied through the efficient renewable energy in the near future. However, the world is facing the challenge of variable renewable energy outputs due to a stochastic feature of the energy sources. Thermal energy storage (TES) can be a good option for mitigating the effects of intermittent renewable resources on the networks. It can not only allow the increased renewable energy and night time low price electricity

utilization, but also provide flexibility and ancillary services for managing future electricity supply/demand challenges. In this paper, various TES forms, including sensible, latent and sorption are explained and summarized for their performance enhancement. More importantly, from the perspective of sustainability, various integration forms for different applications are systematically introduced, such as TES integration with hot water supply, air
conditioners and heat pumps, TES integration with building construction systems, and TES integration with power production cycles, cogeneration, food transport, solar cookers and vehicle systems for thermal comfort. Therefore, this study is beneficial to designing more sustainable thermal systems by the researchers and engineers.

CO_2 capture by Li_4SiO_4 sorbents and their applications: Current developments and new trends

Type Article de revue
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Auteur Wenqiang Liu
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Volume 359
Pages 604-625
Publication Chemical Engineering Journal
ISSN 1385-8947
Date MAR 1 2019
Extra WOS:000454137400059
DOI 10.1016/j.cej.2018.11.128
Résumé It is urgent to reduce the emission of carbon dioxide (CO_2) into the atmosphere and thereby mitigate climate changes. To implement the industrial scenario of carbon capture and storage (CCS), there is a great need for the discovery or development of excellent solid CO_2 sorbents with technological and economic feasibility. Lithium orthosilicate (Li_4SiO_4) has been identified as one of the most promising candidates for CO_2 capture at high temperatures and has drawn worldwide research interests. In the last years, focusing on the ultimate goal of achieving a Li_4SiO_4 sorbent with excellent physicochemical performance for various industrial applications, extensive works have been conducted, including exploring suitable preparation methods, modeling analysis, various modifications for performance enhancement, optimization of operation conditions, granulation and their applications. This work summarizes the state-of-the-art researches in the literature aiming at developments of Li_4SiO_4 sorbents for high-temperature CO_2 capture. The potential new development trends are also discussed in the current work.

Carbon Mineralization by Reaction with Steel-Making Waste: A Review

Type Article de revue

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Auteur Muftah H. El-Naas
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Volume 7
Numéro 2
Pages 115
Publication Processes
ISSN 2227-9717
Date FEB 2019
Extra WOS:000460800900061
DOI 10.3390/pr7020115

Résumé Carbon capture and sequestration (CCS) is taking the lead as a means for mitigating climate change. It is considered a crucial bridging technology, enabling carbon dioxide (CO2) emissions from fossil fuels to be reduced while the energy transition to renewable sources is taking place. CCS includes a portfolio of technologies that can possibly capture vast amounts of CO2 per year. Mineral carbonation is evolving as a possible candidate to sequester CO2 from medium-sized emissions point sources. It is the only recognized form of permanent CO2 storage with no concerns regarding CO2 leakage. It is based on the principles of natural rock weathering, where the CO2 dissolved in rainwater reacts with alkaline rocks to form carbonate minerals. The active alkaline elements (Ca/Mg) are the fundamental reactants for mineral carbonation reaction. Although the reaction is thermodynamically favored, it takes place over a large time scale. The challenge of mineral carbonation is to offset this limitation by accelerating the carbonation reaction with minimal energy and feedstock consumption. Calcium and magnesium silicates are generally selected for carbonation due to their abundance in nature. Industrial waste residues emerge as an alternative source of carbonation minerals that have higher reactivity than natural minerals; they are also inexpensive and readily available in proximity to CO2 emitters. In addition, the environmental stability of the industrial waste is often enhanced as they undergo carbonation. Recently, direct mineral carbonation has been investigated significantly due to its applicability to CO2 capture and storage. This review outlines the main
research work carried out over the last few years on direct mineral carbonation process utilizing steel-making waste, with emphasis on recent research achievements and potentials for future research.

Cette revue décrit les principaux travaux de recherche menés au cours des dernières années sur le procédé de carbonatation directe de minéraux utilisant des déchets de fabrication de l'acier, en mettant l'accent sur les réalisations récentes en matière de recherche et les possibilités de recherche future. Il est basé sur les principes de l'altération naturelle des roches, où le CO2 dissous dans l'eau de pluie réagit avec les roches alcalines pour former des minéraux carbonatés.

Le défi de la carbonatation minérale est de compenser cette limitation en accélérant la réaction de carbonatation avec une consommation minimale d'énergie et de matières premières. Les silicates de calcium et de magnésium sont généralement choisis pour la carbonatation en raison de leur abondance dans la nature. Les résidus de déchets industriels apparaissent comme une source alternative de minéraux de carbonatation ayant une réactivité supérieure à celle des minéraux naturels ; ils sont également peu coûteux et facilement disponibles à proximité des émetteurs de CO2.

A Review of Carbon Capture and Storage Project Investment and Operational Decision-Making Based on Bibliometrics
Type Article de revue
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Auteur Yunbing Hou
Auteur Pengtao Wang
Auteur Bo Yang
Volume 12
Numéro 1
Pages 23
Publication Energies
ISSN 1996-1073
Date JAN 1 2019
Extra WOS:000460665000023
DOI 10.3390/en12010023
Résumé The research on carbon capture and storage (CCS) project planning and investment and operational decision-making can provide a reference for enterprises to invest in CCS and for policy-makers to formulate policies to promote CCS development. So what are the current research hotspots in this field and the gaps that still need to be further studied in the future? This paper reviews the research in the field by a bibliometric analysis. The results show that the research in this field first focus on cost analysis, followed by project investment evaluation, project planning (cost curve and pipeline network), and project operation. In particular, fossil fuel power plants, pipeline transportation, and oil fields are the most crucial objects in the three technical links of CCS projects, respectively. Policies, carbon pricing, and uncertainty in cost and benefits are factors that are mainly discussed in this field. The methods used for CCS project planning are cost curve model and optimization model. The real option approach is suitable for the evaluation of investment decision-making. The evaluation of operational decision is mostly based on optimization model. The future research directions can be summarized as five points: (1) continuously and systematically update the calculated costs in the current research to the unified price of the latest year; (2) calculate the cost curve from the perspective of emission sources; (3) expand the planning region of pipeline network to the country, continent, and even the entire world; (4) pay more
attention to the investment assessment of the CCS project that may be implemented with low cost and high return; and (5) analyze the optimal operation mode of CCS in the low-load power system.
Date d'ajout 2019-04-01 11:36:15
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Marqueurs :
Captage et de stockage, Analyse bibliométrique
Notes :
Cet article passe en revue les recherches sur le terrain par une analyse bibliométrique.
Les résultats montrent que la recherche dans ce domaine se concentre d’abord sur l’analyse des coûts, suivie de l’évaluation des investissements du projet, de la planification du projet (courbe des coûts et réseau de canalisations) et de l’exploitation du projet.
Les centrales à combustibles fossiles, le transport par pipeline et les champs pétrolifères sont les objets les plus importants des trois liens techniques des projets de CSC, respectivement.
Les orientations futures de la recherche peuvent être résumées en cinq points: (1) mettre à jour de manière continue et systématique les coûts calculés dans la recherche actuelle au prix unifié de la dernière année; (2) calculer la courbe de coût du point de vue des sources d’émission; (3) élargir la région de planification du réseau de pipelines au pays, au continent et même au monde entier; (4) accorder une plus grande attention à l'évaluation de l'investissement du projet de CSC qui peut être mise en oeuvre avec un

coût faible et un rendement élevé; et (5) analyser le mode de fonctionnement optimal du CCS dans le système d'alimentation à faible charge.

Gas oxy combustion and conversion technologies for low carbon energy: Fundamentals, modeling and reactors

Type Article de revue
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Auteur Georgios Dimitrakopoulos
Volume 37
Numéro 1
Pages 33-56
Publication Proceedings of the Combustion Institute
ISSN 1540-7489
Date 2019
Extra WOS:000456612200002
DOI 10.1016/j.proci.2018.06.002
Résumé With growing concerns over greenhouse gas emission, novel combustion technologies are timely and critical. Fossil fuels will continue to contribute a large fraction of energy production in the near and intermediate future, making carbon capture and storage an important part of the solution. System studies show that oxy-combustion can play an important role in capturing CO2 efficiently when applied to power systems, because its efficiency and electricity prices are competitive with other low carbon energy. Gas-phase oxy-combustion, diluted with CO to control the flame temperature, utilizes conventional "off-the-shelve" technology. However, the combustion process exhibits characteristics different than those of air combustion because of the chemical activity of CO2, which impacts the combustor design. We summarize these characteristics. It also suffers from an energy penalty associated air separation. Alternative oxygen production technologies includes ion-transport membranes, and chemical looping using metal oxides as oxygen carriers. These
technologies, while still under development, can couple oxygen separation and combustion in one process, i.e., process intensification. While an extensive knowledge base exists for gas phase oxy-combustion, these alternative technologies that rely on surface and electrochemical processes are still in their early stages. We review some fundamentals related to defect chemistry, surface and electrochemical reaction models, and their coupling with internal diffusion and external heat and mass transport, the associated rate-limiting steps and how they impact reactor design and performance. The discussion is used to explain the choice of oxygen carriers for chemical looping, and different reactor designs are summarized. Recent progress in material synthesis and chemistry show promising trends especially using perovskites, mixed oxides and dual-phase materials, and asymmetric structures for membranes and oxygen carriers. ITMs and CLC are dual-use technologies as they lend themselves naturally to water and CO2 splitting and the production of fuels and chemicals, but different materials and reactors are needed. They also present opportunities to integrate/hybridize fossil fuel systems with alternative energy sources for power and fuel production.
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Modifié le 2019-04-01 16:04:26
Marqueurs :
Oxydation, Captage de carbone
Notes :

Nous passons en revue certains principes fondamentaux liés à la chimie des défauts, aux modèles de réaction de surface et électrochimiques et à leur couplage avec la diffusion interne et le transport externe de chaleur et de masse, les étapes associées limitant le débit et leur incidence sur la conception et les performances du réacteur.

Applications of fly ash for CO2 capture, utilization, and storage

Type Article de revue
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Auteur Dang Viet Quang
Auteur Lourdes F. Vega
Auteur Enas Nashef
Auteur Mohammad R. M. Abu-Zahra
Volume 29
Pages 82-102
Publication Journal of Co2 Utilization
ISSN 2212-9820
Date JAN 2019
Extra WOS:000456488700010
DOI 10.1016/j.jcou.2018.11.011
Résumé Utilization is one of the prominent strategies for the management of hazardous industrial wastes like fly ash. As fossil-based power is expected to remain a major source of global electricity supply in the coming years, the absence of effective management strategies will exacerbate the problem of fly ash waste in the environment. Global fly ash utilization rates remain low due to limited utilization opportunities outside the construction industry. This necessitates the development of new pathways for its utilization as a means of diverting it from landfills where it poses a significant threat to the environment. Carbon capture, utilization, and storage presents opportunities to utilize fly ash in various ways; as a capture material, as a medium for permanent CO2 storage via mineralization, and as a catalyst or catalyst support for CO2 utilization processes. This study reviews the different technologies through which fly ash and
materials derived from fly ash are applied in the CO2 capture, utilization, and storage technology while highlighting some challenges and opportunities for further research and development.

Capture and electro-splitting of CO2 in molten salts

Type Article de revue
Auteur Wei Weng
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Auteur Wei Xiao
Volume 28
Pages 128-143
Publication Journal of Energy Chemistry
ISSN 2095-4956
Date JAN 2019
Extra WOS:000450370100018
DOI 10.1016/j.jechem.2018.06.012
Résumé Due to the serious greenhouse gas effects caused by the increasing concentration of atmospheric CO2, carbon capture and storage (CCS) has been an important area of research and many technologies are

developed within this field. Molten salt CO2 capture and electrochemical transformation (MSCC-ET) process is a desirable method due to a high CO2 solubility, a wide potential window of molten salts and easily-controlled electrode reactions. Generally, electro-splitting CO2 in molten salts begins with CO2 absorption reactions to form CO32-, which is then followed by the carbon deposition at the cathode and O-2 evolution at the anode. As a result, CO2 is electro-converted to O-2 and carbon with different morphologies, compositions, microstructures and functional properties. This report introduces the MSCC-ET process, summarizes the reactions occurring in the molten salts and at the electrode surfaces, as well as the morphological variations of the cathodic products. The inert anode materials, cost estimation and scale-up evaluation of the process are then discussed. It is presumed that with a comprehensive understanding of the electrode reactions during electrolysis and the functional
properties of carbon materials obtained during CO2 electro-splitting can provide a foundation for further developing this environmentally friendly process.

Carbon Capture and Storage: A Review of Mineral Storage of CO2 in Greece

Type Article de revue
Auteur Kyriaki Kelektsoglou
Volume 10
Numéro 12
Pages 4400
Publication Sustainability
ISSN 2071-1050
Date DEC 2018
Extra WOS:000455338100066
DOI 10.3390/su10124400
Résumé As the demand for the reduction of global emissions of carbon dioxide (CO2) increases, the need for anthropogenic CO2 emission reductions becomes urgent. One promising technology to this end, is carbon capture and storage (CCS). This paper aims to provide the current state-of-the-art of CO2 capure, transport, and storage and focuses on mineral carbonation, a novel method for safe and permanent CO2 sequestration which is based on the reaction of CO2 with calcium or magnesium oxides or hydroxides to form stable carbonate materials. Current commercial scale projects of CCS around Europe are outlined, demonstrating that only three of them are in operation, and twenty-one of them are in pilot phase, including the only one case of mineral carbonation in Europe the case of CarbFix in Iceland. This paper considers the necessity of CO2 sequestration in Greece as emissions of about 64.6 million tons of CO2 annually, originate from the lignite fired power plants. A real case study concerning the mineral storage of CO2 in Greece has been conducted, demonstrating the applicability of several geological forms around Greece for mineral carbonation. The study indicates that Mount Pindos ophiolite and Vourinos ophiolite complex could be a promising means of CO2 sequestration with mineral carbonation. Further studies are needed in order to confirm this aspect.

Striving towards the Deployment of Bio-Energy with Carbon Capture and Storage (BECCS): A Review of Research Priorities and Assessment Needs

Type Article de revue
Auteur Vassilis Stavrakas
Auteur Niki-Artemis Spyridaki

Auteur Alexandros Flamos
Volume 10
Numéro 7
Pages 2206
Publication Sustainability
ISSN 2071-1050
Date JUL 2018
Extra WOS:000440947600097
DOI 10.3390/su10072206
Résumé Assessing the performance or the implications of climate change mitigation options (CCMOs) is instrumental in achieving research and innovation efficiency in the field of climate change and becomes more imperative considering the Paris Agreement ('the Agreement'). Many climate scientists already believe that meeting the Agreement's goals and stabilizing "well-below 2 degrees C above pre-industrial levels" signals the deployment of currently undetermined and contentious mitigation technologies, such as bio-energy with carbon capture and storage (BECCS). BECCS is considered one of the most promising negative emissions technologies (NETs) with many scenarios already exhibiting its mitigation potential. However, stakeholders and policymakers remain skeptical about widespread reliance on BECCS questioning its unproven credibility. In this article, we aim at identifying research priorities and assessment needs to intensify the further deployment of BECCS, considering relevant technology associations' and platforms' perspectives and insights raised by scientific literature. The main outcome of our study is a list of 10 research priorities along with more specific assessment needs for each priority area. We also focus attention on several implications for potential end-users involved in the field of policy and practice. Overall, our work seeks to bridge the gap between market/industry and academia and to assist policymakers to make better-informed decisions.

Dry carbonate process for CO2 capture and storage: Integration with solar thermal power

Type Article de revue
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Auteur R. Chacartegui
Auteur J. M. Valverde
Auteur J. A. Becerra
Auteur C. Ortiz
Auteur J. Lizana
Volume 82
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Publication Renewable & Sustainable Energy Reviews
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DOI 10.1016/j.rser.2017.06.061
Résumé Capture and sequestration of CO2 released by conventional fossil fuel combustion is an urgent need to mitigate global warming. In this work, main CO2 capture and sequestration (CCS) systems are reviewed, with the focus on their integration with renewables in order to achieve power plants with nearly zero CO2 emissions. Among these technologies under development, the Dry Carbonate Process shows several advantages. This manuscript analyses the integration of a CO2 sorption-desorption cycle based on Na2CO3/NaHCO3 into a coal fired power plant (CFPP) for CO2 capture with solar support for sorbent regeneration. The Dry Carbonate Process relies on the use of a dry regenerable sorbent such as sodium

carbonate (Na_2CO_3) to remove CO_2 from flue gases. Na_2CO_3 is converted to sodium bicarbonate ($NaHCO_3$) through reaction with CO_2 and water steam. Na_2CO_3 is regenerated when $NaHCO_3$ is heated, which yields a gas stream mostly containing CO_2 and H_2O. Condensation of H_2O produces a pure CO_2 stream suitable for its subsequent use or compression and sequestration. In this paper, the application of the Dry Carbonate CO_2 capture process in a coal-based power plant is studied with the goal of optimizing CO_2 capture efficiency, heat and power requirements. Integration of this CO_2 capture process requires an additional heat supply which would reduce the global power plant efficiency by around 9-10%. Dry Carbonate Process has the advantage compared with other CCS technologies that requires a relatively low temperature for sorbent regeneration (< 200 degrees C). It allows an effective integration of medium temperature solar thermal power to assist $NaHCO_3$ decarbonation. This integration reduces the global system efficiency drop to the consumption associated with mechanical parasitic consumption, resulting in a fossil fuel energy penalty of 3-4% (including CO_2 compression). The paper shows the viability of the concept through economic analyses under different scenarios. The results suggest the interest of advancing in this Solar-CCS integrated concept, which shows favourable outputs compared to other CCS technologies.

Trends, application and future prospectives of microbial carbonic anhydrase mediated carbonation process for CCUS

Type Article de revue
Auteur C. Bhagat
Auteur P. Dudhagara
Auteur S. Tank
Volume 124
Numéro 2
Pages 316-335
Publication Journal of Applied Microbiology
ISSN 1364-5072
Date FEB 2018
Extra WOS:000422980800001
DOI 10.1111/jam.13589
Résumé Growing industrialization and the desire for a better economy in countries has accelerated the emission of greenhouse gases (GHGs), by more than the buffering capacity of the earth's atmosphere. Among the various GHGs, carbon dioxide occupies the first position in the anthroposphere and has detrimental effects on the ecosystem. For decarbonization, several non-biological methods of carbon capture, utilization and storage (CCUS) have been in use for the past few decades, but they are suffering from narrow applicability. Recently, CO_2 emission and its disposal related problems have encouraged the implementation of bioprocessing to achieve a zero waste economy for a sustainable environment. Microbial carbonic anhydrase (CA) catalyses reversible CO_2 hydration and forms metal carbonates that mimic the natural phenomenon of weathering/carbonation and is gaining merit for CCUS. Thus, the diversity and specificity of CAs from different micro-organisms could be explored for CCUS. In the literature, more than 50 different microbial CAs have been explored for mineral carbonation. Further, microbial CAs can be engineered for the mineral carbonation process to develop new technology. CA driven carbonation is encouraging due to its large storage capacity and favourable chemistry, allowing site-specific sequestration and reusable product formation for other industries. Moreover, carbonation based CCUS holds five-fold more sequestration capacity over the next 100years. Thus, it is an eco-friendly, feasible, viable option and believed to be the impending technology for CCUS. Here, we attempt to examine the distribution of various types

of microbial CAs with their potential applications and future direction for carbon capture. Although there are few key challenges in bio-based technology, they need to be addressed in order to commercialize the technology.

A review of optimization and decision-making models for the planning of CO2 capture, utilization and storage (CCUS) systems

Type Article de revue
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Auteur Jui-Yuan Lee
Auteur Raymond E. H. Ooi
Auteur Dominic C. Y. Foo
Auteur Raymond R. Tan
Volume 13
Pages 1-15
Publication Sustainable Production and Consumption
ISSN 2352-5509
Date JAN 2018
Extra WOS:000444547100001
DOI 10.1016/j.spc.2017.10.001

Résumé Carbon capture, utilization and storage (CCUS) is considered as one of the key strategies for mitigating climate change. This technology involves CO2 capture from stationary sources, followed by distribution of CO2 to different intermediate utilization and/or final storage options. CO2 capture and utilization (CCU) by itself offers resource conservation benefits by displacing the need for extracted CO2 from natural sources. On the other hand, CO2 capture and storage (CCS) provides CO2 emissions reduction by sequestration of captured CO2 for long-term storage. Combining CCS and CCU can potentially result in valuable symbiosis, but remains debatable due to gaps between the roles of these technologies in energy engineering. Such gaps have resulted in slower commercial deployment of CO2 "-capture. Some important issues resulting from these technologies have been addressed in previous studies through process systems engineering (PSE) methodologies, which are able to provide rigorous decision support during CCUS planning. This review paper provides an in-depth discussion of the state-of-the-art of these tools, and also discusses recent developments on integrating CCUS
components in large-scale planning. While recent literature in this area reveals the availability of tools for planning and policy-making, further research opportunities are identified through the bibliometric trends that show how CCUS research can develop further.

Carbon Capture and Storage (CCS): Technology, Projects and Monitoring Review

Type Article de revue
Auteur Nediljka Gaurina-Medimurec
Auteur Karolina Novak-Mavar
Auteur Matej Majic
Volume 33
Numéro 2
Pages 1-15
Publication Rudarsko-Geolosko-Naftni Zbornik
ISSN 0353-4529
Date 2018

Extra WOS:000431340300001
DOI 10.17794/rgn.2018.2.1
Résumé Carbon capture and storage (CCS) in terms of geological sequestration represents the process of capturing CO2 from large point sources, its transportation to a storage site, and its deposition into deep geological layers. In addition to the ecological benefits, underground injection of CO2 shows certain potential risks associated with unwanted migration of CO2 to groundwater and the surface, so the possibility of carrying out such projects depends on the possibility
of reducing the mentioned risks to an acceptable level. For this purpose, detailed risk assessment and analysis must be carried out, serving as the basis for a monitoring plan. A well designed and implemented monitoring plan and program provides important data on site integrity, well injectivity, and the entire storage complex performance. This paper gives an overview on a large scale and pilot projects of CO2 capture and geological storage in operation, under construction and in the phase of development all over the world, technology basics and available monitoring techniques. An example of CCS project monitoring is given through the monitoring program of the Lacq pilot project in France.

A review of developments in carbon dioxide storage

Type Article de revue
Auteur Mohammed D. Aminu
Auteur Seyed Ali Nabavi
Auteur Christopher A. Rochelle
Auteur Vasilije Manovic
Volume 208
Pages 1389-1419
Publication Applied Energy
ISSN 0306-2619
Date DEC 15 2017
Extra WOS:000416300400105
DOI 10.1016/j.apenergy.2017.09.015
Résumé Carbon capture and storage (CCS) has been identified as an urgent, strategic and essential approach to reduce anthropogenic CO2 emissions, and mitigate the severe consequences of climate change. CO2 storage is the last step in the CCS chain and can be implemented mainly through oceanic and underground geological sequestration, and mineral carbonation. This review paper aims to provide state-of-the-art developments in CO2 storage. The review initially discussed the potential options for CO2 storage by highlighting the present status, current challenges and uncertainties associated with
further deployment of established approaches (such as storage in saline aquifers and depleted oil and gas reservoirs) and feasibility demonstration of relatively newer storage concepts (such as hydrate storage and CO2-based enhanced geothermal systems). The second part of the review outlined the critical criteria that are necessary for storage site selection, including geological, geothermal, geohazards, hydrodynamic, basin maturity, and economic, societal and environmental factors. In the third section, the focus was on identification of CO2 behaviour within the reservoir during and after injection, namely injection-induced seismicity, potential leakage pathways, and long-term containment complexities associated with CO2-brine-rock interaction. In addition, a detailed review on storage capacity estimation methods based on different geological media and trapping mechanisms was provided. Finally, an overview of major CO2 storage projects, including their overall outcomes, were outlined. This review indicates that although CO2 storage is a technically
proven strategy, the discussed challenges need to be addressed in order to accelerate the deployment of the technology. In addition, beside the necessity of techno-economic aspects, public acceptance of CO2

storage plays a central role in technology deployment, and the current ethical mechanisms need to be further improved.

The potential role of carbon capture and storage technology in sustainable electric-power systems under multiple uncertainties

Type Article de revue
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Auteur Y. P. Li
Auteur S. Nie
Auteur J. Sun
Volume 80
Pages 467-480
Publication Renewable & Sustainable Energy Reviews
ISSN 1364-0321
Date DEC 2017
Extra WOS:000412787600037
DOI 10.1016/j.rser.2017.05.230
Résumé One of the problems facing researchers in managing carbon capture and storage (CCS) technology is that complex energy systems accommodate the relevant social, economic, environmental, and political factors. Many system behaviors, factors, and parameters are associated with uncertainties. Effective management of such a complex system involves balancing tradeoffs among these key influencing factors under multiple uncertainties. In this study, an interval-fuzzy stochastic programming (IFSP) method is developed to deal with multiple uncertainties expressed as fuzzy sets, intervals and probability distributions. An IFSP-CCS model is formulated to plan CCS technology of power system in Bayingolin Mongol Autonomous Prefecture (Bazhou). Policy scenarios are introduced to investigate the potential role of CCS technology and sensitivity analyses are performed to assess the influence of various economic factors on system cost. Results indicate various uncertainties existed in CCS development and the related factors can affect the modeling outputs. Results also reveal that CO2-mitigation constraint can induce the development of renewable energy and CCS, and CCS technology can make a
great contribution to CO2 emission reductions from a long-term planning perspective. The findings can provide support for CCS investment in fossilfuel-dominated electric-power system and offer useful information for policy investigation under multiple uncertainties.
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Computational materials chemistry for carbon capture using porous materials

Type Article de revue
Auteur Abhishek Sharma
Auteur Runhong Huang
Auteur Ateeque Malani
Auteur Ravichandar Babarao
Volume 50
Numéro 46
Pages 463002
Publication Journal of Physics D-Applied Physics
ISSN 0022-3727

Date NOV 22 2017
Extra WOS:000413045000002
DOI 10.1088/1361-6463/aa87e9
Résumé Control over carbon dioxide (CO2) release is extremely important to decrease its hazardous effects on the environment such as global warming, ocean acidification, etc. For CO2 capture and storage at industrial point sources, nanoporous materials offer an energetically viable and economically feasible approach compared to chemisorption in amines. There is a growing need to design and synthesize new nanoporous materials with enhanced capability for carbon capture. Computational materials chemistry offers tools to screen and design cost-effective materials for CO2 separation and storage, and it is less time consuming compared to trial and error experimental synthesis. It also provides a guide to synthesize new materials with better properties for real world applications. In this review, we briefly highlight the various carbon capture technologies and the need of computational materials design for carbon capture. This review discusses the commonly used computational chemistry-based simulation methods for structural characterization and prediction of thermodynamic properties of adsorbed gases in porous materials. Finally, simulation studies reported on various potential porous materials, such as zeolites, porous carbon, metal organic frameworks (MOFs) and covalent organic frameworks (COFs), for CO2 capture are discussed.
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Recent advances in the synthesis and applications of metal organic frameworks doped with ionic liquids for CO2 adsorption
Type Article de revue
Auteur Iuliana Cota
Auteur Francisco Fernandez Martinez
Volume 351
Pages 189-204
Publication Coordination Chemistry Reviews
ISSN 0010-8545
Date NOV 15 2017
Extra WOS:000415777700010
DOI 10.1016/j.ccr.2017.04.008
Résumé Carbon dioxide capture and storage technology has received a worldwide attention in the last years due to the environmental impact and pronounced ecosystem change produced by CO2. Ionic liquids (ILs), also called green solvents, show a great potential as adsorbents for CO2, For a more efficient use of ILs, the concept of ILs supported onto porous materials has been developed. Due to their high specific surface porosity and affinity for CO2 adsorption,
metal-organic frameworks (MOF) represent a very interesting candidate for supporting ILs. Tunable physicochemical properties of both MOFs and ILs and their unlimited number of possible combinations offer opportunities to tailor the structures for the best CO2/gas adsorption performance. In this review, we have discussed studies carried out to date on the ILs supported on MOFs and their possible applications in CO2/gas adsorption. (C) 2017 Elsevier B.V. All rights reserved.

Energy-saving pathway exploration of CCS integrated with solar energy: A review of innovative concepts
Type Article de revue
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Auteur Shuai Deng
Auteur Ruikai Zhao
Auteur Junnan He
Auteur Li Zhao
Volume 77
Pages 652-669
Publication Renewable & Sustainable Energy Reviews
ISSN 1364-0321
Date SEP 2017
Extra WOS:000404704500050
DOI 10.1016/j.rser.2017.04.031
Résumé Traditional technologies of carbon capture and storage (CCS) are being focused on capturing CO2 in large-scale demonstrations, which has been proved to result in the high cost and energy penalty. Meanwhile, typical innovative measures, commonly defined as the second generation CCS technologies, elude conventional ones by integrating with solar energy and thus contributing to a more energy-efficient conversion of CO2. However, few reviews pay attention to thermodynamic processes and parameters of these novel technologies, and there is a lack of systematic evaluation and comparison among them. This paper firstly presents a guided tour on the state-of-art of typical and innovative CCS technologies integrated with solar energy. An overview on thermodynamic processes, including chemical reactions, operating conditions and efficiency indexes of five typical technologies is presented so that the current development level can be clarified. Since the high energy requirement and related operating cost are the

main barriers to the application of existing CCS technologies, the minimum work and second-law efficiency are applied as the main indicators in the second part of this paper which relates to performance evaluation. In addition, the performance windows for innovative technologies are illustrated for the comparison of technological maturity. The results show that energy requirement of innovative CCS technologies from the flue gas is avg. 100-200 kJ/mol CO2 and the second-law efficiency of them is only 512%. Therefore, the maturity and popularity of these novel technologies are still relatively low. But the well integrated systems and
diversified output of these technologies can benefit existing energy infrastructures in a long period.

Carbon capture and storage technologies: present scenario and drivers of innovation

Type Article de revue
Auteur Ofelia de Queiroz Fernandes Araujo
Auteur Jose Luiz de Medeiros
Volume 17
Pages 22-34
Publication Current Opinion in Chemical Engineering
ISSN 2211-3398
Date AUG 2017
Extra WOS:000417285800005
DOI 10.1016/j.coche.2017.05.004
Résumé Carbon capture and storage (CCS) technologies are being developed to comply with the intensification of environmental laws and policies. Techniques for carbon capture from exhaust gases include post-combustion, pre-combustion and oxy-combustion. CO2 separation in gas processing is also a relevant application, employing alternatives commonly used in post-combustion, sharing developments and pulling innovations (additional to innovations pushed by knowledge from basic and applied research). The high volume of exhaust gases and expanding reserves of natural gas defy the state-of-the art in chemical and physical absorption (the most mature technology). The review identifies technological gaps and drivers of innovation in the CCS chain. In the context of offshore natural gas processing, this work reports a recent and massive technological niche for commercial use of membrane based processes.

CCS Research Development and Deployment in a Clean Energy Future: Lessons from Australia over the Past Two Decades

Type Article de revue
Auteur Peter J. Cook
Volume 3
Numéro 4
Pages 477-484
Publication Engineering
ISSN 2095-8099
Date AUG 2017
Extra WOS:000414165100010
DOI 10.1016/J.ENG.2017.04.014
Résumé There is widespread, though by no means universal, recognition of the importance of carbon capture and storage (CCS) as a carbon mitigation technology. However, the rate of deployment does not match what is required for global temperatures to stay well below 2 degrees C. Although some consider the hurdles to achieving the widespread application of CCS to be almost insurmountable, a more optimistic

view is that a great deal is now known about CCS through research, demonstration, and deployment. We know how to do it; we are confident it can be done safely and effectively; we know what it costs; and we know that costs are decreasing and will continue to do so. We also know that the world will need CCS as long as countries, companies, and communities continue to use fossil fuels for energy and industrial processes. What is lacking are the necessary policy drivers, along with a technologyneutral approach to decrease carbon emissions in a cost-effective and timely manner while retaining the undoubted benefits of ready access to reliable and secure electricity and energy-intensive industrial products. In this paper, Australia is used as an example of what has been undertaken in CCS over the past 20 years, particularly in research and demonstration, but also in international collaboration. Progress in the large-scale deployment of CCS in Australia has been too slow. However, the world's largest storage project will soon be operational in Australia as part of the Gorgon liquefied natural gas (LNG) project, and investigations are underway into several large-scale CCS Flagship program opportunities. The organization and progress of the Cooperative Research
Centre for Greenhouse Gas Technologies (CO2CRC) Otway Project, which is currently Australia's only operational storage project, is discussed in some detail because of its relevance to the commercial deployment of CCS. The point is made that there is scope for building on this Otway activity to investigate more broadly (through the proposed Otway Stage 3 and Deep Earth Energy and Environment Programme (AusDEEP)) the role of the subsurface in carbon reduction. There are challenges ahead if CCS is to be deployed as widely as bodies such as the International Energy Agency (IEA) and the Intergovernmental Panel on Climate Change (IPCC) consider to be necessary. Closer international collaboration in CCS will be essential to
meeting that challenge.

Calcium Carbonate Precipitation for CO2 Storage and Utilization: A Review of the Carbonate Crystallization and Polymorphism

Type Article de revue
Auteur Ribooga Chang
Auteur Semin Kim
Auteur Seungin Lee
Auteur Soyoung Choi
Auteur Minhee Kim
Auteur Youngjune Park
Volume 5
Pages UNSP 17
Publication Frontiers in Energy Research
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Date JUL 10 2017
Extra WOS:000417044500001
DOI 10.3389/fenrg.2017.00017
Résumé The transformation of CO_2 into a precipitated mineral carbonate through an ex situ mineral carbonation route is considered a promising option for carbon capture and storage (CCS) since (i) the captured CO_2 can be stored permanently and (ii) industrial wastes (i.e., coal fly ash, steel and stainless-steel slags, and cement and lime kiln dusts) can be recycled and converted into value-added carbonate materials by controlling polymorphs and properties of the

mineral carbonates. The final products produced by the ex situ mineral carbonation route can be divided into two categories-low-end high-volume and high-end low-volume mineral carbonates-in terms of their market needs as well as their properties (i.e., purity). Therefore, it is expected that this can partially offset the total cost of the CCS processes. Polymorphs and physicochemical properties of CaCO3 strongly rely on the synthesis variables such as temperature, pH of the solution, reaction time, ion concentration and ratio, stirring, and the concentration of additives. Various efforts to control and fabricate polymorphs of CaCO3 have been made to date. In this review, we present a summary of current knowledge and recent investigations entailing mechanistic studies on the formation of the precipitated CaCO3 and the influences of the synthesis factors on the polymorphs.

Techno-economic analysis and systematic review of carbon capture and storage (CCS) applied to the iron and steel, cement, oil refining and
pulp and paper industries, as well as other high purity sources

Type Article de revue
Auteur D. Leeson
Auteur N. Mac Dowell
Auteur N. Shah
Auteur C. Petit
Auteur P. S. Fennell
Volume 61
Pages 71-84
Publication International Journal of Greenhouse Gas Control
ISSN 1750-5836
Date JUN 2017
Extra WOS:000402214600006
DOI 10.1016/j.ijggc.2017.03.020

Résumé In order to meet the IPCC recommendation for an 80% cut in CO2 emissions by 2050, industries will be required to drastically reduce their emissions. To meet these targets, technologies such as carbon capture and storage (CCS) must be part of the economic set of decarbonisation options for industry. A systematic review of the literature has been carried out on four of the largest industrial sectors (the iron and steel industry, the cement industry, the petroleum refining industry and the pulp and paper industry) as well as selected high-purity sources of CO2 from other industries to assess the applicability of different CCS technologies. Costing data have been gathered, and for the cement, iron and steel and refining industries, these data are used in a model to project costs per tonne of CO2 avoided over the time period extending from first deployment until 2050. A sensitivity analysis was carried out on the model to assess which variables had the greatest impact on the overall cost of wide-scale CCS deployment for future better targeting of cost reduction
measures. The factors found to have the greatest overall impact were the initial cost of CCS at the start of deployment and the start date at which large scale deployment is started, whilst a slower initial deployment rate after the start date also leads to significantly increased costs. (C) 2017 The Authors.
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Carbon Dioxide Capture Adsorbents: Chemistry and Methods

Type Article de revue
Auteur Hasmukh A. Patel
Auteur Jeehye Byun

Auteur Cafer T. Yavuz
Volume 10
Numéro 7
Pages 1303-1317
Publication Chemsuschem
ISSN 1864-5631
Date APR 10 2017
Extra WOS:000398838600001
DOI 10.1002/cssc.201601545
Résumé Excess carbon dioxide (CO_2) emissions and their inevitable consequences continue to stimulate hard debate and awareness in both academic and public spaces, despite the widespread lack of understanding on what really is needed to capture and store the unwanted CO_2. Of the entire carbon capture and storage (CCS) operation, capture is the most costly process, consisting of nearly 70% of the price tag. In this tutorial review, CO_2 capture science and technology based on adsorbents are described and evaluated in the context of chemistry and methods, after briefly introducing the current status of CO_2 emissions. An effective sorbent design is suggested, whereby six checkpoints are expected to be met: cost, capacity, selectivity, stability, recyclability, and
fast kinetics.

Metal-Organic Frameworks for Carbon Dioxide Capture and Methane Storage

Type Article de revue
Auteur Yichao Lin
Auteur Chunglong Kong
Auteur Qiuju Zhang
Auteur Liang Chen
Volume 7
Numéro 4
Pages 1601296
Publication Advanced Energy Materials
ISSN 1614-6832
Date FEB 22 2017
Extra WOS:000396328500003
DOI 10.1002/aenm.201601296
Résumé In the global transition to a sustainable low-carbon economy, CO_2 capture and storage technology still plays a critical role for deep emission reduction, particularly for the stationary sources in power generation and industry. However, for small and mobile emission sources in transportation, CO_2 capture is not suitable and it is more practical to use relatively clean energy, such as natural gas. In these two low-carbon energy technologies, designing highly selective sorbents is one of the key and most challenging steps. Toward this end, metal-organic frameworks (MOFs) have received continuously intensive attention in the past decades for their highly porous and diversified structures. In this review, the recent progress in developing MOFs for selective CO_2 capture from post-combustion flue gas and CH_4 storage for vehicle applications are summarized. For CO_2 capture, several promising strategies being used to improve CO_2 adsorption uptake at low pressures are highlighted and compared. In addition, the conventional and novel regeneration techniques for MOFs are also discussed. In the case of CH_4 storage, the flexible and rigid MOFs, whose CH_4 storage capacity is close to the target set by U. S. Department of Energy are particularly emphasized. Finally, the challenge of using MOFs for CH_4 storage is discussed.

Carbon dioxide absorption into promoted potassium carbonate solutions: A review
Type Article de revue
Auteur Guoping Hu
Auteur Nathan J. Nicholas
Auteur Kathryn H. Smith
Auteur Kathryn A. Mumford
Auteur Sandra E. Kentish
Auteur Geoffrey W. Stevens
Volume 53
Pages 28-40
Publication International Journal of Greenhouse Gas Control
ISSN 1750-5836
Date OCT 2016
Extra WOS:000383725700004
DOI 10.1016/j.ijggc.2016.07.020
Résumé The emission of carbon dioxide into the atmosphere is recognized as a significant driver for climate change. Carbon capture and storage (CCS) techniques are efficient and effective ways to reduce these emissions to the atmosphere. However, the cost of any carbon capture technique has to be reduced to manageable levels before it can be deployed at an industrial scale. Several methods for capturing carbon dioxide, such as absorption, adsorption, membrane techniques and cryogenic separation have been proposed, of which absorption is the closest to commercial reality. Potassium carbonate is a
good solvent for carbon dioxide capture because of its low regeneration energy, low degradation rates and low corrosivity. However, one shortcoming of potassium carbonate in CO2 absorption is that it has relatively slow reaction kinetics with CO2 resulting in the need for large absorption equipment. The most efficient method for improving the absorption kinetics is to add promoters into the potassium carbonate solutions. There have been a number of promoters studied over the last decades, including inorganic promoters such as arsenate, boric acid and vanadate, organic promoters such as different amines and amino acids, enzymatic promoters such as carbonic anhydrase and metal compounds mimicking carbonic anhydrase. In this paper, different promoters for CO2 absorption in potassium carbonate solutions are reviewed and their performance summarized. Additionally, a CO2 hydration promoting mechanism of deprotonation, followed by intermediate formation and then promoter regeneration is presented. (C) 2016 Elsevier Ltd. All rights reserved.
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Carbon-Based Adsorbents for Postcombustion CO2 Capture: A Critical Review
Type Article de revue
Auteur Anne Elise Creamer
Auteur Bin Gao
Volume 50
Numéro 14
Pages 7276-7289
Publication Environmental Science & Technology
ISSN 0013-936X
Date JUL 19 2016
Extra WOS:000380295700003
DOI 10.1021/acs.est.6b00627

Résumé The persistent increase in atmospheric CO2 from anthropogenic sources makes research directed toward carbon capture and storage imperative. Current liquid amine absorption technology has several drawbacks including hazardous byproducts and a high-energy requirement for regeneration; therefore, research is ongoing to develop more practical methods for capturing CO2 in postcombustion scenarios. The unique properties of carbon-based materials make them specifically promising for CO2 adsorption at low temperature and moderate to high partial pressure. This critical review aims to highlight the development of carbon-based solid sorbents for postcombustion CO2 capture. Specifically, it provides an overview of postcombustion CO2 capture processes with solid adsorbents and discusses a variety of carbon-based materials that could be used. This review focuses on low-cost pyrogenic carbon, activated carbon (AC), and metal-carbon composites for CO2 capture. Further, it touches upon the recent progress made to develop metal organic frameworks (MOFs) and carbon nanomaterials and their general CO2 sorption potential.

Property impacts on Carbon Capture and Storage (CCS) processes: A review

Type Article de revue

Auteur Yuting Tan
Auteur Worrada Nookuea
Auteur Hailong Li
Auteur Eva Thorin
Auteur Jinyue Yan

Volume 118
Pages 204-222
Publication Energy Conversion and Management
ISSN 0196-8904
Date JUN 15 2016
Extra WOS:000375817200020
DOI 10.1016/j.enconman.2016.03.079

Résumé The knowledge of thermodynamic and transport properties of CO2-mixtures is important for designing and operating different processes in carbon capture and storage systems. A literature survey was conducted to review the impact of uncertainty in thermos-physical properties on the design and operation of components and processes involved in CO2 capture, conditioning, transport and storage. According to the existing studies on property impacts, liquid phase viscosity and diffusivity as well as gas phase diffusivity significantly impact the process simulation and absorber design for chemical absorption. Moreover, the phase equilibrium is important for regenerating energy estimation. For CO2 compression and pumping processes, thermos-physical properties have more obvious impacts on pumps than on compressors. Heat capacity, density, enthalpy and entropy are the most important properties in the pumping process, whereas the compression process is more sensitive to heat capacity and compressibility. In the condensation and liquefaction process, the impacts of density, enthalpy and entropy are low on heat exchangers. For the transport process, existing studies mainly focused on property impacts on the performance of pipeline steady flow processes. Among the properties, density and heat capacity are most important. In the storage process, density and viscosity have received the most attention in property impact studies and were regarded as the most important properties in terms of storage capacity and enhanced oil recovery rate. However, for physical absorption, physical adsorption and membrane separation, there has been a knowledge gap about the property impact. In addition, due to the lack of experimental data and process complexity, little information is available about the influence of liquid phase properties on the design of the absorber and desorber for chemical absorption process. In the CO2 conditioning process, knowledge of the impacts of properties beyond density and enthalpy is insufficient.

In the transport process, greater attention should focus on property impacts on transient transport processes and ship transport systems. In the storage process, additional research is required on the dispersion process in enhanced oil recovery and the dissolution process in ocean and saline aquifer storage.

Capturing atmospheric carbon: biological and nonbiological methods

Type Article de revue
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Auteur Gurpreet Kaur Sidhu
Auteur Rajesh Mehrotra
Auteur Sandhya Mehrotra
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Pages 266-274
Publication International Journal of Low-Carbon Technologies
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Extra WOS:000376591000015
DOI 10.1093/ijlct/ctt077
Résumé Atmospheric carbon dioxide is one of the primary greenhouse gases on earth and its continuous emission by manmade activities is leading to a rise in atmospheric temperature. On the other hand, various natural phenomena exist that contribute to the sequestration of atmospheric carbon dioxide, i. e. its capture and long-term storage. These phenomena include oceanic, geological and chemical processes happening on earth. In addition to the abovementioned nonbiological methods, various biological methods viz. soil carbon sequestration and phytosequestration have also been contributing to fixation of atmospheric carbon. Phytosequestration is mainly performed by several photosynthetic mechanisms such as C-3, C-4 and crassulacean acid metabolism (CAM) pathways of plants, carboxysomes of cyanobacteria and pyrenoids of microalgae. For an effective mitigation of global climate change, it is required to stabilize the CO2 concentration to viable levels. It requires various permutations and combinations of naturally existing and engineering strategies. Although numerous strategies are in commodious use in the present times, the issues of sustainability and long-term stability still exist. We
present an overview of the natural and manmade biological and nonbiological processes used today to reduce atmospheric CO2 levels and discuss the scope and limitations of each of them.

Application of Electrodeionization Process for Bioproduct Recovery and CO2 Capture and Storage

Type Article de revue
Auteur Guangming Zeng
Auteur Jie Ye
Auteur Ming Yan
Volume 20
Numéro 26
Pages 2790-2798
Publication Current Organic Chemistry
ISSN 1385-2728
Date 2016
Extra WOS:000386811800006

DOI 10.2174/1385272820666160513153326
Résumé Electrodeionization (EDI) process is a relatively new process applied in environmental engineering, which combines electrodialysis and conventional ion exchange. The EDI process has obvious advantages compared with the traditional deionization equipments based on the chemical regeneration. This review first time evaluated the importance of EDI process for bioproduct recovery (organic acid recovery, bio-methane concentration and bioelectricity production) and CO2 capture and storage. It highlighted not only the principal mechanisms but also the recent application development. Meanwhile, gaps
which limited the large-scale field application of EDI process were also discussed in this paper.

Process intensification for post-combustion CO2 capture with chemical absorption: A critical review
Type Article de revue
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Auteur Nuhu M. Musa
Volume 158
Pages 275-291
Publication Applied Energy
ISSN 0306-2619
Date NOV 15 2015
Extra WOS:000364880800024
DOI 10.1016/j.apenergy.2015.08.083
Résumé The concentration of CO2 in the atmosphere is increasing rapidly. CO2 emissions may have an impact on global climate change. Effective CO2 emission abatement strategies such as carbon capture and storage (CCS) are required to combat this trend. Compared with pre-combustion carbon capture and oxy-fuel carbon capture approaches, post-combustion CO2 capture (PCC) using solvent process is one of the most mature carbon capture technologies. There are two main barriers for the PCC process using solvent to be commercially deployed: (a) high capital cost; (b) high thermal efficiency penalty due
to solvent regeneration. Applying process intensification (PI) technology into PCC with solvent process has the potential to significantly reduce capital costs compared with conventional technology using packed columns. This paper intends to evaluate different PI technologies for their suitability in PCC process. The study shows that rotating packed bed (RPB) absorber/stripper has attracted much interest due to its high mass transfer capability. Currently experimental studies on CO2 capture using RPB are based on standalone absorber or stripper. Therefore a schematic process flow diagram of intensified PCC process is proposed so as to motivate other researches for possible optimal design, operation and control. To intensify heat transfer in reboiler, spinning disc technology is recommended. To replace cross heat exchanger in conventional PCC (with packed column) process, printed circuit heat exchanger will be preferred. Solvent selection for conventional PCC process has been studied extensively. However, it needs more studies for solvent selection in intensified PCC process. The authors also predicted research challenges in intensified PCC process and potential new breakthrough from
different aspects.

The potential of renewables versus natural gas with CO2 capture and storage for power generation under CO2 constraints
Type Article de revue

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Auteur Niels Berghout
Auteur Edward S. Rubin
Volume 49
Pages 1296-1322
Publication Renewable & Sustainable Energy Reviews
ISSN 1364-0321
Date SEP 2015
Extra WOS:000357141900102
DOI 10.1016/j.rser.2015.04.089
Résumé The costs of intermittent renewable energy systems (IRES) and power storage technologies are compared on a level playing field to those of natural gas combined cycle power plants with CO2 capture and storage (NGCC-CCS). To account for technological progress over time, an "experience curve" approach is used to project future levelised costs of electricity (LCOE) based on technology progress ratios and deployment rates in worldwide energy scenarios, together with European energy and technology cost estimates. Under base case assumptions, the LCOE in 2040 for baseload NGCC-CCS plants
is estimated to be 71 (sic)(2012)/MWh. In contrast, the LCOE for electricity generated intermittently from IRES is estimated at 68, 82, and 104 (sic)(2012)/MWh for concentrated solar power, offshore wind, and photovoltaic systems, respectively. Considering uncertainties in costs, deployment rates and geographical conditions, LCOE ranges for IRES are wider than for NGCC-CCS. We also assess energy storage technologies versus NGCC-CCS as backup options for IRES. Here, for base case assumptions NGCC-CCS with an LCOE of 90 (sic)(2012)/MWh in 2040 is more costly than pumped hydro storage (PHS) or compressed air and energy storage (CAES) with LCOEs of 57 and 88 (sic)(2012)/MWh, respectively. Projected costs for battery backup are 78, 149, and 321 (sic)(2012)/MWh for Zn-Br, ZEBRA, and Li-ion battery systems, respectively. Finally, we compare four stylised low-carbon systems on a common basis (including all ancillary costs for IRES). In the 2040 base case, the system employing only NGCC-CCS has the lowest LCOE and lowest cost of CO2 avoided with CO2 emissions of 45 kg/MWh. A zero CO2 emission system with IRES plus PHS as backup is 42% more expensive in terms of LCOE, and 13% more costly than a system with IRES plus NGCC-CCS backup with emissions of 23 kg CO2/MWh. Sensitivity results and study limitations are fully discussed within the paper.

A comparative review between amines and ammonia as sorptive media for post-combustion CO2 capture

Type Article de revue
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Auteur Ki-Hyun Kim
Auteur Jan E. Szulejko
Auteur Jae-Woo Park
Volume 148
Pages 10-22
Publication Applied Energy
ISSN 0306-2619
Date JUN 15 2015
Extra WOS:000355063900003
DOI 10.1016/j.apenergy.2015.03.026
Résumé In recent decades, the accelerating economic and social developments have led to exponentially increasing emissions of carbon dioxide (CO2) into the atmosphere. As a result, much research efforts have

been directed toward more effective measures for the carbon capture and storage (CCS). In this review, we first briefly described the general background on the various techniques available for the abatement of CO2 emissions worldwide. Then, we provided an in-depth discussion regarding the two comparable control technologies, i.e., the amine- vs. ammonia-based capture approaches; ammonia has lower energy costs than monoethanolamine (MEA). The applicability of each method was described further with an emphasis on their advantages and disadvantages. We also briefly discussed the available options for post-absorption processing such as recovery of absorbed CO2, compression, and storage.
Many immobilized amines as adsorbents can only be regenerated a few times or are a 'once-through process'. This may deplete the global supply of those materials if CCS is scaled up in excess of Mton CO2 captured per year. Ideally, the captured CO2 should be isolated from the atmosphere indefinitely and/or photochemically reduced (either biologically or industrially). Finally, we explored future challenges in this field of study to envision and suggest more optimized solutions.
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Review of solvent based carbon-dioxide capture technologies
Type Article de revue
Auteur Kathryn A. Mumford
Auteur Yue Wu
Auteur Kathryn H. Smith
Auteur Geoffrey W. Stevens
Volume 9
Numéro 2
Pages 125-141
Publication Frontiers of Chemical Science and Engineering
ISSN 2095-0179
Date JUN 2015
Extra WOS:000360319600001
DOI 10.1007/s11705-015-1514-6
Résumé Currently, a large proportion of global fossil fuel emissions originate from large point sources such as power generation or industrial processes. This trend is expected to continue until the year 2030 and beyond. Carbon capture and storage (CCS), a straightforward and effective carbon reduction approach, will play a significant role in reducing emissions from these sources into the future if atmospheric carbon dioxide (CO2) emissions are to be stabilized and
global warming limited below a threshold of 2 degrees C. This review provides an update on the status of large scale integrated CCS technologies using solvent absorption for CO2 capture and provides an insight into the development of new solvents, including advanced amine solvents, amino acid salts, carbonate systems, aqueous ammonia, immiscible liquids and ionic liquids. These proposed new solvents aim to reduce the overall cost CO2 capture by improving the CO2 absorption rate, CO2 capture capacity, thereby reducing equipment size and decreasing the energy required for solvent regeneration.
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A review on solid adsorbents for carbon dioxide capture
Type Article de revue
Auteur Seul-Yi Lee
Auteur Soo-Jin Park
Volume 23
Pages 1-11
Publication Journal of Industrial and Engineering Chemistry
ISSN 1226-086X
Date MAR 25 2015
Extra WOS:000355234900001
DOI 10.1016/j.jiec.2014.09.001
Résumé Global warming is considered as one of the great challenges of the twenty-first century. CO2 capture and storage (CCS) technology is attracting increasing interest to reduce the ever-increasing amount of CO2 released into the atmosphere and its impact on global climate change. CO2 capture process is a core technology, and accounts for 70-80% of the total cost of CCS technologies. CO2 capture technologies are categorized as post-combustion, pre-combustion, and oxy-fuel combustion. Among these, post-combustion CO2 capture processes are regarded as being important green and economic technologies. It is very important to develop new, highly efficient adsorbents to achieve techno-economic systems for post-combustion CO2 capture. In this review, we therefore summarize dry solid adsorbents, which are divided into non-carbonaceous (e.g., zeolites, silica, metal-organic frameworks and porous

polymers, alkali metal, and metal oxide carbonates) and carbonaceous materials (e.g., activated carbons, ordered porous carbons, activated carbon fibers, and
graphene), with a focus on recent research.

A review of cross-sector decarbonisation potentials in the European energy intensive industry

Type Article de revue
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Auteur Jose Pablo Chaves Avila
Auteur Pedro Linares Llamas
Auteur Tomas Gomez San Roman
Volume 210
Pages 585-601
Publication Journal of Cleaner Production
ISSN 0959-6526
Date FEB 10 2019
Extra WOS:000456762600051
DOI 10.1016/j.jclepro.2018.11.036
Résumé The energy intensive industry (Ell) is responsible for two-thirds of industrial carbon dioxide emissions in the EU. It has been recognised by both public and private stakeholders that a far-reaching transformation of these industries is required to comply with the overall emission reduction goals stated by the European Union for 2050. Contrasting innovations discussed in pathway and roadmap publications for the different industries, it can be concluded that there is little consensus on how deep decarbonisation of the EII will be achieved. In this paper, a review of pathway and roadmap publications and scientific literature is presented. This permits to identify key areas for emission abatement across all subsectors. Results show significant discrepancies in the literature regarding the expected emission reductions achievable, but permit us to identify areas that are key for the transition towards a low-emission Ell: the decarbonisation of low temperature heat by cross-sector technologies, use of membranes in the (petro)-chemical industry, carbon neutral steelmaking, alternative feedstock for the cement production and carbon capture & storage (CCS).

Dans cet article, une revue des publications et des ouvrages scientifiques sur les sentiers et les feuilles de route est présentée. littérature concernant les réductions d’émission attendues, mais nous permettent d’identifier les domaines essentiels pour la transition vers un IIE à faibles émissions: la décarbonisation de la chaleur à basse température par des technologies intersectorielles, l’utilisation de membranes (pétro) - chimique, fabrication d’acier neutre en carbone, matière première alternative pour la production de ciment et captage et stockage du carbone (CSC).

Pollution to solution: Capture and sequestration of carbon dioxide (CO2) and its utilization as a renewable energy source for a sustainable future

Type Article de revue
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Auteur Md Maniruzzaman A. Aziz
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Auteur Wan Azelee Wan Abu Bakar
Auteur M. R. Hainin
Auteur Ramadhansyah Putrajaya
Auteur Norhidayah Abdul Hassan
Volume 71
Pages 112-126
Publication Renewable & Sustainable Energy Reviews
ISSN 1364-0321
Date MAY 2017
Extra WOS:000394920600009
DOI 10.1016/j.rser.2017.01.011
Résumé The major contributor to global warming is human-generated greenhouse gases (GHGs) emissions that pollute the air. GHGs emissions are a global issue dominated by emission of carbon dioxide (CO2). Notably, CO2 accounts for an estimated 77% of GHGs and thus has a huge impact on the environment. The capture, sequestration, and utilization of CO2 emissions from flue gas are now becoming familiar worldwide. These methods are a promising solution to promote sustainability for the benefit of future generations. Previously, many researchers have focused on capturing and storing CO2; however, less effort has been spent on finding ways to utilize flue gas emissions. Moreover, several issues must be overcome in the field of carbon capture and sequestration (CCS) technology, especially regarding the cost, capacity of storage and the durability of the storage reservoir. In addition, this paper addresses new technology in carbon capture and sequestration. To make CCS technology more feasible, this paper suggests a sustainable method combining CCS and biofuel production. using CO2 as a feedstock. This method offers many advantages, such as CO2 emission mitigation and energy security through the production of renewable energy. Due to the many advantages of biofuels, the conversion of CO2 into biofuel is a best practice and
may provide a solution to pollution while encouraging sustainability practises.

From post-combustion carbon capture to sorption-enhanced hydrogen production: A state-of-the-art review of carbonate looping process feasibility

Type Article de revue
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Auteur S. Michalski
Auteur V. Manovic
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-85054289695&doi=10.1016%2fj.enconman.2018.09.058&partnerID=40&md5=7c5054b4c1b2b25501181de64e306bb6
Volume 177
Pages 428-452
Publication Energy Conversion and Management
Date 2018
DOI 10.1016/j.enconman.2018.09.058

Résumé Carbon capture and storage is expected to play a pivotal role in achieving the emission reduction targets established by the Paris Agreement. However, the most mature technologies have been shown to reduce the net efficiency of fossil fuel-fired power plants by at least 7% points, increasing the electricity cost. Carbonate looping is a technology that may reduce these efficiency and economic penalties. Its maturity has increased significantly over the past
twenty years, mostly due to development of novel process configurations and sorbents for improved process performance. This review provides a comprehensive overview of the calcium looping concepts and statistically evaluates their techno-economic feasibility. It has been shown that the most commonly reported figures for the efficiency penalty associated with calcium looping retrofits were between 6 and 8% points. Furthermore, the calciumlooping-based coal-fired power plants and sorption-enhanced hydrogen production systems integrated with combined cycles and/or fuel cells have been shown to achieve net efficiencies as high as 40% and 50–60%, respectively. Importantly, the performance of both retrofit and greenfield scenarios can be further improved by increasing the degree of heat integration, as well as using advanced power cycles and enhanced sorbents. The assessment of the economic feasibility of calcium looping concepts has indicated that the cost of carbon dioxide avoided will be between 10 and 30 € per tonne of carbon dioxide and 10–50 € per tonne of carbon dioxide in the retrofit and greenfield scenarios, respectively. However, limited economic data have been presented in the current literature for the thermodynamic performance of calcium looping concepts. © 2018 The Authors

Advances in CO 2 utilization technology: A patent landscape review

Type Article de revue
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URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-85047534179&doi=10.1016%2fj.jcou.2018.05.022&partnerID=40&md5=41731b921c91a1ccd75697d2f0968705
Volume 26
Pages 323-335
Publication Journal of CO2 Utilization
Date 2018
DOI 10.1016/j.jcou.2018.05.022

Résumé There is rising concern on the increasing trend of global warming due to anthropogenic CO 2 emission which steers progress of carbon capture and storage (CCS) projects worldwide. However, due to high cost and uncertainties in long term geological storage, there is a growing inclination to include utilization, which re-use the CO 2 , hence carbon capture utilization and storage (CCUS). Additionally, it is expected to generate income to offset the initial costs. This
study methodically review patents on CO 2 utilization technologies for CCUS application published between year 1980-2017. It was conducted using the Derwent Innovation patent database and more than 3000 number of patents was identified. The patents identified are in the field of enhanced oil recovery (EOR) and enhanced coal-bed methane (ECBM), chemical and fuel, mineral carbonation, biological algae cultivation and enhanced geothermal system (EGS). Over 60% of these patents were published since the last 10 years, and a sharp increase in patents were seen in the last 5 years (∼38%). The top
major patent types are patents granted in the United States (US), China (CN) and Canada (CA) which makes of 3/5 of the overall patent type found. Recent patents published include enhancements to the state-of-the-art technologies and hybrid concepts such as in photo-bioreactor in algae cultivation, chemical reaction and EGS. From this study, it was found that further research for the best CO 2 utilization method which fulfil the need of an economic, safe, non-location dependent and environmentally friendly whilst

efficiently mitigate the worldwide global warming issue is much needed.

The CO2 economy: Review of CO2 capture and reuse technologies

Type Article de revue

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Volume 132
Pages 3-16
Publication Journal of Supercritical Fluids
Date 2018
DOI 10.1016/j.supflu.2017.07.029

Résumé The continuously increasing share of Renewable Energy Sources (RES) and EU targets for CO2 reduction and energy efficiency necessitate significant changes both on technical and regulatory level. Environmental challenges of CO2 emissions are assessed in a review of CO2 capture and utilization technologies, offering new opportunities in CO2 economy. Commercial applications in the thermal power and industrial sector for pre and post combustion capture as well as the potential of direct air CO2 capture are reviewed. The potential of Carbon Capture and Utilisation (CCU) is assessed focusing on the use of CO2 for fuel as well as for combined heat and power production. Combining CCU with energy storage as an evolutionary measure for balancing RES with thermal power under the power to fuel concept presents high market potentials for fuel and chemical production. Moreover, the recent progress in supercritical CO2 cycles for combined heat and power production is reported.

Carbon Capture and Utilization Update

Type Article de revue

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Auteur A. Krishnamurthy
Auteur A.A. Rownaghi
Auteur F. Rezaei

URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-85014298081&doi=10.1002%2fente.201600747&partnerID=40&md5=39d32c94049ed74049492bcb42fc9c8d
Volume 5
Numéro 6
Pages 834-849
Publication Energy Technology
Date 2017
DOI 10.1002/ente.201600747

Résumé In recent years, carbon capture and utilization (CCU) has been proposed as a potential technological solution to the problems of greenhouse-gas emissions and the ever-growing energy demand. To combat climate change and ocean acidification as a result of anthropogenic CO2 emissions, efforts have already been put forth to capture and sequester CO2 from large point sources, especially power plants; however, the utilization of CO2 as a feedstock to make valuable chemicals, materials, and transportation fuels is potentially more desirable and provides a better and long-term solution than sequestration. The products of CO2 utilization can supplement or replace chemical feedstocks in the fine chemicals, pharmaceutical, and polymer industries. In this review, we first provide an overview of the

current status of CO2-capture technologies and their associated challenges and opportunities with respect to efficiency and economy followed by an overview of various carbon-utilization approaches. The current status of combined CO2 capture and utilization, as a novel
efficient and cost-effective approach, is also briefly discussed. We summarize the main challenges associated with the design, development, and large-scale deployment of CO2 capture and utilization processes to provide a perspective and roadmap for the development of new technologies and opportunities to accelerate their scale-up in the near future.

Overview of carbon reduction, capture, utilization and storage: Development of new framework

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Volume 56
Pages 649-654
Publication Chemical Engineering Transactions
Date 2017
DOI 10.3303/CET1756109
Résumé Carbon capture and storage (CCS) is one of the provisional technologies to mitigate the rise of greenhouse gases emission which comes from carbon dioxide (CO2) emission. The growth and development of CCS technology leads to existence of carbon capture, utilization and storage (CCUS) technologies due to immature technologies of CO2 storage. Criticality of carbon reduction attracts researchers to study the efficiency of implementing CCS and CCUS latest technologies with economic and environmental goals. This paper discusses the overview of the technologies and the work done by researchers on strategies of implementation of CCS and CCUS. This paper also focuses on the optimal planning of CCS and CCUS technologies. A new framework for carbon reduction, capture, utilization and storage (CARSUS) is introduced for future development. CARCUS is expected to present the best route for carbon dioxide avoidance.

Review on recent advances in CO2 utilization and sequestration technologies in cement-based materials
Type Article de revue
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URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-84991696868&doi=10.1016%2fj.conbuildmat.2016.10.017&partnerID=40&md5=5d2da1c6df496a6cd6f61184a18900c9
Volume 127
Pages 762-773
Publication Construction and Building Materials
Date 2016
DOI 10.1016/j.conbuildmat.2016.10.017
Résumé The cement industry is a major industrial producer of greenhouse gases, responsible for 5–8% of man-made CO 2 emissions. The carbonation reaction, which occurs between CO 2 and the corresponding reactive compounds from cement-based materials, can fix CO 2 in the form of thermodynamically stable carbonates. Thus, the CO 2 uptake technology using cement-based materials could be considered as an effective option for Carbon Capture, Utilization and Sequestration projects. This paper presents a review on state of the art studies in this emerging technology and provides information from a scientific and technical perspective on CO 2 utilization and sequestration technologies using cement-based materials. The CO 2 uptake mechanisms of cement-based materials are summarized and factors affecting the kinetic of the carbonation reaction are identified. Furthermore, this paper consolidates available information on CO 2 uptake capacity and efficiency, industrial challenges, critical issue and the need for further investigation regarding the technologies. Lastly, the environmental impact and economic feasibility of using cement-based materials in the CO 2 utilization and sequestration technology sector were analyzed and compared with geologic sequestration and mineral carbonation technologies. © 2016 Elsevier Ltd

Technological advances in CO2 conversion electro-biorefinery: A step toward commercialization
Type Article de revue
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URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-84967014663&doi=10.1016%2fj.biortech.2016.03.023&partnerID=40&md5=9f5d87991d19b08af1a823698ab00bc8
Volume 215
Pages 357-370
Publication Bioresource Technology
Date 2016
DOI 10.1016/j.biortech.2016.03.023
Résumé The global atmospheric warming due to increased emissions of carbon dioxide (CO 2) has attracted great attention in the last two decades. Although different CO 2 capture and storage platforms have been proposed, the utilization of captured CO 2 from industrial plants is progressively prevalent

strategy due to concerns about the safety of terrestrial and aquatic CO 2 storage. Two utilization forms were proposed, direct utilization of CO 2 and conversion of CO 2 to chemicals and energy products. The latter strategy includes the bioelectrochemical techniques in which electricity can be used as an energy source for the microbial catalytic production of fuels and other organic products from CO 2. This approach is a potential technique in which CO 2 emissions are not only reduced, but it also produces more value-added products. This review article highlights the different methodologies for the bioelectrochemical utilization of CO 2, with distinctive focus on the potential opportunities for the commercialization of these techniques. © 2016 Elsevier Ltd.

Carbon capture, storage and utilisation technologies: A critical analysis and comparison of their life cycle environmental impacts

Type Article de revue
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URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-85027920774&doi=10.1016%2fj.jcou.2014.12.001&partnerID=40&md5=b4847222b0ea32a97b43cd2130a3d8a5
Volume 9
Pages 82-102
Publication Journal of CO2 Utilization
Date 2015
DOI 10.1016/j.jcou.2014.12.001

Résumé This paper presents a first comprehensive comparison of environmental impacts of carbon capture and storage (CCS) and carbon capture and utilization (CCU) technologies. Life cycle assessment studies found in the literature have been reviewed for these purposes. In total, 27 studies have been found of which 11 focus on CCS and 16 on CCU. The CCS studies suggest that the global warming potential (GWP) from power plants can be reduced by 63-82%, with the greatest reductions achieved by oxy-fuel combustion in pulverised coal and integrated gasification combined cycle (IGCC) plants and the lowest by post-combustion capture in combined cycle gas turbine (CCGT) plants. However, other environmental impacts such as acidification and human toxicity are higher with than without CCS. For CCU, the GWP varies widely depending on the utilisation option. Mineral carbonation can reduce the GWP by 4-48% compared to no CCU. Utilising CO2 for production of chemicals, specifically, dimethylcarbonate (DMC) reduces the GWP by 4.3 times and ozone layer depletion by 13 times compared to the conventional DMC process. Enhanced oil recovery has the GWP 2.3 times lower compared to discharging CO2 to the atmosphere but acidification is three times higher. Capturing CO2 by microalgae to produce biodiesel has 2.5 times higher GWP than fossil diesel with other environmental impacts also significantly higher. On average, the GWP of CCS is significantly lower than of the CCU options. However, its other environmental impacts are higher compared to CCU except for DMC production which is the worst CCU option overall. © 2014 The Authors. Published by Elsevier Ltd.

BIOÉNERGIE

Biomass and biofuels in China: Toward bioenergy resource potentials and their impacts on the environment

Type Article de revue
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URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-85028560188&doi=10.1016%2fj.rser.2017.08.073&partnerID=40&md5=62f661e09291f0fdac45b68c60820dec
Volume 82
Pages 2387-2400
Publication Renewable and Sustainable Energy Reviews
Date 2018
DOI 10.1016/j.rser.2017.08.073
Résumé Bioenergy can be a promising solution to the energy, food and environment trilemma in China. Currently this coal-dependent nation is in urgent need of alternative fuels to secure its future energy and improve the environment. Biofuels derived from crop residues and bioenergy crops emerge as a great addition to renewable energy in China without compromising food production. This paper reviews bioenergy resources from existing conventional crop (e.g., corn, wheat and rice) residues and energy crops (e.g., Miscanthus) produced on marginal lands. The impacts of biofuel production on ecosystem services are also discussed in the context of biofuel's life cycle. It is estimated that about 280 million metric tons (Mt) of crop residue-based biomass (or 65 Mt of ethanol) and over 150 Mt of energy crop-based ethanol can become available each year, which far exceeds current national fuel ethanol production (< 2 Mt year −1) and the 2020 national target of 10 Mt year −1. Review on environmental impacts suggested that substituting fossil fuels with biofuels could significantly reduce greenhouse gas emissions and air pollution (e.g., particulate matter). However, the impacts of biofuel production on biodiversity, water quantity and quality vary greatly among biomass types, land sources and management practices. Improved agricultural management and landscape planning can be beneficial to ecosystem services. A national investigation is desirable in China to inventory technical and economic potential of biomass feedstocks and evaluate the impacts of biofuel production on ecosystem services and the environment. © 2017

Anaerobic digestion for bioenergy production: Global status, environmental and techno-economic implications, and government policies
Type Article de revue
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Auteur A. Shah
Volume 247
Pages 1015-1026
Publication Bioresource Technology
Date 2018
DOI 10.1016/j.biortech.2017.09.004
Résumé Anaerobic digestion (AD) is a mature technology that can transform organic matter into a bioenergy source – biogas (composed mainly of methane and carbon dioxide), while stabilizing waste. AD implementation around the world varies significantly, from small-scale household digesters in developing countries to large farm-scale or centralized digesters in developed countries. These differences in the implementation of AD technology are due to a complex set of conditions, including economic and environmental implications of the AD technology, and stimulus provided by a variety of polices and incentives related to agricultural systems, waste management, and renewable energy production. This review explores the current status of the AD technology worldwide and some of the environmental, economic and policy-related drivers that have shaped the implementation of this technology. The findings show that the regulations and incentives have been the primary factor influencing the steady growth of this technology, in both developing and developed countries. © 2017 Elsevier Ltd

Bioenergy production and sustainable development: science base for policymaking remains limited
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URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-84962628854&doi=10.1111%2fgcbb.12338&partnerID=40&md5=5a39a52c6f5b2cac238ebefb1f0302bc
Volume 9
Numéro 3
Pages 541-556
Publication GCB Bioenergy
Date 2017
DOI 10.1111/gcbb.12338
Résumé The possibility of using bioenergy as a climate change mitigation measure has sparked a discussion of whether and how bioenergy production contributes to sustainable development. We undertook a systematic review of the scientific literature to illuminate this relationship and found a limited scientific basis for policymaking. Our results indicate that knowledge on the sustainable development impacts of bioenergy production is concentrated in a few well-studied countries, focuses on environmental and economic impacts, and mostly relates to dedicated agricultural biomass plantations. The scope and methodological approaches in studies differ widely and only a small share of the studies sufficiently reports on context and/or baseline conditions, which makes it difficult to get a general understanding of the attribution of impacts. Nevertheless, we identified regional patterns of positive or negative impacts for all categories – environmental, economic, institutional, social and technological. In general, economic and technological impacts were more frequently reported as positive, while social and environmental impacts were more frequently reported as negative (with the exception of impacts on direct substitution of GHG emission from fossil fuel). More focused and transparent research is needed to validate these patterns and develop a strong science underpinning for establishing policies and governance agreements that prevent/mitigate negative and promote positive impacts from bioenergy production. © 2016 The Authors. Global Change Biology Bioenergy Published by John Wiley & Sons Ltd.

Towards a more holistic sustainability assessment framework for agro-bioenergy systems — A review
Type Article de revue
Auteur O. Arodudu
Auteur K. Helming
Auteur H. Wiggering
Auteur A. Voinov
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-84991577020&doi=10.1016%2fj.eiar.2016.07.008&partnerID=40&md5=a6550b24202242bd875ddd3ccb70d9c1
Volume 62
Pages 61-75
Publication Environmental Impact Assessment Review
Date 2017
DOI 10.1016/j.eiar.2016.07.008

Résumé The use of life cycle assessment (LCA) as a sustainability assessment tool for agro-bioenergy system usually has an industrial agriculture bias. Furthermore, LCA generally has often been criticized for being a decision maker tool which may not consider decision takers perceptions. They are lacking in spatial and temporal depth, and unable to assess sufficiently some environmental impact categories such as biodiversity, land use etc. and most economic and social impact categories, e.g. food security, water security, energy security. This study explored tools, methodologies and frameworks that can be deployed individually, as well as in combination with each other for bridging these methodological gaps in application to agro-bioenergy systems. Integrating agronomic options, e.g. alternative farm power, tillage, seed sowing options, fertilizer, pesticide, irrigation into the boundaries of LCAs for agro-bioenergy systems will not only provide an alternative agro-ecological perspective to previous LCAs, but will also lead to the derivation of indicators for assessment of some social and economic impact categories. Deploying life cycle thinking approaches such as energy return on energy invested-EROEI, human appropriation of net primary production-HANPP, net greenhouse gas or carbon balance-NCB, water footprint individually and in combination with each other will also lead to further derivation of indicators suitable for assessing relevant environmental, social and economic impact categories. Also, applying spatio-temporal simulation models has a potential for improving the spatial and temporal depths of LCA analysis. © 2016 Elsevier Inc

An assessment on the sustainability of lignocellulosic biomass for biorefining

Type Article de revue
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Auteur A.K. Dalai
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URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-84930667388&doi=10.1016%2fj.rser.2015.05.058&partnerID=40&md5=5923085e021a0194cf3ecf365dcd73f3
Volume 50
Pages 925-941
Publication Renewable and Sustainable Energy Reviews
Date 2015
DOI 10.1016/j.rser.2015.05.058

Résumé Abstract Biofuels are promoted in a wide-scale as a means of achieving energy security and reducing greenhouse gas emissions. Biofuels derived from lignocellulosic biomass, particularly from agricultural crops are being massively supported worldwide for meeting multiple strategy objectives such as climate change mitigation, energy security and development of the rural economy. Recently, the negative implications of using food crops for fuel have been realized to possess a significant threat towards global food security and competition for arable land. In contrast, lignocellulosic biomass in the form of waste residues from agriculture, forestry and energy crop systems are geographically abundant worldwide and have the potential to support the sustainable production of liquid transportation fuels. This paper encompasses the improvement in biofuels sector in relation to revitalizing and restraining the rural economies across the globe along with the global statistics for lignocellulosic biomass availability. In addition, the socio-environmental impacts of energy and greenhouse gas emissions from biomass conversion technologies have been addressed through highlights on life-cycle assessment of several biomasses. © 2015 Elsevier Ltd.

Harmonising conflicts between science, regulation, perception and environmental impact: The case of soil conditioners from bioenergy

Type Article de revue
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Auteur B.M.J. Herbert
Auteur L. Ricketts
Auteur I. Dodd
Auteur N. Ostle
Auteur K.T. Semple
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-84910002142&doi=10.1016%2fj.envint.2014.10.025&partnerID=40&md5=cc46867b9aeb8ab5afa93e39f49267b5
Volume 75
Pages 52-67
Publication Environment International
Date 2015
DOI 10.1016/j.envint.2014.10.025
Résumé As the global population is expected to reach 9 billion by 2050, humanity needs to balance an ever increasing demand for food, energy and natural resources, with sustainable management of ecosystems and the vital services that they provide. The intensification of agriculture, including the use of fertilisers from finite sources, has resulted in extensive soil degradation, which has increased food production costs and CO2 emissions, threatening food security. The Bioenergy sector has significant potential to contribute to the formation of a circular economy. This paper presents the scientific, regulatory and socioeconomic barriers to the use of the nutrient waste streams from biomass thermal conversion (ash) and anaerobic digestion (digestate) as sustainable soil amendments for use in place of traditional fertilisers. It is argued that whilst the ability of combined ash and digestate to remedy many threats to ecosystems and provide a market to incentivise the renewable bio-energy schemes is promising, a step-change is required to alter perceptions of 'waste', from an expensive problem, to a product with environmental and economic value. This can only be achieved by well-informed interactions between scientists, regulators and end users, to improve the spread and speed of innovation with this sector. © 2014 Elsevier Ltd.

A mini review on renewable sources for biofuel
Type Article de revue
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Auteur H.H. Ngo
Auteur W. Guo
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-84907595330&doi=10.1016%2fj.biortech.2014.07.022&partnerID=40&md5=7afcc288e0ca63c01ec1fc2fd10c80c5
Volume 169
Pages 742-749
Publication Bioresource Technology
Date 2014
DOI 10.1016/j.biortech.2014.07.022
Résumé Rapid growth in both global energy demand and carbon dioxide emissions associated with the use of fossil fuels has driven the search for alternative sources which are renewable and have a lower environmental impact. This paper reviews the availability and bioenergy potentials of the current biomass feedstocks. These include (i) food crops such as sugarcane, corn and vegetable oils, classified as the first generation feedstocks, and (ii) lignocellulosic biomass derived from agricultural and forestry residues and municipal waste, as second generation feedstocks. The environmental and ocioeconomic
limitations of the first generation feedstocks have placed greater emphasis on the lignocellulosic biomass, of which the conversion technologies still faces major constraints to full commercial deployment. Key technical challenges and opportunities of the lignocellulosic biomass-to-bioenergy production are discussed in comparison with the first generation technologies. The potential of the emerging third generation biofuel from algal biomass is also reviewed.

Future carbon dioxide removal via biomass energy constrained by agricultural efficiency and dietary trends
Type Article de revue
Auteur T.W.R. Powell
Auteur T.M. Lenton
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-84864270613&doi=10.1039%2fc2ee21592f&partnerID=40&md5=812d0b9a0af9c90320b76deb757ca64b
Volume 5
Numéro 8
Pages 8116-8133
Publication Energy and Environmental Science
Date 2012
DOI 10.1039/c2ee21592f
Résumé We assess the quantitative potential for future land management to help rebalance the global carbon cycle by actively removing carbon dioxide (CO2) from the atmosphere with simultaneous bio-energy offsets of CO2 emissions, whilst meeting global food demand, preserving natural ecosystems and minimising CO2 emissions from land use change. Four alternative future scenarios are considered out to 2050 with different combinations of high or low technology food production and high or low meat diets. Natural ecosystems are protected except when additional land is necessary to fulfil the dietary demands of the global population. Dedicated bio-energy crops can only be grown on land that is already under

management but is no longer needed for food production. We find that there is only room for dedicated bio-energy crops if there is a marked increase in the efficiency of food production (sustained annual yield growth of 1%, shifts towards more efficient animals like pigs and poultry, and increased recycling of wastes and residues). If there is also a return to lower meat diets, biomass energy with carbon storage (BECS) as CO2 and biochar could remove up to 5.2 Pg C per year in 2050 and lower atmospheric CO2 in 2050 by 25 ppm. With the current trend to higher meat diets there is only room for limited expansion of bio-energy crops after 2035 and instead BECS must be based largely on biomass residues, removing up to 3.6 Pg C per year in 2050 and lowering atmospheric CO2 in 2050 by 13 ppm. A high-meat, low-efficiency future would be a catastrophe for natural ecosystems (and thus for the humans that depend on their services) with around 9.3 Gha under cultivation in 2050 and a net increase in atmospheric CO2 in 2050 by 55 ppm due to land use changes. We conclude that future improvements in agricultural efficiency, especially in the livestock sector, could make a decisive contribution to tackling climate change, but this would be maximised if the global trend towards more meat intensive diets can be reversed.

Negative CO2 emissions through the use of biofuels in chemical looping technology: A review

Type Article de revue

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Auteur F. Garcia-Labiano
Auteur A. Abad
Auteur P. Gayan
Auteur L. F. de Diego
Auteur M. T. Izquierdo
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Volume 232
Pages 657-684
Publication Applied Energy
ISSN 0306-2619
Date DEC 15 2018
Extra WOS:000451356200047
DOI 10.1016/j.apenergy.2018.09.201

Résumé In order to limit the increase in the global average temperature to 2 degrees C or below, the Paris Agreement proposed the reduction of CO2 emissions throughout this century. Bioenergy with CO2 capture and storage (BECCS) technologies represent an interesting option in order to allow this goal to be metgoal, because they are able to achieve negative CO2 emissions. Chemical looping (CL) is recognized as one of the most innovative CO2 capture technologies owing to its low energy penalty. CL processes permit the utilization of renewable fuels in a nitrogen-free atmosphere, given that the required oxygen is supplied by solid oxygen carriers. The present work presents an overview of the status of development of the use of biofuels in chemical looping technologies, including chemical looping combustion (CLC) and chemical looping with oxygen uncoupling (CLOU) for the production of heat/electricity, as well as chemical looping reforming (CLR), chemical looping gasification (CLG) and chemical looping coupled with water splitting (CLWS) for
syngas/H-2 generation. The main milestones in the development of such processes are shown, and the future trends and opportunities for CL technology with biofuels are discussed.

Biorefineries of carbon dioxide: From carbon capture and storage (CCS) to bioenergies production

Type Article de revue
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Auteur Tau Chuan Ling
Auteur Joon Ching Juan
Auteur Duu-Jong Lee
Auteur Jo-Shu Chang
Auteur Pau Loke Show
Volume 215
Pages 346-356
Publication Bioresource Technology
ISSN 0960-8524
Date SEP 2016
Extra WOS:000377935100038
DOI 10.1016/j.biortech.2016.04.019
Résumé Greenhouse gas emissions have several adverse environmental effects, like pollution and climate change. Currently applied carbon capture and storage (CCS) methods are not cost effective and have not been proven safe for long term sequestration. Another attractive approach is CO2 valorization, whereby CO2 can be captured in the form of biomass via photosynthesis and is subsequently converted into various form of bioenergy. This article summarizes the current carbon sequestration and utilization technologies, while emphasizing the value of bioconversion of CO2. In particular, CO2 sequestration by terrestrial plants, microalgae and other microorganisms are discussed. Prospects and challenges for CO2 conversion are addressed. The aim of this review is to provide comprehensive knowledge and updated information on the current advances in biological CO2 sequestration and valorization, which are essential if this approach is to achieve environmental sustainability and economic feasibility. (C) 2016 Elsevier Ltd. All rights reserved.

The potential of biotechnology for mitigation of greenhouse gasses effects: solutions, challenges, and future perspectives

Type Article de revue
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Auteur Mohammad Behrouzi Varjovi
Auteur Behnam Asgari Lajayer
Auteur Mansour Ghorbanpour
Volume 12
Numéro 5
Pages 174
Publication Arabian Journal of Geosciences
ISSN 1866-7511
Date MAR 2019
Extra WOS:000459981500004
DOI 10.1007/s12517-019-4339-7
Résumé Global warming is a serious threat to humans and other creatures' existence. In recent years, it has led to devastating consequences among which storms, as witnessed in all over the world, can be pointed out. It has also caused sea and ocean levels rise, the soil grows dry, and the quantity and quality of agricultural crops decrease. Moreover, the extinction of species is the other side of the problem. Political conflicts caused by the migration of people from

poor and crisis-hit countries to rich countries can be mentioned as one of the other consequences. Human activities, such as vast consumptions of fossil fuels, which release gases including carbon dioxide (CO2) and methane (CH4) into the atmosphere, preserve the temperature in the atmosphere as the main causes of global warming. However, some natural phenomena can alter climatic conditions around the world. Couple of studies has proven that the role of human is more destructive than natural ones. The Paris World Summit on global warming and climate change has underscored the importance of country's combat against this phenomenon. Biotechnology, as a leading science, provides novel solutions for this crisis and plays an inevitable role in reducing greenhouse gases. Genetic engineering methods such as genome editing, or gene transfer could suitably overcome the severe environmental conditions by increasing the efficiency of photosynthesis and overall biomass. Optimizing biofuel production and providing environmentally friendly fuels that are easily feasible via biotechnology are the possible methods that reduce greenhouse gases and ultimately control the global warming. Here, in this review, we discuss the possible ways that biotechnology can help to ameliorate the global warming effect.

Biogas and its opportunities-A review
Type Article de revue
Auteur Panagiotis G. Kougias
Auteur Irini Angelidaki
Volume 12
Numéro 3
Pages 14
Publication Frontiers of Environmental Science & Engineering
ISSN 2095-2201
Date JUN 2018
Extra WOS:000434945100014
DOI 10.1007/s11783-018-1037-8
Résumé Biogas production is a well-established technology primarily for the generation of renewable energy and also for the valorization of organic residues. Biogas is the end product of a biological mediated process, the so called anaerobic digestion, in which different microorganisms, follow diverse metabolic pathways to decompose the organic matter. The process has been known since ancient times and was widely applied at domestic households providing heat and power for hundreds of years. Nowadays, the biogas sector is rapidly growing and novel achievements create the foundation for constituting biogas plants as advanced bioenergy factories. In this context, the biogas plants are the basis of a circular economy concept targeting nutrients recycling, reduction of greenhouse gas emissions and biorefinery purposes. This review summarizes the current state-of-the-art and presents future perspectives related to the anaerobic digestion process for biogas production. Moreover, a historical retrospective of biogas sector from the early years of its development till its
recent advancements gives an outlook of the opportunities that are opening up for process optimisation. (c) Higher Education Press and Springer- Verlag GmbH Germany, part of Springer Nature 2018
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Crop residue harvest for bioenergy production and its implications on soil functioning and plant growth: A review
Type Article de revue
Auteur Mauricio Roberto Cherubin

Auteur Dener Marcio da Silva Oliveira
Auteur Brigitte Josefine Feigl
Auteur Laisa Gouveia Pimentel
Auteur Izaias Pinheiro Lisboa
Auteur Maria Regina Gmach
Auteur Leticia Leal Varanda
Auteur Maristela Calvente Morais
Auteur Lucas Santos Satiro
Auteur Gustavo Vicentini Popin
Auteur Silvia Rodrigues de Paiva
Auteur Arthur Klebson Belarmino dos Santos
Auteur Ana Luisa Soares de Vasconcelos
Auteur Paul Lineker Amaral de Melo
Auteur Carlos Eduardo Pellegrino Cerri
Auteur Carlos Clemente Cerri
Volume 75
Numéro 3
Pages 255-272
Publication Scientia Agricola
ISSN 1678-992X
Date MAY-JUN 2018
Extra WOS:000424389600011
DOI 10.1590/1678-992X-2016-0459
Résumé The use of crop residues as a bioenergy feedstock is considered a potential strategy to mitigate greenhouse gas (GHG) emissions. However, indiscriminate harvesting of crop residues can induce deleterious effects on soil functioning, plant growth and other ecosystem services. Here, we have summarized the information available in the literature to identify and discuss the main trade-offs and synergisms involved in crop residue management for bioenergy production. The data consistently showed that crop residue harvest and the consequent lower input of organic matter into the soil led to C storage depletions over time, reducing cycling, supply and availability of soil nutrients, directly affecting the soil biota. Although the biota regulates key functions in the soil, crop residue can also cause proliferation of some important agricultural pests. In addition, crop residues act as physical barriers that protect the soil against raindrop impact and temperature variations. Therefore, intensive crop residue harvest can cause soil structure degradation, leading to soil
compaction and increased risks of erosion. With regard to GHG emissions, there is no consensus about the potential impact of management of crop residue harvest. In general, residue harvest decreases CO2 and N2O emissions from the decomposition process, but it has no significant effect on CH4 emissions. Plant growth responses to soil and microclimate changes due to crop residue harvest are site and crop specific. Adoption of the best management practices can mitigate the adverse impacts of crop residue harvest. Longterm experiments within strategic production regions are essential to understand and monitor
the impact of integrated agricultural systems and propose customized solutions for sustainable crop residue management in each region or landscape. Furthermore, private and public investments/cooperations are necessary for a better understanding of the potential environmental, economic and social implications of crop residue use for bioenergy production.
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Sweet sorghum-a promising alternative feedstock for biofuel production

Type Article de revue

Auteur Rouf Ahmad Dar
Auteur Eajaz Ahmad Dar
Auteur Ajit Kaur
Auteur Urmila Gupta Phutela

Volume 82
Pages 4070-4090
Publication Renewable & Sustainable Energy Reviews
ISSN 1364-0321
Date FEB 2018
Extra WOS:000418574800146
DOI 10.1016/j.rser.2017.10.066

Résumé The key principle in resource management is sustainability which consists of operational robustness, attenuation of environmental footprint and socioeconomic considerations. Dependence on fossil fuels is unviable due to their continuous depletion all over the world and also the inexperienced greenhouse gas emissions related to their utilization. Therefore, the continuous initiatives geared towards developing various renewable and probably carbon neutral biofuels as energy resources are being taken up. Alternate energy resources such as 1st generation biofuels derived from terrestrial crops
like sugarcane, sugar beet, corn and wheat place a colossal stress on global food markets, but this potential food versus fuel conflict is palliated by using sweet sorghum as a bioenergy crop. It can be processed into both biofuel and valuable co-products, thus meeting the various requirements of food, fuel and fodder. This paper mainly reviewed the technologies for bioethanol production from sweet sorghum, focussing on its potential benefits as feedstock for ethanol production over other substrates and recent advancements to enhance ethanol yield. It also reviewed the advances in pretreatment along with the novel process of ethanol production from sweet sorghum stalks, biogas production from sweet sorghum and environmental cum socio-economic aspects. No doubt, there are outstanding issues related to ethanol production and yield, still sweet sorghum derived bioethanol could progressively substitute a significant proportion of the fossil fuels required to meet the growing energy demand.

A research challenge vision regarding management of agricultural waste in a circular bio-based economy

Type Article de revue

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Auteur Ulf Sonesson
Auteur Morten Birkved
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Auteur Ana Paula Batista
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Numéro 6
Pages 614-654
Publication Critical Reviews in Environmental Science and Technology
ISSN 1064-3389
Date 2018
Extra WOS:000452011700002
DOI 10.1080/10643389.2018.1471957

Résumé Agricultural waste is a huge pool of untapped biomass resources that may even represent economic and environmental burdens. They can be converted into bioenergy and bio-based products by cascading conversion processes, within circular economy, and should be considered residual resources. Major challenges are discussed from a transdisciplinary perspective, focused on Europe situation. Environmental and economic consequences of agricultural residue management chains are difficult to assess due to their complexity, seasonality and regionality. Designing multi-criteria decision support tools, applicable at an early-stage of research, is discussed. Improvement of Anaerobic Digestion (AD), one of the most mature conversion technologies, is discussed from a technological point of view and waste feedstock geographical and seasonal variations. Using agricultural residual resources for producing high-value chemicals is a considerable challenge analysed here, taking into account innovative eco-efficient and cost-effective cascading conversion processes (bio-refinery concept). Moreover, the promotion of agricultural residues-based business is discussed through industrial ecology, to promote synergy, on a local basis, between different agricultural and industrial value chains. Finally, to facilitate a holistic approach and optimise materials and knowledge flows management, the connection of stakeholders is discussed to promote cross-sectorial collaboration and resource exchange at appropriate geographic scales.

In pursuit of Sustainable Development Goal (SDG) number 7: Will biofuels be reliable?
Type Article de revue
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Auteur Funda Cansu Ertem
Auteur Benjamin Kappler
Auteur Peter Neubauer
Volume 75
Pages 927-937
Publication Renewable & Sustainable Energy Reviews
ISSN 1364-0321
Date AUG 2017
Extra WOS:000401395000075
DOI 10.1016/j.rser.2016.11.074
Résumé Driven by the desire to mitigate climate change and reduce overdependence on fossil fuels, biofuels have been actively pursued in recent years because they are believed to be inherently environmentally friendly. In the past few years, however, critics have objected to the basis for which it should be adopted due to potential negative trade-offs. Sustainable Development Goals (SDG) number seven seeks to substantially increase contribution of renewable energy to global energy supply, as well as double the rate of improvement in efficiency of energy. Biofuels are likely to play a key role in the pursuit of these goals being one of the most advanced alternative energy sources. This review assesses the potential of biofuels to contribute to the set SDGs by presenting an appraisal of their development over the years. It sheds light on some main arguments surrounding biofuels from the perspective of proponents and critics alike. Even though biofuels have a great potential in aiding climate change mitigation, its large scale adoption is regarded as problematic in its current
state. This is because of its potential negative trade-offs in terms of land use change and emissions, especially for first and second generation biofuels. However, a combination of plant biology, carbon capture techniques and novel bioconversion processes provided by third and fourth generation biofuel technologies have set open an era of fuels that will be abundant, energy efficient and clean to support the seventh SDG.

Progress in biofuel production from gasification
Type Article de revue
Auteur Vineet Singh Sikarwar
Auteur Ming Zhao
Auteur Paul S. Fennell
Auteur Nilay Shah
Auteur Edward J. Anthony
Volume 61
Pages 189-248
Publication Progress in Energy and Combustion Science
ISSN 0360-1285
Date JUL 2017
Extra WOS:000402809600006
DOI 10.1016/j.pecs.2017.04.001
Résumé Biofuels from biomass gasification are reviewed here, and demonstrated to be an attractive option. Recent progress in gasification techniques and key generation pathways for biofuels production, process design and integration and socio-environmental impacts of biofuel generation are discussed, with the goal of investigating gasification-to-biofuels' credentials as a sustainable and eco-friendly technology.

The synthesis of important biofuels such as bio-methanol, bio-ethanol and higher alcohols, bio-dimethyl ether, Fischer Tropsch fuels, bio-methane, bio-hydrogen and algae-based fuels is reviewed, together with recent technologies, catalysts and reactors. Significant thermodynamic studies for each biofuel are also examined. Syngas cleaning is demonstrated to be a critical issue for biofuel production, and innovative pathways such as those employed by Choren Industrietechnik, Germany, and BioMCN, the Netherlands, are shown to allow efficient methanol generation. The conversion of syngas to FT transportation fuels such as gasoline and diesel over Co or Fe catalysts is reviewed and demonstrated to be a promising option for the future of biofuels. Bio-methane has emerged as a lucrative
alternative for conventional transportation fuel with all the advantages of natural gas including a dense distribution, trade and supply network. Routes to produce H_2 are discussed, though critical issues such as storage, expensive production routes with low efficiencies remain. Algae-based fuels are in the research and development stage, but are shown to have immense potential to become commercially important because of their capability to fix large amounts of CO_2, to rapidly grow in many environments and versatile end uses. However, suitable process configurations resulting in optimal plant designs
are crucial, so detailed process integration is a powerful tool to optimize current and develop new processes. LCA and ethical issues are also discussed in brief. It is clear that the use of food crops, as opposed to food wastes represents an area fraught with challenges, which must be resolved on a case by case basis. (C) 2017 The Authors. Published by Elsevier Ltd.

Bioconversion of carbon dioxide in anaerobic digesters for on-site carbon capture and biogas enhancement - A review

Type Article de revue
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Auteur A. Soares
Auteur K. Koch
Auteur P. Vale
Auteur E. Cartmell
Volume 47
Numéro 17
Pages 1555-1580
Publication Critical Reviews in Environmental Science and Technology
ISSN 1064-3389
Date 2017
Extra WOS:000419156000001
DOI 10.1080/10643389.2017.1372001

Résumé Energy consumption of the water sector presents an increasing energy demand, contrary to GHG mitigation aims. As a result, research aimed at capturing emitted CO_2 and at developing treatment technologies with a low energy demand and increased renewable energy production has increased, leading to a surge in implementation of anaerobic digestion (AD). Valorization of the biogenic CO_2 emitted with biogas AD (estimated at over 1 MtCO(2) per annum for the UK water and organic waste sectors), presents an opportunity to further reduce carbon footprint and support energy supply decarburization. This
paper reviews bioconversion of CO_2 into CH_4 in ADs (without addition of H-2) as a means to valorize CO_2 emissions. The review has concluded this to be a promising solution to reduce carbon footprint and uplift renewable energy production. However, in order to increase readiness for implementation (1) the

mechanisms of CO_2 utilization need to be elucidated, including the sources of additional H_2 needed, (2) studies need to report more thoroughly the conditions of CO_2 injection and (3) trials where ADs are integrated with gas to liquid mass transfer technologies need to be performed.

FORÊTS

Forest Operations and Woody Biomass Logistics to Improve Efficiency, Value, and Sustainability
Type Article de revue
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Auteur D. Mitchell
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-84964264776&doi=10.1007%2fs12155-016-9735-1&partnerID=40&
md5=8e7664682c6690eb263ec72785278777
Volume 9
Numéro 2
Pages 518-533
Publication Bioenergy Research
Date 2016
DOI 10.1007/s12155-016-9735-1
Résumé This paper reviews the most recent work conducted by scientists and engineers of the Forest Service of the US Department of Agriculture (USDA) in the areas of forest operations and woody biomass logistics, with an emphasis on feedstock supply for emerging bioenergy, biofuels, and bioproducts applications. This work is presented in the context of previous research in this field by the agency and is measured against the goals and objectives provided by several important national-level initiatives, including the USDA Regional Biomass Research Centers. Research conducted over the past 5 years in cooperation with a diverse group of research partners is organized in four topic sections: innovative practices, innovative machines, sustainability, and integration. A wide range of studies in operations and logistics address advances in harvest and processing technology, transportation systems, scheduling and planning, feedstock quality, biomass conversion processes, and environmental impacts, including greenhouse gas emissions. We also discuss potential future research to address persistent knowledge gaps, especially those in fire and fuel management. Overall, the research reviewed here aligns well with broad national goals of providing the USA with sustainable and efficient forest biomass management and production systems, specifically including: (1) improved harvest, collection, handling, and transportation systems for woody biomass; (2) cost and equipment information and options for field processing biomass to improve efficiency and mitigate impacts; and (3) forest biomass management systems and technologies to offset impacts and enhance environmental outcomes. However, as needs evolve, professionals in this field must strive to adapt research, development, and dissemination to address relevant future challenges and strengthen capabilities to solve critical problems in the forest sector. © 2016, Springer Science+Business Media New York (outside the USA).

Greenhouse gas emissions in response to nitrogen fertilization in managed forest ecosystems
Type Article de revue
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Auteur B.D. Strahm
Auteur E.B. Sucre
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-84925502830&doi=10.1007%2fs11056-014-9454-4&partnerID=40&
md5=0092867e494f29bd625aba09b26dd2b3
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Date 2015
DOI 10.1007/s11056-014-9454-4
Résumé Nitrogen (N) fertilizer use in managed forest ecosystems is increasing in the United States and worldwide to enhance social, economical and environmental services. However, the effects of N-fertilization on production and consumption of greenhouse gases (GHGs), especially carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) in managed forest ecosystems are poorly understood, unlike in agriculture where effects are well documented. Therefore, a review of the available literature was conducted to comprehend the effects of N-fertilization on CO_2, CH_4 and N_2O emissions in managed forest ecosystems to summarize sources, sinks, and controlling factors, as well as potential mitigation strategies and research gaps to reduce GHG emissions. This review clearly identifies the importance of N-fertilizer management practices on CO_2, CH_4 and N_2O emissions. Potential N management practices to mitigate GHG emissions in managed forest ecosystems include improving N uptake efficiency, identifying and managing spatial variation in soil fertility, using the right fertilizer source at the right time, adopting appropriate methods of N-fertilizer application, and introducing nitrification/denitrification inhibitors. Nitrogen-fertilizer response is affected by soil physical (e.g., moisture, drainage, bulk density, and texture), chemical (e.g., nutrient availability, labile carbon, soil pH, and C/N ratio) and local climatic factors (e.g., temperature, relative humidity, and rainfall). Therefore, the interactions of these factors on GHG emissions need to be considered while evaluating N-fertilizer management practices. Existing studies are often limited, focusing primarily on temperate forest ecosystems, lacking estimation of net emissions considering all three predominant soil-derived GHGs, and were often conducted on a small scale, making upscaling challenging. Therefore, large-scale studies conducted in diverse climates, evaluating cumulative net emissions, are needed to better understand N-fertilization effects on GHG emissions and develop mitigation strategies. Mitigation strategies and research gaps have also been identified, which require the collaborative efforts of forest owners, managers, and scientists to increase adoption of N-fertilization best management practices and understand the importance of N-fertilizer management strategies in reducing emissions and enhancing the net GHG sink potential for managed forest ecosystems.

Biodiversity as a solution to mitigate climate change impacts on the functioning of forest ecosystems

Type Article de revue
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Auteur Eric B. Searle
Auteur Han Y. H. Chen
Volume 93
Numéro 1
Pages 439-456
Publication Biological Reviews
ISSN 1464-7931
Date FEB 2018
Extra WOS:000419965700022
DOI 10.1111/brv.12351
Résumé Forest ecosystems are critical to mitigating greenhouse gas emissions through carbon sequestration. However, climate change has affected forest ecosystem functioning in both negative and positive ways, and has led to shifts in species/functional diversity and losses in plant species diversity which may impair the positive effects of diversity on ecosystem functioning. Biodiversity may mitigate climate change impacts on (I) biodiversity itself, as more-diverse systems could be more resilient to climate change

impacts, and (II) ecosystem functioning through the positive relationship between diversity and ecosystem functioning. By surveying the literature, we examined how climate change has affected forest ecosystem functioning and plant diversity. Based on the biodiversity effects on ecosystem functioning (B -> EF), we specifically address the potential for biodiversity to mitigate climate change impacts on forest ecosystem functioning. For this purpose, we formulate a concept whereby biodiversity may reduce the negative impacts or enhance the positive impacts of climate change on ecosystem functioning. Further B -> EF studies on climate change in natural forests are encouraged to elucidate how biodiversity might influence ecosystem functioning. This may be achieved through the detailed scrutiny of large spatial/long temporal scale data sets, such as long-term forest inventories. Forest management strategies based on B -> EF have strong potential for augmenting the effectiveness of the roles of forests in the mitigation of climate change impacts on ecosystem functioning.

Disturbance and the carbon balance of US forests: A quantitative review of impacts from harvests, fires, insects, and droughts

Type Article de revue
Auteur Christopher A. Williams
Auteur Huan Gu
Auteur Richard MacLean
Auteur Jeffrey G. Masek
Auteur G. James Collatz
Volume 143
Pages 66-80
Publication Global and Planetary Change
ISSN 0921-8181
Date AUG 2016
Extra WOS:000380594000007
DOI 10.1016/j.gloplacha.2016.06.002
Résumé Disturbances are a major determinant of forest carbon stocks and uptake. They generally reduce land carbon stocks but also initiate a regrowth legacy that contributes substantially to the contemporary rate of carbon stock increase in US forestlands. As managers and policy makers increasingly look to forests for climate protection and mitigation, and because of increasing concern about changes in disturbance intensity and frequency, there is a need for synthesis and integration of current understanding about the role of disturbances and other processes in governing forest carbon cycle dynamics, and the likely future of this and other sinks for atmospheric carbon. This paper aims to address that need by providing a quantitative review of the distribution, extent and carbon impacts of the major disturbances active in the US. We also review recent trends in disturbances, climate, and other global environmental changes and consider their individual and collective contributions to the US carbon budget now and in the likely future. Lastly, we identify some key challenges
and opportunities for future research needed to improve current understanding, advance predictive capabilities, and inform forest management in the face of these pressures. Harvest is found to be the most extensive disturbance both in terms of area and carbon impacts, followed by fire, windthrow and bark beetles, and lastly droughts. Collectively these lead to the gross loss of about 200 Tg C y(-1) in live biomass annually across the conterminous US. At the same time, the net change in forest carbon stocks is positive (190 Tg C y(-1)), indicating not only forest resilience but also an apparently large response to growth enhancements such as fertilization by CO2 and nitrogen. Uncertainty about disturbance legacies, disturbance interactions, likely trends, and global change factors make the future of the US forest carbon sink unclear. While there is scope for management to enhance carbon sinks in US forests, tradeoffs with

other values and uses are likely to significantly limit practical implementation. Continued and expanded remote sensing and field-based monitoring
capabilities and manipulative experimentation are needed to improve understanding of the US forest carbon sink, and assess how disturbance processes are responding to the pressures of global environmental change. In addition, continued development and application of holistic, decision support tools that consider a range of forest values are needed to enable managers and policy makers to use the best available information for guiding forest resources now and into the future.

Forest Carbon Calculators: A Review for Managers, Policymakers, and Educators

Type Article de revue
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Auteur Thomas A. Spies
Auteur Mark E. Harmon
Auteur Mark J. Twery
Volume 114
Numéro 2
Pages 134-143
Publication Journal of Forestry
ISSN 0022-1201
Date MAR 2016
Extra WOS:000372046900008
DOI 10.5849/jof.15-019
Résumé Forests play a critical role sequestering atmospheric carbon dioxide, partially offsetting greenhouse gas emissions, and thereby mitigating climate change. Forest management, natural disturbances, and the fate of carbon in wood products strongly influence carbon sequestration and emissions in the forest sector. Government policies, carbon offset and trading programs, and sustainable forestry certification programs make it increasingly important that carbon dynamics are incorporated into forest management decisionmaking. Many analytical tools (which we refer to as forest carbon calculators) have been developed to quantify carbon stores and dynamics in the forest sector, but it can be difficult for potential users to know which carbon calculator(s) may be best for any given application. We review 12 forest carbon calculators, providing a classification and synthesis to assist forest managers, policymakers, and educators. Additionally, we discuss key characteristics missing in existing forest carbon calculators that are needed for current. and future forest management decisionmaking.

Bioenergy farming using woody crops. A review

Type Article de revue
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Auteur Victor Hugo Duran Zuazo
Auteur Charles Bielders
Auteur Juan Antonio Jimenez Bocanegra
Auteur Francisco PereaTorres
Auteur Jose Ramon Francia Martinez
Volume 35
Numéro 1

Pages 95-119
Publication Agronomy for Sustainable Development
ISSN 1774-0746
Date JAN 2015
Extra WOS:000348065500006
DOI 10.1007/s13593-014-0262-1
Résumé The global energy consumption was 540 EJ in 2010, representing an increase of about 80 % from 1980. Energy demand is predicted to grow more than 50 % by 2025. Fossil fuels will supply about 75 % of the future energy demand in 2030-2050 if there are no significant technological innovations or carbon emission constraints. This will induce in a substantial increase of CO2 atmospheric concentration and, in turn, adverse climatic impacts. A solution to this issue is to replace fossil fuels by renewable fuels such as biomass. For instance cultivated woody biomass shows many advantages such as allowing multiple harvests without having to re-plant. Poplar, eucalyptus, salix, paulownia and black locust are common examples of woody biomass. Here we review the current situation and future tendency of renewable energy focusing on solid biomass in Europe and Spain. We also discuss the potential production for short-rotation plantations in the bioenergy sector and existing constraints for the implantation in Spain in a sustainable context. Countries with low biomass resources and high targets for renewable electricity may have to depend on imported solid biomass, whereas countries with wide solid biomass resources benefit from international markets. The expansion of short-rotation plantations is much lower than expected in some countries such as Spain.

INDUSTRIE

A state-of-the-art review of solar air-conditioning systems

Type Article de revue
Auteur D.N. Nkwetta
Auteur J. Sandercock
Volume 60
Pages 1351-1366
Publication Renewable and Sustainable Energy Reviews
Date 2016
DOI 10.1016/j.rser.2016.03.010

Résumé To reduce greenhouse gas emission, solar cooling is an attractive and environmentally friendly application since there is a direct match with cooling demand and peak incident solar radiation. In addition, solar absorption refrigeration technologies are regarded as a promising way to meet the growing refrigeration needs related to thermal comfort, vaccines, conservation of foods and medicines as well as crop drying. Presently, two systems in common used are, the single and double effects absorption chillers with the difference between the two systems being the operating temperature range. This comprehensive review looks at the available methods (theoretical modeling/simulation and experimental) that have been used for the powering of single and double effects solar absorption chillers, other solar cooling systems and their merits, system integration, design optimization and cost effectiveness of each system. Furthermore, solar collectors area and efficiency needed for each load profile is reviewed. Higher temperature differential generated by concentrated augmented solar collectors appears to be economically viable for solar cooling systems, as peak incident solar radiations are a direct coincidence with peak solar cooling needs. Research has demonstrated that the use of evacuated tube and concentrated augmented solar collectors helps to improve the coefficient of performance of single and double-effect lithium bromide-water (LiBr/H2O) absorption chillers. However, there is still the need for more research on system integration and optimization of concentrated augmented solar collectors powering single and double-effect lithium bromide-water (LiBr/H2O) absorption chillers with thermal energy storage. © 2016 Elsevier Ltd.

CO2 sequestration by mineral carbonation: a review

Type Article de revue
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Auteur V. Arora
Auteur S. Yadav
Volume 20
Numéro 3
Pages 497-503
Publication Global Nest Journal
ISSN 1790-7632
Date DEC 2018
Extra WOS:000455246400008
DOI 10.30955/gnj.002597

Résumé The mineral sequestration, one of the methods of CO2 sequestration, is considered advantageous, as it not only facilitates permanent and leakage free storage of CO2 but also obviates the need for regular monitoring. Mineral sequestration involves the dissolution of minerals and subsequently carbonation of dissolved minerals. In the direct mineral sequestration all the processes occur within a single reactor, whereas in the cases of indirect mineral

sequestration, they take place in separate reactors. The main aim of the present study is to investigate the efficacy of these mineral sequestration methods and examine their suitability for industrial application and ensuring environmental friendliness. For this purpose, literature pertaining to these methods was extensively reviewed, and observations made by several researchers were collected, collated and compared based on the various parameters such as reaction pathways, reaction kinetics and cost of the process. The process cost was found to depend on the type of the process, process parameters, input materials and additives. It was noted that the direct mineral sequestration suffers from the sluggish reaction kinetics, thereby becomes economically unviable. The success of direct mineral sequestration process is yet to be achieved despite research carried out for several years. The problem of sluggish reaction kinetics was overcome by using multi-steps indirect carbonation routes, where separate reactors were used for dissolution and precipitation processes. The indirect sequestration method was noted to be most efficient as it offered several advantages such as improved reaction kinetics and recovery of the market value of by-product due to the better quality control of the product. Hence, based on interpretation of an extensive review of literature it can be concluded that the indirect mineral sequestration may be a viable option to carry out the CO2 sequestration and may be proved as a guiding light to ensure the clean environment for future generation.

Alternative pathways for efficient CO2 capture by hybrid processes-A review

Type Article de revue

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Auteur Qingling Liu
Auteur Na Ji
Auteur Shuai Deng
Auteur Jun Zhao
Auteur Yang Li
Auteur Yingjin Song
Auteur Hailong Li

Volume 82
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Publication Renewable & Sustainable Energy Reviews
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Date FEB 2018
Extra WOS:000417079400017
DOI 10.1016/j.rser.2017.09.040

Résumé CO2 capture and storage technologies have been recognized as the primary option to mitigate the issue of climate change caused by the utilization of fossil fuels. In the last decades, several CO2 capture approaches have been developed, such as absorption, adsorption, membrane, cryogenic, hydrate and chemical looping combustion etc. However, the energy penalty is a general challenge for each technology. To overcome the disadvantages of standalone technology, the combination of two or more approaches (namely hybrid CO2 capture processes) has been considered as a potential option. In this work, the status and development of hybrid CO2 capture processes is presented in a classification of primary technology as absorption-based, adsorption-based, membrane-based and cryogenic-based. The detail configuration of each hybrid process is introduced. Simultaneously, the characteristics, advantages and potential challenges of each hybrid process are also summarized. Compared to the standalone methods, hybrid processes showed the superiority not only in CO2 recovery and energy penalty, but also in the installation investment. Therefore, hybrid processes can be a promising alternative to conventional CO2 capture technologies in future.

Perspectives on NMR studies of CO_2 adsorption
Type Article de revue
Auteur Diana Bernin
Auteur Niklas Hedin
Volume 33
Pages 53-62
Publication Current Opinion in Colloid & Interface Science
ISSN 1359-0294
Date JAN 2018
Extra WOS:000433649500007
DOI 10.1016/j.cocis.2018.02.003
Résumé There is a consensus about a long-term goal of a carbon-neutral energy cycle, but the CO2 emissions to the atmosphere are currently very large. Carbon Capture and Storage (CCS) technologies could allow a transformation of the global energy system into a carbon-neutral one and simultaneously keeping the temperature rises within agreed bounds. The CO2 separation step of CCS is, however, very expensive, and adsorption-driven technologies have been put forward as alternatives. Hence, a recent focus has been on studying solid adsorbents for CO2, which include activated carbons, zeolites, metal-organic frameworks, and amine-modified silica. In this context, we summarize the literature concerning CO2 sorption studied with Nuclear Magnetic Resonance (NMR), outline selected NMR methods, and present an outlook for further studies. (C) 2018 Elsevier Ltd. All rights reserved.

The technology of CO2 sequestration by mineral carbonation: current status and future prospects
Type Article de revue
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Auteur D. B. Dreisinger
Auteur M. Jarvis
Auteur T. Hitchins
Volume 57
Numéro 1
Pages 46-58
Publication Canadian Metallurgical Quarterly
ISSN 0008-4433
Date 2018
Extra WOS:000429209100007
DOI 10.1080/00084433.2017.1375221
Résumé Mineral carbonation (MC) has been extensively researched all over the world since it was found as a naturally exothermic process to permanently sequester CO2. In order to accelerate the natural process, various methods for carbonation of Mg-/Ca-silicate minerals have been studied. It has been found that the MC efficiency will increase with an increase in CO2 pressure, retention time, temperature, mass ratio of Mg/Ca to Si in minerals, specific surface area, and the slurry concentration in a specific range, and with the introduction of NaCl and NaHCO3 or carbonic anhydrase. However, there is still no successful industrial application because of high economic costs and slow reaction rate. It is not economic to exploit Mg-/Ca-silicate minerals deposits or tailings to sequester CO2 by the MC due to the cost of grinding and heat pre-treatment. In some cases, the whole sequestration process may result in more CO2 emissions than the sequestered CO2 due to the requirements of energy inputs. The process, however, may be profitable as a whole (with carbon

credits). It is suggested to combine the MC with valuable metals recovery from ore deposits in order to reduce the cost of the MC by cost sharing for mineral recovery.

Epigrammatic status and perspective of sequestration of carbon dioxide: Role of TiO2 as photocatalyst

Type Article de revue
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Auteur Sapna Jain
Auteur Bhawna Yadav Lamba
Auteur Pankaj Kumar
Volume 159
Pages 423-433
Publication Solar Energy
ISSN 0038-092X
Date JAN 1 2018
Extra WOS:000423007300041
DOI 10.1016/j.solener.2017.11.007

Résumé Owing to tremendous increasing Carbon dioxide emissions, the environment and our lives have been affected by global warming and climate changes. There is a growing need to mitigate CO2 emissions. Some of the strategies to mitigate CO2 emissions are energy conservation, carbon capture and storage and using CO2 as a raw material in chemical processes. One of the best routes to remedy CO2 is to transform it to hydrocarbons via photo reduction. The paper presents the trends on the different methods of conversion of carbon dioxide into hydrocarbons. Among various methods, use of photo catalyst TiO2 is widely studied due to its comparatively low cost, low toxicity and its ability to resist photo corrosion. The importance of titania correlating with its properties is presented. Different doping of TiO2 is mentioned. The review concluded that TiO2 represents an effective photo catalyst for conversion of carbon dioxide leading to purification of environment and solution to energy crisis.

Critical review of applications of iron and steel slags for carbon sequestration and environmental remediation

Type Article de revue
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Auteur Archana Gopakumar
Auteur Jyoti K. Chetri
Volume 18
Numéro 1
Pages 127-152
Publication Reviews in Environmental Science and Bio-Technology
ISSN 1569-1705
Date MAR 2019
Extra WOS:000459408200006
DOI 10.1007/s11157-018-09490-w

Résumé One of the major concerns faced by the iron and steel industry, other than the abundant emission of carbon dioxide into the atmosphere, is the huge quantity of slag that is generated during the manufacturing of iron and steel. A comprehensive understanding of the iron and steel slag properties has diverted them away from stockpiling or landfilling to useful engineering applications. The similarity of these slags to natural minerals used in geologic carbon dioxide sequestration has made them sustainable alternative for industrial-scale carbon capture and storage. Further, they possess properties that are conducive for remediation of soil and groundwater contaminated with heavy metals and other toxic chemicals. This paper reviews the iron and steel slag characteristics suitable for engineering applications, describes several engineering application examples, and discusses challenges and opportunities to develop practical applications using iron and steel slags. This paper also discusses the on-going research which explores the use of steel slag along with the biochar-amended soil to develop a biogeochemical landfill cover to sequester fugitive gas emissions such as CH4, CO2 and H2S from MSW landfills and attain zero-emissions landfill.

Industrial energy use and carbon emissions reduction: a UK perspective

Type Article de revue
Auteur Paul W. Griffin
Auteur Geoffrey P. Hammond
Auteur Jonathan B. Norman
Volume 5
Numéro 6
Pages 684-714
Publication Wiley Interdisciplinary Reviews-Energy and Environment
ISSN 2041-8396
Date NOV-DEC 2016
Extra WOS:000393209900005
DOI 10.1002/wene.212
Résumé Progress in reducing industrial energy demand and carbon dioxide (CO2) emissions is evaluated with a focus is on the situation in the United Kingdom (UK), although the lessons learned are applicable across much of the industrialized world. The UK industrial sector is complex, because it may be viewed as consisting of some 350 separate combinations of subsectors, devices and technologies. Various energy analysis and carbon accounting techniques applicable to industry are described and assessed. The contributions of the energy-intensive (EI) and nonenergy-intensive (NEI) industrial subsectors over recent decades are evaluated with the aid of decomposition analysis. An observed drop in aggregate energy intensity over this timescale was driven by different effects: energy efficiency improvements; structural change; and fuel switching. Finally, detailed case studies drawn from the Cement subsector and that associated with Food and Drink are examined; representing the EI and NEI subsectors, respectively. Currently available technologies will lead to further, short-term energy and CO2 emissions savings in manufacturing, but the prospects for the commercial exploitation of innovative technologies by mid-21st century are far more speculative. There are a number of nontechnological barriers to the take-up of such technologies going forward. Consequently, the transition pathways to a low carbon future in UK industry by 2050 will exhibit large uncertainties. The attainment of significant falls in carbon emissions over this period depends critically on the adoption of a limited number of key technologies [e.g., carbon capture and storage (CCS), energy efficiency techniques, and bioenergy], alongside a decarbonization of the electricity supply. (C) 2016 The Authors. WIREs Energy and Environment published by John Wiley & Sons, Ltd.

CaO-based chemical looping gasification of biomass for the production of hydrogen-enriched gas and CO 2 negative emissions: A review

Type Article de revue
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Auteur S. Wang
Auteur R. Zeng

Auteur M. Luo
Auteur X. Tang
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-85051513801&doi=10.1615%2fInterJEnerCleanEnv.2018025185&partnerID=40&md5=e9b46d93152d75aa2c7a3adf551ebc35
Volume 19
Numéro 3-4
Pages 257-302
Publication International Journal of Energy for a Clean Environment
Date 2018
DOI 10.1615/InterJEnerCleanEnv.2018025185
Résumé Hydrogen as an energy carrier plays an important role in the energy consumption system. Compared to other technologies, CaO-based chemical looping gasifi cation of biomass (CaO-based CLGB) is a sustainable way for producing hydrogen-enriched gas and CO 2 negative emissions. As the residence time of fi xed carbon in a gasifi er is short, the CO 2 capture effi ciency of the CaO-based CLGB system is low. To conquer this problem, the CaO-based CLGB con fi guring with carbon stripper was discussed in this paper. The decay of the CO 2 capture capacity of natural CaO-based sorbents is a main factor to restrain the development of CaO-based CLGB. Some promising methods have been applied to solve this problem. According to the purpose of technology, three representative technologies were discussed in this paper. Compared to other technologies, replacing natural or synthetic CaO-based sorbents is an economic and environmentally friendly solution. Calcium-rich industrial waste (CRIW) combined with the characteristics of cheapness, wide-source and environmental protection is an ideal substitute of CaO-based sorbents for replacing natural or synthetic CaO-based sorbents. The prospect of CRIW as a CaO-based sorbent was discussed in this paper. © 2018 by Begell House, Inc.

TRANSPORT

How to decarbonise international shipping: Options for fuels, technologies and policies

Type Article de revue

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Auteur James Brierley
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Auteur Jamie Speirs
Auteur Adam Hawkes
Auteur Iain Staffell

Volume 182
Pages 72-88
Publication Energy Conversion and Management
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DOI 10.1016/j.enconman.2018.12.080

Résumé International shipping provides 80-90% of global trade, but strict environmental regulations around NOx, SOx and greenhouse gas (GHG) emissions are set to cause major technological shifts. The pathway to achieving the international target of 50% GHG reduction by 2050 is unclear, but numerous promising options exist. This study provides a holistic assessment of these options and their combined potential to decarbonise international shipping, from a technology, environmental and policy perspective. Liquefied natural gas (LNG) is reaching mainstream and provides 20-30% CO2 reductions whilst minimising SOx and other emissions. Costs are favourable, but GHG benefits are reduced by methane slip, which varies across engine types. Biofuels, hydrogen, nuclear and carbon capture and storage (CCS) could all decarbonise much further, but each faces significant barriers around their economics, resource potentials and public acceptability. Regarding efficiency measures, considerable fuel and GHG savings could be attained by slow-steaming, ship design changes and utilising renewable resources. There is clearly no single route and a multifaceted response is required for deep decarbonisation. The scale of this challenge is explored by estimating the combined decarbonisation potential of multiple options. Achieving 50% decarbonisation with LNG or electric propulsion would likely require 4 or more complementary efficiency measures to be applied simultaneously. Broadly, larger GHG reductions require stronger policy and may differentiate between short- and long-term approaches. With LNG being economically feasible and offering moderate
environmental benefits, this may have short-term promise with minor policy intervention. Longer term, deeper decarbonisation will require strong financial incentives. Lowest-cost policy options should be fuel- or technology-agnostic, internationally applied and will require action now to ensure targets are met by 2050.

A systematic review of key challenges of CO2 transport via pipelines
Type Article de revue
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Auteur A. Kolios
Auteur D. P. Hanak
Auteur C. Biliyok
Auteur V. Manovic
Volume 81
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Publication Renewable & Sustainable Energy Reviews
ISSN 1364-0321
Date JAN 2018
Extra WOS:000417078200072
DOI 10.1016/j.rser.2017.06.064
Résumé Transport of carbon dioxide (CO2) via pipeline from the point of capture to a geologically suitable location for either sequestration or enhanced hydrocarbon recovery is a vital aspect of the carbon capture and storage (CCS) chain. This means of CO2 transport has a number of advantages over other means of CO2 transport, such as truck, rail, and ship. Pipelines ensure continuous transport of CO2 from the capture point to the storage site, which is essential to transport the amount of CO2 captured from the source facilities, such as fossil fuel power plants, operating in a continuous manner.
Furthermore, using pipelines is regarded as more economical than other means of CO2 transport The greatest challenges of CO2 transport via pipelines are related to integrity, flow assurance, capital and operating costs, and health, safety and environmental factors. Deployment of CCS pipeline projects is based either on point-to-point transport, in which case a specific source matches a specific storage point, or through the development of pipeline networks with a backbone CO2 pipeline. In the latter case, the CO2 streams, which are characterised by a varying impurity level and handled by the individual operators, are linked to the backbone CO2 pipeline for further compression and transport. This may pose some additional challenges. This review involves a systematic evaluation of various challenges that delay the deployment of CO2 pipeline transport and is based on an extensive survey of the literature. It is aimed at confidence-building in the technology and improving economics in the long run. Moreover, the knowledge gaps were identified, including lack of
analyses on a holistic assessment of component impurities, corrosion consideration at the conceptual stage, the effect of elevation on CO2 dense phase characteristics, permissible water levels in liquefied CO2, and commercial risks associated with project abandonment or cancellation resulting from high project capital and operating costs.

Reviews on Current Carbon Emission Reduction Technologies and Projects and their Feasibilities on Ships

Type Article de revue
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Auteur Peilin Zhou
Auteur Zhongcheng Wang
Volume 16
Numéro 2
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Publication Journal of Marine Science and Application
ISSN 1671-9433
Date JUN 2017
Extra WOS:000414189900002
DOI 10.1007/s11804-017-1413-y
Résumé Concern about global climate change is growing, and many projects and researchers are committed to reducing greenhouse gases from all possible sources. International Maritime Organization (IMO) has set a target of 20% CO2 reduction from shipping by 2020 and also presented a series of carbon emission reduction methods, which are known as Energy Efficiency Design Index (EEDI) and Energy Efficiency Operation Indicator (EEOI). Reviews on carbon emission reduction from all industries indicate that, Carbon Capture and Storage (CCS) is an excellent solution to global warming. In this paper, a comprehensive literature review of EEDI and EEOI and CCS is conducted and involves reviewing current policies, introducing common technologies, and considering their feasibilities for marine activities, mainly shipping. Current projects are also presented in this paper, thereby illustrating that carbon emission reduction has been the subject of attention from all over the world. Two case ship studies indicate the economic feasibility of carbon emission reduction and provide a guide for CCS system application and practical installation on ships.

RÉCUPÉRATION DES GAZ D'ENFOUISSEMENT

Intergovernmental panel on climate change's landfill methane protocol: Reviewing 20 years of application

Type Article de revue
Auteur M.J. Krause
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-85053404715&doi=10.1177%2f0734242X18793935&partnerID=40&md5=9ec7601535398f69c3be9c21978498cb
Volume 36
Numéro 9
Pages 827-840
Publication Waste Management and Research
Date 2018
DOI 10.1177/0734242X18793935

Résumé The Intergovernmental Panel on Climate Change (IPCC) protocol for predicting national methane emission inventories from landfills was published 22 years ago in the 1996 Revised Guidelines. There currently exists a broad dataset to review landfill parameters and reported values and their appropriateness in use and application in a range of site-specific, regional, and national estimates. Degradable organic carbon (DOC) content was found to range from 0.0105 to 0.65 g C/g waste, with an average of 0.166 g C/g waste. The fraction of DOC that would anaerobically degrade (DOC f) was reported to range from 50–83%, whereas higher and lower values have been experimentally determined for a variety of waste components, such as wood (0–50%) and food waste (50–75%). Where field validation occurred for the methane correction factor, values were substantially lower than defaults. The fraction of methane in anaerobic landfill gas (F) default of 50% is almost universally applied and is appropriate for cellulosic wastes. The methane generation rate constant (k) varied widely from 0.01 to 0.51 y^{-1}, representing half-lives from 1 to 69 years. Methane oxidation (OX) default values of 0 and 10% may be valid, but values greater than 30% have been reported for porous covers at managed sites. The IPCC protocol is a practical tool with uncertainties and limitations that must be addressed when used for purposes other than developing inventories. © The Author(s) 2018.

Low-carbon emission development in Asia: energy sector, waste management and environmental management system

Type Article de revue
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Auteur N.E. Mohammad Rozali
Auteur Y. Van Fan
Auteur J.J. Klemeš
Auteur S. Towprayoon
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-85044018910&doi=10.1007%2fs10098-018-1512-8&partnerID=40&md5=dcb8dd6adc4aa02e0bfc3b85e4ca0cc8
Volume 20
Numéro 3
Pages 443-449
Publication Clean Technologies and Environmental Policy
Date 2018
DOI 10.1007/s10098-018-1512-8

Résumé Mitigation of greenhouse gases (GHG) emissions is desirable without compromising the economic growth. This paper reviews the recent trends to mitigate GHG emissions in the key sectors of energy and solid waste. The energy sector is the key admitter for global GHG emissions, and a range of optimization and modelling tool has been developed to minimise the GHG emissions and overall cost, especially for the implementation of renewable energies such as biofuel and biogas. A few carbon sequestration technologies such as the carbon capture and storage (CCS) and biochar application have been reviewed.
The review included the challenges and knowledge gaps regarding the utilisation of CCS, such as the storage capacity, long-term policy framework, high costs and the potential risk. Although solid waste contributes about < 5% of the global GHG emissions, effective solid waste management remained a great challenge in many fast-growing cities in Asia. Considering the high organic portion (> 40%) in the municipal solid waste for many developing countries in Asia, composting has been proposed as a viable treatment technology to convert waste-to-wealth. A range of waste management tools, including scenario analyses on different waste technologies, optimisation of waste collection routes, multi-criteria decision tools, is reviewed to support the decision-making for solid waste management. A range of environmental management system (EMS) has been adopted by organisations to improve product quality, reducing production cost and improves reputation of firms. An environmental policy such as tax exemption could be helpful to promote the adoption of EMS that could be costly. CO_2 and material flow footprint tools, such as water–energy–materials nexus, are applicable at a city and regional level. The tools are used to mitigate GHG emissions by developing the mechanisms with shared markets of virtual resource flows (carbon, water, food, energy) between the trading partners regionally and internationally. © 2018, Springer-Verlag GmbH Germany, part of Springer Nature.

Development of adsorbents for CO_2 capture from waste materials: A review
Type Article de revue
Auteur M. Olivares-Marín
Auteur M.M. Maroto-Valer
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-84859779002&doi=10.1002%2fghg.45&partnerID=40&md5=b8f09a0925e8081e988362aec9a1b9c1
Volume 2
Numéro 1
Pages 20-35
Publication Greenhouse Gases: Science and Technology
Date 2012
DOI 10.1002/ghg.45

Résumé In recent years, a number of scientific papers have been published on the use of residues from industrial and agricultural operations to develop adsorbents for CO_2 capture at low, medium, and high temperatures. This is mainly because these waste materials are low-cost and abundant, and may contribute to a reduction of the total costs in carbon capture technologies. In addition, environmental concerns may also be addressed by developing strategies that can use
these waste materials instead of burning or sending them to landfills. This review analyses the recent progress made in the development of CO_2 adsorbents made from waste precursors. The different preparation approaches developed for the synthesis of adsorbents, including type of raw wastematerial, experimental methods, and further modifications, are reviewed. © 2012 Society of Chemical Industry and John Wiley & Sons, Ltd.

Biogas production - A review on composition, fuel properties, feed stock and principles of anaerobic digestion

Type Article de revue

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Volume 90
Pages 570-582
Publication Renewable & Sustainable Energy Reviews
ISSN 1364-0321
Date JUL 2018
Extra WOS:000434917700039
DOI 10.1016/j.rser.2018.03.093

Résumé In the prevailing scenario, the aberrant use of conventional fuels and the impact of greenhouse gases on the environment have leveraged the research efforts into renewable energy production from organic resources and waste. The global energy demand is high and most of the energy is produced from fossil resources. Recent studies refer the anaerobic digestion (AD) as alternative and efficient technology which combines biofuel production and sustainable waste management. There are different technological trends in biogas industry in order to enhance the production and the quality of biogas.

Nevertheless, the success of AD for further investments will rise from the low cost of feedstocks availability and the wide variety of usable forms of biogas (heating, electricity and fuel). Biogas, a combination of two-thirds of methane (CH4) and the rest is mostly carbon dioxide (CO2) with traces of hydrogen sulfide. The spent slurry from the produced biogas can be enriched to be utilized as manure for agricultural crop, promoting sustainable biomass production in the world. Biogas can be utilized to produce centralized or distributed power supply in rural and urban areas and are considered to be cost

beneficial. The aim of this review paper is to analyze various feedstocks, which are widely used all over the world. The working operations of anaerobic digestion process, current trends along with its merits and demerits are also discussed in order to draw more research and development towards producing a sustainable environment.

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Decentralized anaerobic digestion systems for increased utilization of biogas from municipal solid waste

Type Article de revue
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Auteur Saeid Baroutian
Volume 90
Pages 982-991
Publication Renewable & Sustainable Energy Reviews
ISSN 1364-0321
Date JUL 2018
Extra WOS:000434917700066
DOI 10.1016/j.rser.2018.03.009
Résumé Biogas may be able to compete favorably with cheaper fossil fuels for domestic purposes if anaerobic digestion systems are used for processing the organic fraction of municipal solid waste (OFMSW) in a decentralized manner and within an integrated solid waste management scheme. To harness this opportunity, this study reviews how a typical integrated solid waste management system (ISWM) may be reconfigured into one with lower operation costs and minimal GHG emissions. First, four literatures which conducted various environmental analyses on several ISWM scenarios for municipal solid waste
management were reviewed to determine which ISWM among them had the lowest quantity of greenhouse gas (GHG) emissions in CO(2)eq. Then, a simplified comparative economic analysis was conducted on the operation strategies of five different commercial solid-state anaerobic digestion (SS-AD) technologies. This economic analysis was then followed with frugal recommendations on how best an SS-AD system can be incorporated into the 'least GHG emitting' ISWM to lower the operational costs of the ISWM system. The final ISWM superstructure recommended by this study included a centralized section for commercial MSW waste, and a decentralized section primarily for residential MSW waste, and the superstructure was
recommended for densely poulated urban areas. Furthermore, the decentralized section of the ISWM superstructure included the collection of sourcesorted waste from households, decentralized storage for collected recyclables and digestate, and the sale of biogas exclusively as domestic cooking gas. Innovative design and operational modifications proposed for the decentralized SS-AD system were: modular and detachable digester cells for managing digester bed failure, and a vertical stacking design for achieving compactness and scalability for the digester.

AUTRES - GÉNÉRAL

Negative emissions - Part 1: Research landscape and synthesis
Type Article de revue
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Auteur F. Creutzig
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Auteur T. Khanna
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Auteur G. Luderer
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Auteur J. Rogelj
Auteur P. Smith
Auteur J.L. Vicente Vicente
Auteur J. Wilcox
Auteur M. Del Mar Zamora Dominguez
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-85049794304&doi=10.1088%2f1748-9326%2faabf9b&partnerID=40&md5=9fd6e88809ecb0c816e6ed0cae960c1b
Volume 13
Numéro 6
Publication Environmental Research Letters
Date 2018
DOI 10.1088/1748-9326/aabf9b
Résumé With the Paris Agreement's ambition of limiting climate change to well below 2 °C, negative emission technologies (NETs) have moved into the limelight of discussions in climate science and policy. Despite several assessments, the current knowledge on NETs is still diffuse and incomplete, but also growing fast. Here, we synthesize a comprehensive body of NETs literature, using scientometric tools and performing an in-depth assessment of the quantitative and qualitative evidence therein. We clarify the role of NETs in climate change mitigation scenarios, their ethical implications, as well as the challenges involved in bringing the various NETs to the market and scaling them up in time. There are six major findings arising from our assessment: first, keeping warming below 1.5 °C requires the large-scale deployment of NETs, but this dependency can still be kept to a minimum for the 2 °C warming limit. Second, accounting for economic and biophysical limits, we identify relevant potentials for all NETs except ocean fertilization. Third, any single NET is unlikely to sustainably achieve the large NETs deployment observed in many 1.5 °C and 2 °C mitigation scenarios. Yet, portfolios of multiple NETs, each deployed at modest scales, could be invaluable for reaching the climate goals. Fourth, a substantial gap exists between the upscaling and rapid diffusion of NETs implied in scenarios and progress in actual innovation and deployment. If NETs are required at the scales currently discussed, the resulting urgency of implementation is currently neither reflected in science nor policy. Fifth, NETs face severe barriers to

implementation and are only weakly incentivized so far. Finally, we identify distinct ethical discourses relevant for NETs, but highlight the need to root them firmly in the available evidence in order to render such discussions relevant in practice.

Negative emissions - Part 2: Costs, potentials and side effects
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Auteur J.V. Vicente
Auteur J. Wilcox
Auteur M. Del Mar Zamora Dominguez
Auteur J.C. Minx
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-85049271237&doi=10.1088%2f1748-9326%2faabf9f&partnerID=40&
md5=4c8980ad8eb3a0f0f2f014633f35f80c
Volume 13
Numéro 6
Publication Environmental Research Letters
Date 2018
DOI 10.1088/1748-9326/aabf9f
Résumé The most recent IPCC assessment has shown an important role for negative emissions technologies (NETs) in limiting global warming to 2 °C cost-effectively. However, a bottom-up, systematic, reproducible, and transparent literature assessment of the different options to remove CO2 from the atmosphere is currently missing. In part 1 of this three-part review on NETs, we assemble a comprehensive set of the relevant literature so far published, focusing on seven technologies: bioenergy with carbon capture and storage (BECCS), afforestation and reforestation, direct air carbon capture and storage (DACCS), enhanced weathering, ocean fertilisation, biochar, and soil carbon sequestration. In this part, part 2 of the review, we present estimates of costs, potentials, and side-effects for these technologies, and qualify them with the authors' assessment. Part 3 reviews the innovation and scaling challenges that must be addressed to realise NETs deployment as a viable climate mitigation strategy. Based on a systematic review of the literature, our best estimates for
sustainable global NET potentials in 2050 are 0.5-3.6 GtCO2 yr-1 for afforestation and reforestation, 0.5-5 GtCO2 yr-1 for BECCS, 0.5-2 GtCO2 yr-1 for biochar, 2-4 GtCO2 yr-1 for enhanced weathering, 0.5-5 GtCO2 yr-1 for DACCS, and up to 5 GtCO2 yr-1 for soil carbon sequestration. Costs vary widely across the technologies, as do their permanency and cumulative potentials beyond 2050. It is unlikely that a single

NET will be able to sustainably meet the rates of carbon uptake described in integrated assessment pathways consistent with 1.5 °C of global warming.

Negative emissions-Part 3: Innovation and upscaling

Type Article de revue
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Auteur Max W. Callaghan
Auteur Felix Creutzig
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Auteur Jens Hartmann
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Auteur William F. Lamb
Auteur Jan C. Minx
Auteur Sophia Rogers
Auteur Pete Smith
Volume 13
Numéro 6
Pages 063003
Publication Environmental Research Letters
ISSN 1748-9326
Date JUN 2018
Extra WOS:000432858900002
DOI 10.1088/1748-9326/aabff4
Résumé We assess the literature on innovation and upscaling for negative emissions technologies (NETs) using a systematic and reproducible literature coding procedure. To structure our review, we employ the framework of sequential stages in the innovation process, with which we code each NETs article in innovation space. We find that while there is a growing body of innovation literature on NETs, 59% of the articles are focused on the earliest stages of the innovation process, 'research and development' (R&D). The subsequent stages of innovation are also represented in the literature, but at much lower levels of activity than R&D. Distinguishing between innovation stages that are related to the supply of the technology (R&D, demonstrations, scale up) and demand for the technology (demand pull, niche markets, public acceptance), we find an overwhelming emphasis (83%) on the supply side. BECCS articles have an above average share of demand-side articles while direct air carbon capture and storage has a very low share. Innovation in NETs has much to learn from successfully diffused technologies; appealing to heterogeneous users, managing policy risk, as well as understanding and addressing public concerns are all crucial yet not well represented in the extant literature. Results from integrated assessment models show that while NETs play a key role in the second half of the 21st century for 1.5 degrees C and 2 degrees C scenarios, the major period of new NETs deployment is between 2030 and 2050. Given that the broader innovation literature consistently finds long time periods involved in scaling up and deploying novel technologies, there is an urgency to developing NETs that is largely unappreciated. This challenge is exacerbated by the thousands to millions of actors that potentially need to adopt these technologies for them to achieve planetary scale. This urgency is reflected neither in the Paris Agreement nor in most of the literature we review here. If NETs are to be deployed at the levels required to meet 1.5 degrees C and 2 degrees C targets, then important post-R&D issues will need to be addressed in the literature, including incentives for early deployment, niche markets, scale-up, demand, and-particularly if deployment is to be hastened public acceptance.

Negative emissions technologies and carbon capture and storage to achieve the Paris Agreement commitments

Type Article de revue

Auteur R. Stuart Haszeldine
Auteur Stephanie Flude
Auteur Gareth Johnson
Auteur Vivian Scott

Volume 376
Numéro 2119
Pages 20160447
Publication Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences
ISSN 1364-503X
Date MAY 13 2018
Extra WOS:000429046300003
DOI 10.1098/rsta.2016.0447

Résumé How will the global atmosphere and climate be protected? Achieving net-zero CO2 emissions will require carbon capture and storage (CCS) to reduce current GHG emission rates, and negative emissions technology (NET) to recapture previously emitted greenhouse gases. Delivering NET requires radical cost and regulatory innovation to impact on climate mitigation. Present NET exemplars are few, are at small-scale and not deployable within a decade, with the exception of rock weathering, or direct injection of CO2 into selected ocean water masses. To keep warming less than 2 degrees C, bioenergy with CCS (BECCS) has been modelled but does not yet exist at industrial scale. CCS already exists in many forms and at low cost. However, CCS has no political drivers to enforce its deployment. We make a new analysis of all global CCS projects and model the build rate out to 2050, deducing this is 100 times too slow. Our projection to 2050 captures just 700 Mt CO2 yr(-1), not the minimum 6000 Mt CO2 yr(-1) required to meet the 2 degrees C target. Hence new policies are needed to incentivize commercial CCS. A first urgent action for all countries is to commercially assess their CO2 storage. A second simple action is to assign a Certificate of CO2 Storage onto producers of fossil carbon, mandating a progressively increasing proportion of CO2 to be stored. No CCS means no 2 degrees C. This article is part of the theme issue 'The Paris Agreement: understanding the physical and social challenges for a warming world of 1.5 degrees C above pre-industrial levels'.

Carbon capture and storage (CCS): the way forward

Type Article de revue

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Auteur Andre Bardow
Auteur Edward J. Anthony
Auteur Andy Boston
Auteur Solomon Brown
Auteur Paul S. Fennell
Auteur Sabine Fuss
Auteur Amparo Galindo
Auteur Leigh A. Hackett
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Auteur Howard J. Herzog
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Auteur Paul Webley
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Numéro 5
Pages 1062-1176
Publication Energy & Environmental Science
ISSN 1754-5692
Date MAY 1 2018
Extra WOS:000432599100004
DOI 10.1039/c7ee02342a

Résumé Carbon capture and storage (CCS) is broadly recognised as having the potential to play a key role in meeting climate change targets, delivering low carbon heat and power, decarbonising industry and, more recently, its ability to facilitate the net removal of CO2 from the atmosphere. However, despite this broad consensus and its technical maturity, CCS has not yet been deployed on a scale commensurate with the ambitions articulated a decade ago. Thus, in this paper we review the current state-of-the-art of CO2 capture, transport, utilisation and storage from a multi-scale perspective, moving from the global to molecular scales. In light of the COP21 commitments to limit warming to less than 2 degrees C, we extend the remit of this study to include the key negative emissions technologies (NETs) of bioenergy with CCS

(BECCS), and direct air capture (DAC). Cognisant of the non-technical barriers to deploying CCS, we reflect on recent experience from the UK's CCS commercialisation programme and consider the commercial and political barriers to the large-scale deployment of CCS. In all areas, we focus on identifying and clearly articulating the key research challenges that could usefully be
addressed in the coming decade.

Links between energy usage and climate: implications on increasing CO2 emissions and carbon capture and storage

Type Article de revue

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Auteur Jyotirmoy Mallik

Volume 114

Numéro 7

Pages 1430-1437

Publication Current Science

ISSN 0011-3891

Date APR 10 2018

Extra WOS:000429353700023

DOI 10.18520/cs/v114/i07/1430-1437

Résumé Global climate change due to increase in greenhouse gases in the atmosphere resulting from persistent use of fossil fuels over the past century is one of the major challenges of the contemporary industrial world. The exploitation of natural resources including fossil fuels has not always been done in a sustainable way. One of its adverse effects, faced by our generation, is climate change. We must not only be alert to these changes, but also make necessary efforts to adopt scientific measures to combat their ill effects. The combustion of fossil fuels together with added emissions from cement production, and land use change result in net annual increase in CO2 in the atmosphere by 4 GtC. Scientists have clearly demonstrated the role of CO2 emission in global warming. Carbon capture and storage (CCS) is an advanced technology to capture CO2 from its source, isolate it from the atmosphere and store it typically in underground geological formations. We highlight the need to invest in obtaining cleaner energy from fossil fuels by implementing technologies like CCS along with technological advancements in renewables. We present here a review on the general debate around implementing CCS technology and dwell on some developments in India to understand if CCS will be effective in the future towards reducing the carbon footprint in our growing economy.

Waste biorefineries: Enabling circular economies in developing countries
Type Article de revue
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Auteur I. M. I. Ismail
Auteur Deepak Pant
Volume 241
Pages 1101-1117
Publication Bioresource Technology
ISSN 0960-8524
Date OCT 2017
Extra WOS:000405502400131
DOI 10.1016/j.biortech.2017.05.097
Résumé This paper aims to examine the potential of waste biorefineries in developing countries as a solution to current waste disposal problems and as facilities to produce fuels, power, heat, and value-added products. The waste in developing countries represents a significant source of biomass, recycled materials, chemicals, energy, and revenue if wisely managed and used as a potential feedstock in various biorefinery technologies such as fermentation, anaerobic digestion (AD), pyrolysis, incineration, and gasification. However, the selection or integration of biorefinery technologies in any developing country should be based on its waste characterization. Waste biorefineries if developed in developing countries could provide energy generation, land savings, new businesses and consequent job creation, savings of landfills costs, GHG emissions reduction, and savings of natural resources of land, soil, and groundwater. The challenges in route to successful implementation of biorefinery concept in the developing countries are also presented using life cycle assessment (LCA) studies.

Green conversion of municipal solid wastes into fuels and chemicals
Type Article de revue
Auteur Leonidas Matsakas
Auteur Qiuju Gao
Auteur Stina Jansson
Auteur Ulrika Rova
Auteur Paul Christakopoulos
Volume 26
Pages 69-83
Publication Electronic Journal of Biotechnology
ISSN 0717-3458
Date MAR 15 2017
Extra WOS:000397905100012
DOI 10.1016/j.ejbt.2017.01.004

Résumé Presently, the society is facing a serious challenge for the effective management of the increasing amount of produced municipal solid wastes. The accumulated waste has caused a series of environmental problems such as uncontrolled release of greenhouse gases. Moreover, the increasing amount of wastes has resulted in a shortage of areas available for waste disposal, resulting in a nonsustainable waste management. These problems led to serious public concerns, which in turn resulted in political actions aiming to reduce the amount of wastes reaching the environment. These actions aim to promote sustainable waste management solutions. The main objective of these policies is to promote the recycling of municipal solid waste and the conversion of waste to energy and valuable chemicals. These conversions can be performed using either biological (e.g., anaerobic digestion) or thermochemical processes (e.g., pyrolysis). Research efforts during the last years have been fruitful, and many publications demonstrated the effective conversation of municipal solid waste to energy and chemicals. These processes are discussed in the current review article together with the change of the waste policy that was implemented in the EU during the last years.

Biogas Management: Advanced Utilization for Production of Renewable Energy and Added-value Chemicals

Type Article de revue
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Auteur Grammatiki Goula
Volume 5
Pages 7
Publication Frontiers in Environmental Science
ISSN 2296-665X
Date 2017
Extra WOS:000458352900005
DOI 10.3389/fenvs.2017.00007
Résumé Biogas is widely available as a product of anaerobic digestion of urban, industrial, animal and agricultural wastes. Its indigenous local-base production offers the promise of a dispersed renewable energy source that can significantly contribute to regional economic growth. Biogas composition typically consists of 35-75% methane, 25-65% carbon dioxide, 1-5% hydrogen along with minor quantities of water vapor, ammonia, hydrogen sulfide and halides.
Current utilization for heating and lighting is inefficient and polluting, and, in the case of poor quality biogas ($CH4/CO2 < 1$), exacerbated by detrimental venting to the atmosphere. Accordingly, innovative and efficient strategies for improving the management and utilization of biogas for the production of sustainable electrical power or high added-value chemicals are highly desirable. Utilization is the focus of the present review in which the scientific and technological basis underlying alternative routes to the efficient and eco-friendly exploitation of biogas are described and discussed. After concisely reviewing state-of-the-art purification and upgrading methods, in-depth consideration is given to the exploitation of biogas in the renewable energy, liquid fuels, transport and chemicals sectors along with an account of potential impediments to further progress.

AUTRES – MARCHÉS POUR LE CO_2 OU UTILISATION POUR LE MÉTHANE

Potential application of high pressure carbon dioxide in treated wastewater and water disinfection: Recent overview and further trends

Type Article de revue

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URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-84943234800&doi=10.1016%2fj.jes.2015.04.006&partnerID=40&md5=5a012c2824263315862179b0c0add160
Volume 36
Pages 38-47
Publication Journal of Environmental Sciences (China)
Date 2015
DOI 10.1016/j.jes.2015.04.006

Résumé Recently emerging disadvantages in conventional disinfection have heightened the need for finding a new solution. Developments in the use of high pressure carbon dioxide for food preservation and sterilization have led to a renewed interest in its applicability in wastewater treatment and water disinfection. Pressurized CO 2 is one of the most investigated methods of antibacterial treatment and has been used extensively for decades to inhibit pathogens in dried food and liquid products. This study reviews the literature concerning the utility of CO 2 as a disinfecting agent, and the pathogen inactivation mechanism of CO 2 treatment is evaluated based on all available research. In this paper, it will be argued that the successful application and high effectiveness of CO 2 treatment in liquid foods open a potential opportunity for its use in wastewater treatment and water disinfection. The findings from models with different operating conditions (pressure, temperature, microorganism, water content, media ...) suggest that most microorganisms are
successfully inhibited under CO 2 treatment. It will also be shown that the bacterial deaths under CO 2 treatment can be explained by many different mechanisms. Moreover, the findings in this study can help to address the recently emerging problems in water disinfection, such as disinfection by-products (resulting from chlorination or ozone treatment). © 2015.

Review of methane mitigation technologies with application to rapid release of methane from the arctic

Type Article de revue

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Auteur C.A. Smith
Auteur W.L. Bourcier
Auteur P.J. Cameron-Smith
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URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-84862515336&doi=10.1021%2fes204686w&partnerID=40&md5=7ea922db4249144160a2d8e1a69b8741
Volume 46
Numéro 12
Pages 6455-6469
Publication Environmental Science and Technology
Date 2012
DOI 10.1021/es204686w

Résumé Methane is the most important greenhouse gas after carbon dioxide, with particular influence on near-term climate change. It poses increasing risk in the future from both direct anthropogenic sources and potential rapid release from the Arctic. A range of mitigation (emissions control) technologies have been developed for anthropogenic sources that can be developed for further application, including to Arctic sources. Significant gaps in understanding remain of the mechanisms, magnitude, and likelihood of rapid methane release from the Arctic. Methane may be released by several pathways, including lakes, wetlands, and oceans, and may be either uniform over large areas or concentrated in patches. Across Arctic sources, bubbles originating in the sediment are the most important mechanism for methane to reach the atmosphere. Most known technologies operate on confined gas streams of 0.1% methane or more, and may be applicable to limited Arctic sources where methane is concentrated in pockets. However, some mitigation strategies developed for rice paddies and agricultural soils are promising for Arctic wetlands and thawing permafrost. Other mitigation strategies specific to the Arctic have been proposed but have yet to be studied. Overall, we identify four avenues of research and development that can serve the dual purposes of addressing current methane sources and potential Arctic sources: (1) methane release detection and quantification, (2) mitigation units for small and remote methane streams, (3) mitigation methods for dilute (<1000 ppm) methane streams, and (4) understanding methanotroph and methanogen ecology. (Figure Presented).

Carbon capture and utilization technologies: a literature review and recent advances
Type Article de revue
Auteur Francisco M. Baena-Moreno
Auteur Monica Rodriguez-Galan
Auteur Fernando Vega
Auteur Bernabe Alonso-Farinas
Auteur Luis F. Vilches Arenas
Auteur Benito Navarrete
Volume 41
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Pages 1403-1433
Publication Energy Sources Part a-Recovery Utilization and Environmental Effects
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Date JUN 18 2019
Extra WOS:000456008200001
DOI 10.1080/15567036.2018.1548518
Résumé This paper presents a comprehensive list of Carbon Capture and Utilization technologies and applications, ranging from lab-scale R&D activities reported in academic papers to commercially established uses of carbon dioxide. Carbon dioxide, as a source of carbon, has the potential to be used as a solvent, as a raw material in the manufacturing of fuels, carbonates, polymers, and chemicals, or as a recovery agent in techniques such as enhanced oil recovery or enhanced coal bed methane. In this paper, a literature review and recent advances of each technology are explained. To finish, most relevant Life Cycle Assessment studies carried out by experts in this field are included. Among the different alternatives studied for the use of carbon dioxide, the processes of carboxylation, consisting the synthesis of carbonates and carboxylates, have stood out. Both the production of salicylic acid as well as that of dimethyl carbonate and mineral carbonation are presented as the most likely applications of carbon dioxide, at least, in the short term.

Carbon Dioxide Captured by Metal Organic Frameworks and Its Subsequent Resource Utilization Strategy: A Review and Prospect
Type Article de revue
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Auteur Leilei Xu
Auteur Mindong Chen
Auteur Cai-e Wu
Auteur Wenjing Li
Auteur Bingbo Huang
Auteur Yan Cui
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Extra WOS:000458411600002
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Résumé The carbon dioxide (CO_2) is notorious as the greenhouse gas, which could cause the global warming and climate change. Therefore, the reduction of the atmospheric CO_2 emissions from power plants and other industrial facilities has become as an increasingly urgent concern. In the recent years, CO_2 capture and storage technologies have received a worldwide attention. Adsorption is considered as one of the efficient options for CO_2 capture because of its cost advantage, low energy requirement and extensive applicability over a relatively wide range of temperature and pressure. The metal organic frameworks (MOFs) show widely potential application prospects in CO_2 capture and storage owing to their outstanding textural properties, such as the extraordinarily high specific surface area, tunable pore size, ultrahigh porosity (up to 90%), high crystallinity, adjustable internal surface properties, and controllable structure. Herein, the most important research progress of MOFs materials on the CO_2 capture and storage in recent years has been comprehensively reviewed. The extraordinary characteristics and CO_2 capture performance of Zeolitic Imidazolate Frameworks (ZIFs), Bio-metal organic frameworks (bio-MOFs), IL@MOFs and MOF-composite materials were highlighted. The promising strategies for improving the CO_2 adsorption properties of MOFs materials, especially the low-pressure adsorption performance under actual flue gas conditions, are also carefully summarized. Besides, CO_2 is considered as an abundant, nontoxic, nonflammable, and renewable C1 resource for the synthesis of useful chemicals and fuels. The potential routes for resource utilization of the captured CO_2 are briefly proposed.

Policies and Motivations for the CO2 Valorization through the Sabatier Reaction Using Structured Catalysts. A Review of the Most Recent
Advances
Type Article de revue
Auteur Juan C. Navarro
Auteur Miguel A. Centeno
Auteur Oscar H. Laguna
Auteur Jose A. Odriozola
Volume 8
Numéro 12
Pages 578
Publication Catalysts
ISSN 2073-4344
Date DEC 2018
Extra WOS:000454711500010
DOI 10.3390/catal8120578
Résumé The current scenario where the effects of global warming are more and more evident, has motivated different initiatives for facing this, such as the creation of global policies with a clear environmental guideline. Within these policies, the control of Greenhouse Gase (GHG) emissions has been defined as mandatory, but for carrying out this, a smart strategy is proposed. This is the application of a circular economy model, which seeks to minimize the generation of waste and maximize the efficient use of resources. From this point of view, CO_2 recycling is an alternative to reduce emissions to the atmosphere, and we need to look for new business models which valorization this compound which now must be considered as a renewable carbon source. This has renewed the interest in known processes for the chemical transformation of CO_2 but that have not been applied at industrial level because they do not offer evident profitability. For example, the methane produced in the Sabatier reaction has a great potential for application, but this depends on the existence of a sustainable supply of hydrogen and a greater efficiency during the process that allows maximizing energy efficiency and thermal control to maximize the methane yield. Regarding energy efficiency and thermal control of the process, the use of

structured reactors is an appropriate strategy. The evolution of new technologies, such as 3D printing, and the consolidation of knowledge in the structing of catalysts has enabled the use of these reactors to develop a wide range of possibilities in the field. In this sense, the present review presents a brief description of the main policies that have motivated the transition to a circular economy model and within this, to CO2 recycling. This allows understanding, why efforts are being focused on the development of different reactions for CO2 valorization. Special attention to the case of the Sabatier reaction and in the application of structured reactors for such process is paid.

Mechanical activation of magnesium silicates for mineral carbonation, a review

Type Article de revue
Auteur Jiajie Li
Auteur Michael Hitch
Volume 128
Pages 69-83
Publication Minerals Engineering
ISSN 0892-6875
Date NOV 2018
Extra WOS:000447109700007
DOI 10.1016/j.mineng.2018.08.034

Résumé Mechanical activation is one of the most efficient pretreatment methods used to accelerate the reaction rate in the mineral carbonation technology. This paper reviews the current research related to this technique with a specific focus on three types of magnesium silicates - olivine and serpentine, and partially serpentinized olivine. First, the effects of mechanical activation on magnesium silicates are listed and compared with regard to a variety of milling conditions, including diverse energy inputs, grinding aids and mill types. Then, the existing literature determines the extents of mechanical activation, reviewed with respect to downstream carbonation processes, including direct gas/solid carbonation, direct aqueous carbonation, indirect aqueous carbonation, and indirect solid/solid mechanochemical carbonation. Finally, suggestions are made for further study on applying mechanical activation in an integrated mineral carbonation process, in order to lower the energy consumption of commercial systems.

Holistic Assessment of Carbon Capture and Utilization Value Chains

Type Article de revue
Auteur Tryfonas Pieri
Auteur Alexandros Nikitas
Auteur Arturo Castillo-Castillo
Auteur Athanasios Angelis-Dimakis
Volume 5
Numéro 10
Pages 108
Publication Environments
ISSN 2076-3298
Date OCT 2018
Extra WOS:000448546500002
DOI 10.3390/environments5100108

Résumé Carbon capture and utilization (CCU) is recognized by the European Union, along with carbon, capture and storage (CCS), as one of the main tools towards global warming mitigation. It has, thus, been extensively studied by various researchers around the world. The majority of the papers published so far

focus on the individual stages of a CCU value chain (carbon capture, separation, purification, transportation, and transformation/utilization). However, a holistic approach, taking into account the matching and the interaction between these stages, is also necessary in order to optimize and develop technically and economically feasible CCU value chains. The objective of this contribution is to present the most important studies that are related to the individual stages of CCU and to perform a critical review of the major existing methods, algorithms and tools that focus on the simulation or optimization of CCU value chains. The key research gaps will be identified and examined in order to lay the foundation for the development of a methodology towards
the holistic assessment of CCU value chains.

Advances in CO2 utilization technology: A patent landscape review

Type Article de revue
Auteur R. S. Norhasyima
Auteur T. M. I. Mahlia
Volume 26
Pages 323-335
Publication Journal of Co2 Utilization
ISSN 2212-9820
Date JUL 2018
Extra WOS:000439069700034
DOI 10.1016/j.jcou.2018.05.022
Résumé There is rising concern on the increasing trend of global warming due to anthropogenic CO2 emission which steers progress of carbon capture and storage (CCS) projects worldwide. However, due to high cost and uncertainties in long term geological storage, there is a growing inclination to include utilization, which re-use the CO2, hence carbon capture utilization and storage (CCUS). Additionally, it is expected to generate income to offset the initial costs. This
study methodically review patents on CO2 utilization technologies for CCUS application published between year 1980-2017. It was conducted using the Derwent Innovation patent database and more than 3000 number of patents was identified. The patents identified are in the field of enhanced oil recovery (EOR) and enhanced coal-bed methane (ECBM), chemical and fuel, mineral carbonation, biological algae cultivation and enhanced geothermal system (EGS). Over 60% of these patents were published since the last 10 years, and a sharp increase in patents were seen in the last 5 years (similar to 38%). The
top major patent types are patents granted in the United States (US), China (CN) and Canada (CA) which makes of 3/5 of the overall patent type found. Recent patents published include enhancements to the state-of-the-art technologies and hybrid concepts such as in photo-bioreactor in algae cultivation, chemical reaction and EGS. From this study, it was found that further research for the best CO2 utilization method which fulfil the need of an economic, safe, non-location dependent and environmentally friendly whilst efficiently mitigate the worldwide global warming issue is much needed.

A review of gas separation technologies within emission reduction programs in the iron and steel sector: Current application and development perspectives

Type Article de revue
Auteur Alvaro A. Ramirez-Santos
Auteur Christophe Castel
Auteur Eric Favre
Volume 194

Pages 425-442
Publication Separation and Purification Technology
ISSN 1383-5866
Date APR 3 2018
Extra WOS:000425072100050
DOI 10.1016/j.seppur.2017.11.063
Résumé Worldwide steel production is still mainly achieved from primary manufacturing by carbon-intensive processes in integrated steel mills, making this industry the first in terms of direct CO_2 emissions. Both carbon capture and storage (CCS) and carbon capture and utilization (CCU) approaches are currently considered to offer a solution to the high carbon-footprint of primary steel production. Design of available or development of new gas separationpurification
technologies are at the heart of these strategies, and often represent the largest share of the total project cost. This work presents the current state of development of the main technologies that have shown potential thus far at pilot or industrial scale for the treatment of gases within the steelmaking industry. An analysis of the opportunities and limitations of each technology is presented, related to their ability to separate existing gas streams into the two main carbon-bearing species, CO_2 and CO. Recovery of H-2, available in important quantities, is also considered. Main results from previous and ongoing research are presented and analyzed to draw a picture of the current situation, and offer key points for future development.

Integrated Mineral Carbonation of Ultramafic Mine Deposits-A Review

Type Article de revue
Auteur Jiajie Li
Auteur Michael Hitch
Auteur Ian M. Power
Auteur Yueyi Pan
Volume 8
Numéro 4
Pages 147
Publication Minerals
ISSN 2075-163X
Date APR 2018
Extra WOS:000434883100027
DOI 10.3390/min8040147
Résumé Recently, integrated mineral carbonation for CO_2 sequestration has received significant attention due to the high potential for commercialization towards mitigating climate change. This review compiles the work conducted by various researchers over the last few years on integrated mineral carbonation processes in the mining industry, which use ultramafic mine wastes as feedstock for mineral carbonation. Here, we introduce the basic concepts of mineral
carbonation including a brief description of the process routes and pre-treatment techniques. We discuss the scope of integrated mineral carbonation process application, and critically review the integrated mineral carbonation process in the mining industry including modified passive carbonation techniques in tailing storage facilities, and ex-situ carbonation routes using fresh tailings. The focus of the discussions is the role of reaction condition on
the carbonation efficiency of mine waste with various mineralogical compositions, and the benefits and drawbacks of each integrated mineral carbonation process. All discussions lead to suggestions for the technological improvement of integrated mineral carbonation. Finally, we review the techno-economic

assessments on existing integrated mineral carbonation technologies. Research to date indicates that value-added by-products will play an important role in the commercialization of an integrated mineral carbonation process.

Technologies and infrastructures underpinning future CO2 value chains: A comprehensive review and comparative analysis

Type Article de revue
Auteur Sean M. Jarvis
Auteur Sheila Samsatli
Volume 85
Pages 46-68
Publication Renewable & Sustainable Energy Reviews
ISSN 1364-0321
Date APR 2018
Extra WOS:000428614200003
DOI 10.1016/j.rser.2018.01.007

Résumé In addition to carbon capture and storage, efforts are also being focussed on using captured CO2, both directly as a working fluid and in chemical conversion processes, as a key strategy for mitigating climate change and achieving resource efficiency. These processes require large amounts of energy, which should come from sustainable and, ideally, renewable sources. A strong value chain is required to support the production of valuable products from CO2. A value chain is a network of technologies and infrastructures (such as conversion, transportation, storage) along with its associated activities (such as sourcing raw materials, processing, logistics, inventory management, waste management) required to convert low-value resources to high-value products and energy services, and deliver them to customers. A CO2 value chain involves production of CO2 (involving capture and purification), technologies that convert CO2 and other materials into valuable products, sourcing of low-carbon energy to drive all of the transformation processes required to convert CO2 to products (including production of hydrogen, syngas, methane etc.), transport of energy and materials to where they are needed, anaging inventory levels of resources, and delivering the products to customers, all in order to create value (economic, environmental, social etc.). Technologies underpinning future CO2 value chains were examined. CO2 conversion technologies, such as urea production, Sabatier synthesis, Fischer-Tropsch synthesis, hydrogenation to methanol, dry reforming, hydrogenation to formic acid and electrochemical reduction, were assessed and compared based on key performance indicators such as: CAPEX, OPEX, electricity consumption, TRL, product price, net CO2 consumption etc. Technologies for
transport and storage of key resources are also discussed. This work lays the foundation for a comprehensive whole-system value chain analysis, modelling and optimisation.

Development of CO2 Selective Poly(Ethylene Oxide)-Based Membranes: From Laboratory to Pilot Plant Scale

Type Article de revue
Auteur Torsten Brinkmann
Auteur Jelena Lillepaerg
Auteur Heiko Notzke
Auteur Jan Pohlmann
Auteur Sergey Shishatskiy
Auteur Jan Wind
Auteur Thorsten Wolff

Volume 3
Numéro 4
Pages 485-493
Publication Engineering
ISSN 2095-8099
Date AUG 2017
Extra WOS:000414165100011
DOI 10.1016/J.ENG.2017.04.004
Résumé Membrane gas separation is one of the most promising technologies for the separation of carbon dioxide (CO2) from various gas streams. One application of this technology is the treatment of flue gases from combustion processes for the purpose of carbon capture and storage. For this application, poly(ethylene oxide)-containing block copolymers such as Pebax r or PolyActive T polymer are well suited. The thin-film composite membrane that is considered in this overview employs PolyActive T polymer as a selective layer material. The membrane shows excellent CO2 permeances of up to 4
m(3)(STP) . (m(2) . h bar)(-1) (1 bar = 105 Pa) at a carbon dioxide/nitrogen (CO2/N-2) selectivity exceeding 55 at ambient temperature. The membrane can be manufactured reproducibly on a pilot scale and mounted into flat-sheet membrane modules of different designs. The operating performance of these modules can be accurately predicted by specifically developed simulation tools, which employ single-gas permeation data as the only experimental input. The performance of membranes and modules was investigated in different pilot plant studies, in which flue gas and biogas were used as the feed gas streams. The investigated processes showed a stable separation performance, indicating the applicability of PolyActive T polymer as a membrane material for industrial-scale gas processing.

Carbon Dioxide Dynamics and Sequestration in Mine Water and Waste
Type Article de revue
Auteur Natalie A. Kruse
Auteur William H. J. Strosnider
Volume 34
Numéro 1
Pages 3-9
Publication Mine Water and the Environment
ISSN 1025-9112
Date MAR 2015
Extra WOS:000349889500002
DOI 10.1007/s10230-014-0320-6
Résumé The role and importance of CO2 in the mining sector has been overlooked until relatively recently. This review presents the complexities of CO2 and mine water evolution. Carbon sequestration using mine waters and solid wastes and recent research on the profound impacts of dissolved CO2 on active and passive treatment were reviewed. The literature indicates great promise for more efficient and fiscally competitive operations, lower environmental impacts, and a decreased carbon footprint for such operations. However, a tremendous amount of research and field testing is necessary to move many of these approaches forward to full scale common application.

Carbohydrate-to-hydrogen production technologies: A mini-review
Type Article de revue
Auteur Kamlesh Sharma
Volume 105
Pages 138-143
Publication Renewable & Sustainable Energy Reviews
ISSN 1364-0321
Date MAY 2019
Extra WOS:000460121000011
DOI 10.1016/j.rser.2019.01.054
Résumé Hydrogen is a promising future with high-energy utilization efficiency and a clean energy carrier featuring lower emissions of pollutants as compared to the liquid fuels used in internal combustion engines. Hydrogen fuel production from renewable biomass carbohydrates has a better future perspective as it achieves zero CO2 emissions lifecycle and hence will reduce global warming, acid rain and improve rural economy. Herein, we present H-2 production from biomass carbohydrates by using different types of catalysis such chemical catalysis, biocatalysis, and their combinations. The chemical catalysis
includes aqueous phase reforming, pyrolysis, gasification, and gasification in supercritical water. The biocatalysis includes electrohydrogenesis, anaerobic fermentation, photo-fermentation, cell-free synthetic pathway biotransformation (cell-free SyPaB). Since, energy efficiency or hydrogen yield is the most critical economic factor for H-2 production, cell-free SyPaB which can produce 12H(2) / glucose equivalent appears to be a potential solution for H-2
production. In addition, the pathway design of cell-free SyPaB has several advantages such as use of availability of stable enzymes and coenzymes building blocks, less expensive bioreactors, modest reaction conditions, acceptable reaction rates, metabolic load balancing, in-situ monitoring, absence of cell membrane, real-time control, and reduced toxicity effects. Along with all these advantages, cell-free SyPaB addresses few more challenges associated with costly infrastructure, distribution, storage and safety.

Recent progress in carbon dioxide (CO2) as feedstock for sustainable materials development: Co-polymers and polymer blends

Type Article de revue
Auteur Rajendran Muthuraj
Auteur Tizazu Mekonnen
Volume 145
Pages 348-373
Publication Polymer
ISSN 0032-3861
Date JUN 6 2018
Extra WOS:000433147700035
DOI 10.1016/j.polymer.2018.04.078

Résumé Combustion of fossil fuels and many other industrial activities inevitably produces carbon dioxide (CO2) that is released into the atmosphere and is currently deemed to be among the major contributors to global warming. One of the prominent solutions proposed to mitigate global warming concerns from CO2, capture and storage (CCS), did not attract many CO2 emitting industries as expected, mainly because of economic reasons. On the contrary, environmental pollution concerns associated with plastic waste, and the demand for sustainable feedstock for their production constitute grand challenges

facing our society with regard to the production and use of plastics. As a result, the materials science community is striving to generate sustainable and biodegradable plastics to substitute conventional synthetic plastics from resources that do not pose direct completion with food production. This manuscript aims to provide a general overview of the recent progress achieved in CO2 based polymers for sustainable biopolymers such as co-polymers, and polymer blends. The synthesis, material properties, processability, and performances of important CO2 based co-polymers are critically reviewed.

Furthermore, a critical review of CO2 co-polymers as components of polymer blend with a focus on the most relevant CO2 based aliphatic polycarbonates, poly (propylene carbonates) (PPC), is conducted. (C) 2018 Elsevier Ltd. All rights reserved.

Mitigating Methane: Emerging Technologies To Combat Climate Change's Second Leading Contributor

Type Article de revue
Auteur Chris Pratt
Auteur Kevin Tate
Volume 52
Numéro 11
Pages 6084-6097
Publication Environmental Science & Technology
ISSN 0013-936X
Date JUN 5 2018
Extra WOS:000434892900003
DOI 10.1021/acs.est.7b04711

Résumé Methane (CH4) is the second greatest contributor to anthropogenic climate change. Emissions have tripled since preindustrial times and continue to rise rapidly, given the fact that the key sources of food production, energy generation and waste management, are inexorably tied to population growth. Until recently, the pursuit of CH4 mitigation approaches has tended to align with opportunities for easy energy recovery through gas capture and flaring. Consequently, effective abatement has been largely restricted to confined high concentration sources such as landfills and anaerobic digesters, which do not represent a major share of CH4's emission profile. However, in more recent years we have witnessed a

quantum leap in the sophistication, diversity and affordability of CH4 mitigation technologies on the back of rapid advances in molecular analytical techniques, developments in material sciences and increasingly efficient engineering processes. Here, we present some of the latest concepts, designs and applications in CH4 mitigation, identifying a number of abatement synergies across multiple industries and sectors. We also propose novel ways to manipulate cutting-edge technology approaches for even more effective mitigation potential. The goal of this review is to stimulate the ongoing quest for and uptake of practicable CH4 mitigation options; supplementing established and proven approaches with immature yet potentially high-impact technologies. There has arguably never been, and if we do not act soon nor will there be, a better opportunity to combat climate change's second most significant greenhouse gas.

Synthesis of Urea Derivatives using Carbon Dioxide as Carbonylation Reagent in Ionic Liquids
Type Article de revue
Auteur Xing He
Auteur Xiao-Ya Li
Auteur Yu Song
Auteur Shu-Mei Xia
Auteur Xian-Dong Lang
Auteur Liang-Nian He
Volume 4
Numéro 2
Pages 112-121
Publication Current Organocatalysis
ISSN 2213-3372
Date 2017
Extra WOS:000423974000003
DOI 10.2174/2213337204666171101142906
Résumé Urea and its derivatives, which are usually generated through the carbonylation reaction between amines and carbonylation reagent, have been found widespread applications in agriculture and pharmaceuticals. Among the carbonylation reaction, it is the most appealing and promising strategy that employs CO2 as a green carbonylation reagent. However, CO2 inherent thermodynamic stability and kinetic inertness limit its application. Apart from being regarded as one of the green solvents, ionic liquid is also an efficient organocatalyst for CO2 capture or activation due to the interaction between
CO2 with cation or anion of ionic liquid. In this mini-review, we have summarized representative synthetic methodologies of urea derivatives using carbon dioxide as a green carbonylation reagent and using ionic liquids as solvents and/or organocatalysts.

Review: recent advances in biogas purifying technologies
Type Article de revue
Auteur F.M. Baena-Moreno
Auteur M. Rodríguez-Galán
Auteur F. Vega
Auteur L.F. Vilches
Auteur B. Navarrete
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-85061046712&doi=10.1080%2f15435075.2019.1572610&partnerID=40&md5=ed258ff8c52613f60606c68f718d7f94
Volume 16

Numéro 5
Pages 401-412
Publication International Journal of Green Energy
Date 2019
DOI 10.1080/15435075.2019.1572610
Résumé Biomethane production through biogas upgrading is a promising renewable energy for some industries which could be part of the equilibrium needed with fossil fuels consumption to achieve a sustainable society. This paper presents a comprehensive list of biogas upgrading technologies focused on carbon dioxide removal as well as recent advances reported by researcher with wide expertise in this topic. Additionally, an extensive costs–performance comparison among the technologies studied is discussed. Among the different alternatives, chemical scrubbing stood out to achieve high biomethane purities while cryogenic technologies proved to be effective against methane losses. Regarding the different costs, water scrubbing and membrane separation seem to be the most affordable techniques. © 2019, © 2019 Taylor & Francis Group, LLC.

Hydrogen production with CO2 capture

Type Article de revue
Auteur M. Voldsund
Auteur K. Jordal
Auteur R. Anantharaman
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-85027943690&doi=10.1016%2fj.ijhydene.2016.01.009&partnerID=40&md5=4ea99013f4eeb213821265cb47cbcab4
Volume 41
Numéro 9
Pages 4969-4992
Publication International Journal of Hydrogen Energy
Date 2016
DOI 10.1016/j.ijhydene.2016.01.009
Résumé In view of the abundance of fossil fuels, hydrogen production with CO2 capture could be a key transition technology for moving in the direction of a sustainable hydrogen-using society. An overview of technologies for hydrogen production from fossil fuels with CO2 capture is provided in this paper: reforming or gasification with subsequent gas separation by adsorption, absorption, membranes or cryogenic/low-temperature separation; process routes with integrated syngas production and gas separation by water-gas shift membrane reactors, reformer membrane reactors, sorption-enhanced water-gas shift and sorption-enhanced reforming; and processes utilizing the concept of chemical looping. Furthermore, purity requirements for the produced CO2 and hydrogen are reviewed. Few technologies exist that can produce both high-purity hydrogen and CO2 at transport quality simultaneously, and the few possible approaches are maximum on the pilot stage. Producing hydrogen from fossil fuels, while capturing the CO2 for transport and storage is therefore a matter of matching hydrogen and CO2 separation technologies in a best possible manner, taking into account the planned transport option for the CO2 and
the way in which the hydrogen will be used. Hydrogen production with CO2 capture can potentially lead to large CO2 emission reductions in eg. Transport sector. Copyright © 2016 Hydrogen Energy Publications, LLC.

Removal of non-CO 2 greenhouse gases by large-scale atmospheric solar photocatalysis

Type Article de revue

Auteur R. de Richter
Auteur T. Ming
Auteur P. Davies
Auteur W. Liu
Auteur S. Caillol

URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-85010416802&doi=10.1016%2fj.pecs.2017.01.001&partnerID=40&md5=df2ce1d3316fc2016fb602045159e3c0
Volume 60
Pages 68-96
Publication Progress in Energy and Combustion Science
Date 2017
DOI 10.1016/j.pecs.2017.01.001

Résumé Large-scale atmospheric removal of greenhouse gases (GHGs) including methane, nitrous oxide and ozone-depleting halocarbons could reduce global warming more quickly than atmospheric removal of CO 2. Photocatalysis of methane oxidizes it to CO 2, effectively reducing its global warming potential (GWP) by at least 90%. Nitrous oxide can be reduced to nitrogen and oxygen by photocatalysis; meanwhile halocarbons can be mineralized by red-ox photocatalytic reactions to acid halides and CO 2. Photocatalysis avoids the need for capture and sequestration of these atmospheric components. Here review an unusual hybrid device combining photocatalysis with carbon-free electricity with no-intermittency based on the solar updraft chimney. Then we review experimental evidence regarding photocatalytic transformations of non-CO 2 GHGs. We propose to combine TiO 2 -photocatalysis with solar chimney power plants (SCPPs) to cleanse the atmosphere of non-CO 2 GHGs. Worldwide installation of 50,000 SCPPs, each of capacity 200 MW, would generate a cumulative 34 PWh of renewable electricity by 2050, taking into account construction time. These SCPPs equipped with photocatalyst would process 1 atmospheric volume each 14–16 years, reducing or stopping the atmospheric growth rate of the non-CO 2 GHGs and progressively reducing their atmospheric concentrations. Removal of methane, as compared to other GHGs, has enhanced efficacy in reducing radiative forcing because it liberates more ° OH radicals to accelerate the cleaning of the troposphere. The overall reduction in non-CO 2 GHG concentration would help to limit global temperature rise. By physically linking greenhouse gas removal to renewable electricity generation, the hybrid concept would avoid the moral hazard associated with most other climate engineering proposals.

GÉOINGÉNIERIE

Aaheim, A., Romstad, B., Wei, T.Y., Kristjansson, J.E., Muri, H., Niemeier, U., Schmidt, H., 2015. **An economic evaluation of solar radiation management.** Sci. Total Environ. 532, 61-69. doi:10.1016/j.scitotenv.2015.05.106.
Economic evaluations of solar radiation management (SRM) usually assume that the temperature will be stabilized, with no economic impacts of climate change, but with possible side-effects. We know from experiments with climate models, however, that unlike emission control the spatial and temporal distributions of temperature, precipitation and wind conditions will change. Hence, SRM may have economic consequences under a stabilization of global mean temperature even if side-effects other than those related to the climatic responses are disregarded. This paper addresses the economic impacts of implementing two SRM technologies; stratospheric sulfur injection and marine cloud brightening. By the use of a computable general equilibrium model, we estimate the economic impacts of climatic responses based on the results from two earth system models, MPI-ESM and NorESM. We find that under a moderately increasing greenhouse-gas concentration path, RCP4.5, the economic benefits of implementing climate engineering are small, and may become negative. Global GDP increases in three of the four experiments and all experiments include regions where the benefits from climate engineering are negative.

Adelman, S., 2017. **Geoengineering: Rights, risks and ethics.** Journal of Human Rights and the Environment 8, 119-138. doi:10.4337/jhre.2017.01.06.
This article discusses arguments that manipulating the Earth's climate may provoke unforeseen, unintended and uncontrollable consequences that threaten human rights. The risks arise from both main types of geoengineering: solar radiation management (SRM) techniques and carbon dioxide removal (CDR). SRM creates particular risks because it is difficult to test on a wide scale and may not be capable of being recalled after deployment. Adequate, enforceable governance structures do not currently exist to assess and regulate the risks of climate engineering, not least whether such technologies can be terminated in the absence of significant emissions reductions. This article is divided into six sections. After the opening introductory section, section 2 discusses the links between climate change and human rights. It briefly outlines the range of rights, including procedural rights, that might be violated by geoengineering. This is followed, in section 3, by an evaluation of the risks of SRM and CDR. The fourth section discusses debates on the ethics of geoengineering. Section 5 critiques hubristic faith in technological solutions. The final section examines the governance of geoengineering and the extent to which international environmental law and human rights law might be used to regulate the research and deployment of geoengineering.

Amelung, D., Funke, J., 2015. **Laypeople's risky decisions in the climate change context: Climate engineering as a risk-defusing strategy?** Human and Ecological Risk Assessment 21, 533-559. doi:10.1080/10807039.2014.932203.
This study explores the development of laypeople's preferences for newly emerging climate engineering technology (CE). It examines whether laypeople perceive CE to be an acceptable back-up strategy (plan B) if current efforts to mitigate CO_2 emissions were to fail. This idea is a common justification for CE research in the scientific debate and may significantly influence future public debates. Ninety-eight German participants chose their preferred climate policy strategy in a quasi-realistic scenario. Participants could chose between mitigation and three CE techniques as alternative options. We employed a think-aloud interview technique, which allowed us to trace participants' informational needs and thought processes.

Drawing on Huber's risk management decision theory, the study addressed whether specific CE options are more likely to be accepted if they are mentally represented as a back-up strategy. Results support this assumption, especially for cloud whitening. This result is especially relevant considering the high prevalence of the plan B framing in CE appraisal studies and its implications for public opinion-formation processes.

Baatz, C., 2016. **Can we have it both ways? On potential trade-offs between mitigation and solar radiation management.** Environmental Values 25, 29-49. doi:10.3197/096327115x14497392134847.
Many in the discourse on climate engineering agree that if deployment of solar radiation management (SRM) technologies is ever permissible, then it must be accompanied by far-reaching mitigation of greenhouse gas (GHG) emissions. This raises the question of if and how both strategies interact. Although raised in many publications, there are surprisingly few detailed investigations of this important issue. The paper aims at contributing to closing this research gap by (i) reconstructing moral hazard claims to clarify their aim, (ii) offering one specific normative justification for far-reaching mitigation and (iii) investigating in greater detail different mechanisms that could potentially cause a trade-off between mitigation and SRM. I conclude that the empirical evidence questioning the trade-off hypothesis is inconclusive. Moreover, theoretical reflections as well as economic model studies point to a trade-off. In our current epistemic situation these findings must be taken seriously. They caution against researching and developing SRM technologies before measures to avoid or minimise a trade-off are implemented.

Bataille, C., Åhman, M., Neuhoff, K., Nilsson, L.J., Fischedick, M., Lechtenböhmer, S., Solano-Rodriquez, B., Denis-Ryan, A., Stiebert, S., Waisman, H., Sartor, O., Rahbar, S., 2018. **A review of technology and policy deep decarbonization pathway options for making energy-intensive industry production consistent with the Paris agreement.** 187, 960-973. doi:10.1016/j.jclepro.2018.03.107
The production of commodities by energy-intensive industry is responsible for 1/3 of annual global greenhouse gas (GHG) emissions. The climate goal of the Paris Agreement, to hold the increase in the global average temperature to well below 2 °C above pre-industrial levels while pursuing efforts to limit the temperature increase to 1.5 °C, requires global GHG emissions reach net-zero and probably negative by 2055–2080. Given the average economic lifetime of industrial facilities is 20 years or more, this indicates all new investment must be net-zero emitting by 2035–2060 or be compensated by negative emissions to guarantee GHG-neutrality. We argue, based on a sample portfolio of emerging and near-commercial technologies for each sector (largely based on zero carbon electricity & heat sources, biomass and carbon capture, and catalogued in an accompanying database), that reducing energy-intensive industrial GHG emissions to Paris Agreement compatible levels may not only be technically possible, but can be achieved with sufficient prioritization and policy effort. We then review policy options to drive innovation and investment in these technologies. From this we synthesize a preliminary integrated strategy for a managed transition with minimum stranded assets, unemployment, and social trauma that recognizes the competitive and globally traded nature of commodity production. The strategy includes: an initial policy commitment followed by a national and sectoral stakeholder driven pathway process to build commitment and identify opportunities based on local zero carbon resources; penetration of near-commercial technologies through increasing valuation of GHG material intensity through GHG pricing or tradable performance based regulations with protection for competitiveness and against carbon leakage; research and demand support for the output of pilot plants, including some combination of guaranteed above-market prices that decline with output and an increasing requirement for low carbon inputs in government procurement; and finally, key supporting institutions.

978-3-940388-47-6; Weber, K.M., Rohracher, H., **Legitimizing research, technology and innovation policies for transformative change: combining insights from innovation systems and multi-level**

perspective in a comprehensive "failures" framework (2012) Res. Pol., 41, pp. 1037-1047; Weber, T.A., Neuhoff, K., Carbon markets and technological innovation (2010) J. Environ. Econ. Manag., 60, pp. 115-132; Weigel, M., Fischedick, M., Marzinkowski, J., Winzer, P., Multicriteria analysis of primary steelmaking technologies (2016) J. Clean. Prod., 112, pp. 1064-1076; Wesseling, J., Lechtenböhmer, S., Åhman, M., Nilsson, L., Worrell, E., Coenen, L., The transition of energy intensive processing industries towards deep decarbonization: characteristics and implications for future research (2017) Renew. Sustain. Energy Rev., 79, pp. 1303-1313; Williams, J.H., DeBenedictis, A., Ghanadan, R., Mahone, A., Moore, J., Morrow, W.R., Price, S., Torn, M.S., The technology path to deep greenhouse gas emissions cuts by 2050: the pivotal role of electricity (2012) Science (New York), 335, pp. 53-59. , N.Y; WSP Parson Brinkerhoff, DNV GL, Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050: Cross Sector Summary, Glass, Cement and Pulp and Paper Reports [WWW Document] (2015), https://www.gov.uk/government/publications/industrial-decarbonisation-and-energy-efficiency-roadmaps-to-2050, URLUR
- https://www.scopus.com/inward/record.uri?eid=2-s2.0-85050038265&doi=10.1016%2fj.jclepro.2018.03.107&partnerID=40&md5=df475d0e6bd561cb4b01046016990960.
The recent policy debates about orientating research, technology and innovation policy towards societal challenges, rather than economic growth objectives only, call for new lines of argumentation to systematically legitimize policy interventions. While the multi-level perspective on long-term transitions has attracted quite some interest over the past years as a framework for dealing with long-term processes of transformative change, but the innovation systems approach is still the dominant perspective for devising innovation policy. Innovation systems approaches stress the importance of improving innovation capabilities of firms and the institutional settings to support them, but they are less suited for dealing with the strategic challenges of transforming systems of innovation, production and consumption, and thus with long-term challenges such as climate change or resource depletion. It is therefore suggested to consider insights from transition studies more prominently in a policy framework that is based on the innovation systems approach and the associated notion of 'failures'. We propose a comprehensive framework that allows legitimizing and devising policies for transformative change that draws on a combination of market failures, *structural* system failures and *transformational* system failures.

Bellamy, R., Healey, P., 2018. **'Slippery slope' or 'uphill struggle'? Broadening out expert scenarios of climate engineering research and development.** Environ. Sci. Policy 83, 1-10. doi:10.1016/j.envsci.2018.01.021.
It is increasingly recognised that meeting the obligations set out in the Paris Agreement on climate change will not be physically possible without deploying large-scale techniques for either removing greenhouse gasesalready in the atmosphere or reflecting sunlight away from the Earth. In this article we report on the findings of a scenarios method designed to interrogate how far these 'climate engineering' ideas may develop in the future and under what governance arrangements. Unlike previous studies in climate engineering foresight that have narrowly focussed on academic perspectives, a single climate engineering idea and a restricted range of issues, our approach sought to respond to theoretical imperatives for 'broadening out' and 'opening up' research methods applied to highly uncertain and ambiguous topics. We convened a one-day event with experts in climate change and climate engineering from across the sectors of government, industry, civil society and academia in the UK, with additional experts from Brazil, Germany and India. The participants were invited to develop scenarios for four climate engineering ideas: bioenergy with carbon capture and storage, direct air capture and storage, stratospheric aerosol injection and marine cloud brightening. Manifold challenges for future research were identified, placing the scenarios in sharp contrast with early portrayals of climate engineering research as threatening a 'slippery slope' of possible entrenchments, lock-ins and path dependencies that would inexorably lead to deployment. We suggest that the governance challenges for

climate engineering should therefore today be thought of as less of a slippery slope than an 'uphill struggle' and that there is an increasingly apparent need for governance that responsibly incentivises, rather than constrains, research. We find that affecting market processes by introducing an effective global carbon price and direct government expenditure on research and development are incentives with broad potential applications to climate engineering. Responsibly incentivising research will involve a pluralistic architecture of governance arrangements and policy instruments that attends to collective ambitions as well as national differences and emerges from an inclusive and reflexive process.

Cai, J., Wang, S., Zeng, R., Luo, M., Tang, X., 2018. **Cao-based chemical looping gasification of biomass for the production of hydrogen-enriched gas and co 2 negative emissions: A review**. 19, 257-302. doi:10.1615/InterJEnerCleanEnv.2018025185.

Steam gasification of biomass undergoes the problem of undesirable CO_2 and tar formation. Calcium oxide (CaO), when added to the gasification, could play the dual role of tar reforming catalyst and CO_2 sorbent, and thereby produce more hydrogen. However, the deactivation of CaO after carbonation reaction is challenging for continuous hydrogen production and economical perspective. The concept of CaO-based chemical looping gasification (CaO-CLG) plays a key role in overcoming such a challenge. This work primarily aims at studying steam gasification of biomass with the presence of CaO in a uniquely designed chemical looping gasification (CLG) system for hydrogen production with in situ CO_2 capture and tar reduction. The effect of solid circulation rates on gas and tar production is studied. A comparison of CaO-CLG, sand-based chemical looping gasification (Sand-CLG) and CaO-based bubbling fluidized bed gasification (CaO-BFBG) is presented mainly focusing on gas and tar production. The maximum H_2 and minimum CO_2concentrations as well as maximum H_2 yields of 78%, 4.98% and 451.11 ml (STP)/g of biomass, respectively, are obtained at the solid circulation rate of 1.04 kg/m^{2}s. At the same point, the maximum total gas yield was 578.38 ml (STP)/g of biomass and the tar content of 2.48 g/Nm^3 was the lowest. 30% higher concentration of H_2 and triple yield of H_2 were found in CaO-CLG compared to Sand-CLG. Compared to CaO-BFBG, CaO-CLG resulted in 15% higher concentration of H_2 and almost double yield of H_2. Moreover, the lowest tar content of 2.48 g/Nm^3 was obtained for CaO-CLG while the tar content was 68.5 g/Nm^3 for Sand-CLG and 26.71 g/Nm^3 for CaO-BFBG. CO_2concentration obtained for CaO-CLG also significantly reduced by 13–17% as compared to both Sand-CLG and CaO-BFBG.

Dagon, K., Schrag, D.P., 2017. **Regional climate variability under model simulations of solar geoengineering.** Journal of Geophysical Research-Atmospheres 122, 12106-12121. doi:10.1002/2017jd027110.

Solar geoengineering has been shown in modeling studies to successfully mitigate global mean surface temperature changes from greenhouse warming. Changes in land surface hydrology are complicated by the direct effect of carbon dioxide (CO2) on vegetation, which alters the flux of water from the land surface to the atmosphere. Here we investigate changes in boreal summer climate variability under solar geoengineering using multiple ensembles of model simulations. We find that spatially uniform solar geoengineering creates a strong meridional gradient in the Northern Hemisphere temperature response, with less consistent patterns in precipitation, evapotranspiration, and soil moisture. Using regional summertime temperature and precipitation results across 31-member ensembles, we show a decrease in the frequency of heat waves and consecutive dry days under solar geoengineering relative to a high-CO2 world. However in some regions solar geoengineering of this amount does not completely reduce summer heat extremes relative to present day climate. In western Russia and Siberia, an increase in heat waves is connected to a decrease in surface soil moisture that favors persistent high temperatures. Heat waves decrease in the central United States and the Sahel, while the hydrologic response increases terrestrial water storage. Regional changes in soil moisture exhibit trends over time as the model adjusts to solar geoengineering, particularly in Siberia and the Sahel, leading to robust shifts in climate variance. These results suggest potential benefits and complications of large-scale uniform climate intervention schemes.

de Richter, R., Ming, T., Davies, P., Liu, W., Caillol, S., 2017. **Removal of non-co 2 greenhouse gases by large-scale atmospheric solar photocatalysis.** 60, 68-96. doi:10.1016/j.pecs.2017.01.001

Large-scale atmospheric removal of greenhouse gases (GHGs) including methane, nitrous oxide and ozone-depleting halocarbons could reduce global warming more quickly than atmospheric removal of CO_2. Photocatalysis of methane oxidizes it to CO_2, effectively reducing its global warming potential(GWP) by at least 90%. Nitrous oxide can be reduced to nitrogen and oxygen by photocatalysis; meanwhile halocarbons can be mineralized by red-ox photocatalytic reactions to acid halides and CO_2. Photocatalysis avoids the need for capture and sequestration of these atmospheric components. Here review an unusual hybrid device combining photocatalysis with carbon-freeelectricity with no-intermittency based on the solar updraft chimney. Then we review experimental evidence regarding photocatalytic transformations of non-CO_2 GHGs. We propose to combine TiO_2-photocatalysis with solar chimney power plants (SCPPs) to cleanse the atmosphere of non-CO_2 GHGs. Worldwide installation of 50,000 SCPPs, each of capacity 200 MW, would generate a cumulative 34 PWh of renewable electricity by 2050, taking into account construction time. These SCPPs equipped with photocatalyst would process 1 atmospheric volume each 14–16 years, reducing or stopping the atmospheric growth rate of the non-CO_2 GHGs and progressively reducing their atmospheric concentrations. Removal of methane, as compared to other GHGs, has enhanced efficacy in reducing radiative forcing because it liberates more ◦OH radicals to accelerate the cleaning of the troposphere. The overall reduction in non-CO_2 GHG concentration would help to limit global temperature rise. By physically linking greenhouse gas removal to renewable electricity generation, the hybrid concept would avoid the moral hazard associated with most other climate engineering proposals.

Gregory, R., Satterfield, T., Hasell, A., 2016. **Using decision pathway surveys to inform climate engineering policy choices.** Proc. Natl. Acad. Sci. U. S. A. 113, 560-565. doi:10.1073/pnas.1508896113.

A growing number of scientists now believe that climate engineering technologies could be required to control global temperatures and protect ecosystems. Decision makers often rely on surveys to inform them about citizens' views, but when novel technologies are involved results can fail to reflect the assumptions, knowledge, and values that underlie people's choices. To bridge this gap, we describe a new, behaviorally and cognitively responsive "decision pathway" survey (n = 800) that mimics the conversational depth of small-group deliberations by adopting a broader context that includes competing objectives, civic priorities, factual information, and risk–benefit tradeoffs. Results yield important insights into citizens' reasoning strategies and the ethical and governance concerns influencing the conditional nature of climate engineering policy choices.

Gunderson, R., Petersen, B., Stuart, D., 2018**. A critical examination of geoengineering: Economic and technological rationality in social context.** Sustainability 10, 21. doi:10.3390/su10010269.

Geoengineering—specifically stratospheric aerosol injection—is not only risky, but supports powerful economic interests, protects an inherently ecologically harmful social formation, relegates the fundamental social-structural changes needed to address climate change, and is rooted in a vision of a nature as a set of passive resources that can be fully controlled in line with the demands of capital. The case for geoengineering is incomprehensible without analyzing the social context that gave birth to it: capitalism's inability to overcome a contradiction between the need to accumulate capital, on the one hand, and the need to maintain a stable climate system on the other. Substantial emissions reductions, unlike geoengineering, are costly, rely more on social-structural than technical changes, and are at odds with the current social order. Because of this, geoengineering will increasingly be considered a core response to climate change. In light of Herbert Marcuse's critical theory, the promotion of geoengineering as a market-friendly and high-tech strategy is shown to reflect a society that cannot set substantive aims through reason and transforms what should be considered means (technology and economic production) into ends themselves. Such a condition echoes the first-generation Frankfurt School's central thesis: instrumental rationality remains irrational.

Gupta, A., Moller, I., 2019. **De facto governance: How authoritative assessments construct climate engineering as an object of governance.** Environmental Politics 28, 480-501. doi:10.1080/09644016.2018.1452373.

Analyses of climate engineering (CE) governance have accelerated in the last decade. A key claim is that CE remains a largely ungoverned space, with shared norms, institutional arrangements, and formal rules to regulate CE not yet present. In contrast, here it is argued that de facto governance of CE is underway, discernible in an ordering of this nascent field of inquiry by unacknowledged sources of steering. One key source of de facto governance is analyzed: high-level 'authoritative assessments' of CE. The focus is on how these assessments are constructing CE as an object of governance through demarcating and categorizing this emerging field of inquiry, and how this contributes to normalizing and institutionalizing CE research (and CE research communities). Scrutinizing the distinct nature and political implications of de facto governance, particularly of novel and speculative technological trajec-tories not yet subject to formal steering, remains a key task for governance scholars.

Heutel, G., Moreno-Cruz, J., Ricke, K., 2016. **Climate engineering economics**, in: Rausser, G.C. (Ed), Annual review of resource economics, vol 8. Annual Reviews, Palo Alto, pp. 99-118.

This article reviews and evaluates the nascent literature on the economics of climate engineering. The literature distinguishes between two broad types of climate engineering: solar radiation management and carbon dioxide removal. We review the science and engineering characteristics of these technologies and analyze the implications of those characteristics on economic policy design. We discuss optimal policy and carbon price, inter-regional and inter-generational equity issues, strategic interaction in the design of international environmental agreements, and the sources of risk and uncertainty surrounding these technologies. Along with mitigation and adaptation, climate engineering technologies can be incorporated into future domestic and global climate policy design. More research on the topic is needed.

Kurosawa, A., Kato, E., Sugiyama, M., Masuda, K., 2017. **The Paris agreement and climate change countermeasure technologies.** Kagaku Kogaku Ronbunshu 43, 171-177. doi:10.1252/kakoronbunshu.43.171.

Knowledge of climate change research has influenced international politics. The Kyoto Protocol in the United Nations Framework Convention on Climate Change obliges developed economic parties to reduce greenhouse gas emissions, while the Paris Agreement requests all parties to join the reduction framework. Climate change countermeasure technology is categorized into mitigation, adaptation, and climate engineering. Research organizations internationally have analyzed mitigation scenarios such as new energy technology feasibility and greenhouse gas emission pathways utilizing integrated assessment models. An inventory of model results contributed meta-analyses in the fifth assessment reports of the intergovernmental panel on climate change. Consideration of the energy system should include viewpoints of both supply and demand. For example, the net zero energy building is proposed as a new concept in which net annual energy consumption of a building is almost zero; and this could lead to zero emission in the building sector in combination with low CO2 energy carriers. Summation of nationally determined contribution greenhouse gas emission numbers would not reach the level required to achieve the long-term temperature rise target adopted in the Paris Agreement. Some scientists consider climate engineering, namely, human intervention in the climate, as an option. CO2 removal and solar radiation management are the options of climate engineering, and practical evaluations are under way in the area of climate-energy system modeling and social sciences. Chemical engineering-related research, development and deployment will play an important role in almost all fields of technological climate change countermeasures in the future.

Lederer, M., Kreuter, J., 2018. **Organising the unthinkable in times of crises: Will climate engineering become the weapon of last resort in the anthropocene?** Organization 25, 472-490. doi:10.1177/1350508418759186.

In this article, we ask how the approaches of climate engineering – mostly highly technological approaches to address the challenge of global climate change – might be organised in the age of the Anthropocene. We understand the term ‘Anthropocene’ to be characterised by crisis, on one hand, and by promise, on the other. In particular, we aim to raise doubts on the dominant perspective on the organisation of climate engineering, which assumes these approaches to be regulated through legalistic means. Drawing an analogy to the early development stages of nuclear weapons, we point out that, instead of following a legalistic rationale, climate engineering organisation might pursue a logic of technical feasibility, political acceptance and bureaucratic momentum.

Linner, B.O., Wibeck, V., 2015. **Dual high-stake emerging technologies: A review of the climate engineering research literature.** Wiley Interdisciplinary Reviews-Climate Change 6, 255-268. doi:10.1002/wcc.333.

The literature on climate engineering, or geoengineering, covers a wide range of potential methods for solar radiation management or carbon dioxide removal that vary in technical aspects, temporal and spatial scales, potential environmental impacts, and legal, ethical, and governance challenges. This paper presents a comprehensive review of social and natural science papers on this topic since 2006 and listed in SCOPUS and Web of Science. It adds to previous literature reviews by combining analyses of bibliometric patterns and of trends in how the technologies are framed in terms of content, motivations, stakes, and recommendations. Most peer-reviewed climate engineering literature does not weigh the risks and new, additional, benefits of the various technologies, but emphasizes either the potential dangers of climate engineering or the climate change consequences of refraining from considering the research, development, demonstration, and/or deployment of climate engineering technologies. To analyse this polarity, not prevalent in the literature on earlier emerging technologies, we explore the concept of dual high-stake technologies. As appeals to fear have proven ineffective in spurring public engagement in climate change, we may not expect significant public support for climate engineering technologies whose rationale is not to achieve benefits in addition to avoiding the high stakes of climate change. Furthermore, in designing public engagement exercises, researchers must be careful not to steer discussions by emphasizing one type of stake framing over another. A dual high-stake, rather than risk–benefit, framing should also be considered in analysing some emerging technologies with similar characteristics, for example, nanotechnology for pollution control. WIREs Clim Change 2015, 6:255–268. doi: 10.1002/wcc.333 This article is categorized under: Social Status of Climate Change Knowledge > Knowledge and Practice

Markusson, N., Venturini, T., Laniado, D., Kaltenbrunner, A., 2016. **Contrasting medium and genre on wikipedia to open up the dominating definition and classification of geoengineering**. Big Data & Society 3, 17. doi:10.1177/2053951716666102.

Geoengineering is typically defined as a techno-scientific response to climate change that differs from mitigation and adaptation, and that includes diverse individual technologies, which can be classified as either solar radiation management or carbon dioxide removal. We analyse the representation of geoengineering on Wikipedia as a way of opening up this dominating, if contested, model for further debate. We achieve this by contrasting the dominating model as presented in the encyclopaedic article texts with the patterns of hyper-link associations between the articles. Two datasets were created tracing the geoengineering construct on Wikipedia, shedding light on its boundary with its context, as well as on its internal structure. The analysis shows that the geoengineering category tends to be associated on Wikipedia primarily with atmospheric solar radiation management rather than land-based carbon dioxide removal type technologies. The results support the notion that the dominant model of defining and classifying geoengineering technology has been beneficial for solar radiation management type technologies more than for land-based carbon dioxide removal ones. The article also demonstrates that controversy mapping with Wikipedia data affords analysis that can open up dominating definitions and classifications of technologies, and offer resistance to their frequent naturalising and decontextualising tendencies. This work is in line with recent work on digital sociology, but the article contributes a new methodology and reports on the first empirical application of controversy mapping using Wikipedia data to a technology.

Merk, C., Ponitzsch, G., Rehdanz, K., 2019. **Do climate engineering experts display moral-hazard behaviour?** Clim. Policy 19, 231-243. doi:10.1080/14693062.2018.1494534.

Discourse analyses and expert interviews about climate engineering (CE) report high levels of reflectivity about the technologies' risks and challenges, implying that CE experts are unlikely to display moral hazard behaviour, i.e. a reduced focus on mitigation. This has, however, not been empirically tested. Within CE experts we distinguish between experts for radiation management (RM) and for carbon dioxide removal (CDR) and analyse whether RM and CDR experts display moral hazard behaviour. For RM experts, we furthermore look at whether they agree to laboratory and field research, and how they perceive the risks and benefits of one specific RM method, Stratospheric Aerosol Injection (SAI). Analyzing experts' preferences for climate-policy options, we do not find a reduction of the mitigation budget, i.e. moral hazard, for RM or CDR experts compared to climate-change experts who are neither experts for RM nor for CDR. In particular, the budget shares earmarked for RM are low. The perceptions of risks and benefits of SAI are similar for RM and climate-change experts. Despite the difference in knowledge and expertise, experts and laypersons share an understanding of the benefits, while their perceptions of the risks differ: experts perceive the risks to be larger.

Meysman, F.J.R., Montserrat, F., 2017. **Negative co2 emissions via enhanced silicate weathering in coastal environments**. 13. doi:10.1098/rsbl.2016.0905.

Negative emission technologies (NETs) target the removal of carbon dioxide (CO_2) from the atmosphere, and are being actively investigated as a strategy to limit global warming to within the 1.5–2°C targets of the 2015 UN climate agreement. Enhanced silicate weathering (ESW) proposes to exploit the natural process of mineral weathering for the removal of CO_2 from the atmosphere. Here, we discuss the potential of applying ESW in coastal environments as a climate change mitigation option. By deliberately introducing fast-weathering silicate minerals onto coastal sediments, alkalinity is released into the overlying waters, thus creating a coastal CO_2 sink. Compared with other NETs, coastal ESW has the advantage that it counteracts ocean acidification, does not interfere with terrestrial land use and can be directly integrated into existing coastal management programmes with existing (dredging) technology. Yet presently, the concept is still at an early stage, and so two major research challenges relate to the efficiency and environmental impact of ESW. Dedicated experiments are needed (i) to more precisely determine the weathering rate under *in situ* conditions within the seabed and (ii) to evaluate the ecosystem impacts—both positive and negative—from the released weathering products.

Oschlies, A., Klepper, G., 2017. **Research for assessment, not deployment, of climate engineering: The german research foundation's priority program** spp 1689. Earths Future 5, 128-134. doi:10.1002/2016ef000446.

The historical developments are reviewed that have led from a bottom–up responsibility initiative of concerned scientists to the emergence of a nationwide interdisciplinary Priority Program on the assessment of Climate Engineering (CE) funded by the German Research Foundation (DFG). Given the perceived lack of comprehensive and comparative appraisals of different CE methods, the Priority Program was designed to encompass both solar radiation management (SRM) and carbon dioxide removal (CDR) ideas and to cover the atmospheric, terrestrial, and oceanic realm. First, key findings obtained by the ongoing Priority Program are summarized and reveal that, compared to earlier assessments such as the 2009 Royal Society report, more detailed investigations tend to indicate less efficiency, lower effectiveness, and often lower safety. Emerging research trends are discussed in the context of the recent Paris agreement to limit global warming to less than two degrees and the associated increasing reliance on negative emission technologies. Our results show then when deployed at scales large enough to have a significant impact on atmospheric CO_2, even CDR methods such as afforestation—often perceived as "benign"—can have substantial side effects and may raise severe ethical, legal, and governance issues. We suppose that before being deployed at climatically relevant scales, any negative emission or CE method will require careful analysis of efficiency, effectiveness, and undesired side effects.

Scott, D., 2018. **Ethics of climate engineering: Chemical capture of carbon dioxide from air.** Hyle 24, 55-77.

In the coming decades, scientists will be increasingly confronted with opportunities to pursue research with implications for one or more climate engineering proposals. Now is the time for chemists to critically reflect on the controversial possibility of managing the climate and its ethical implications. The ultimate goal of this case study on ethics and climate engineering is to promote critical reflection and discussion on the ethics of climate engineering research. To fulfill its goal, this paper will investigate four questions: (1) Why should scientists and engineers consider climate engineering research? (2) What is climate engineering? (3) What is the substance of a common ethical objection to climate engineering, the moral hazard objection? (4) How might we begin to address crucial ethical concerns with climate engineering?

Scott, V., Geden, O., 2018. **The challenge of carbon dioxide removal for EU policy-making**. 3, 350-352. doi:10.1038/s41560-018-0124-1.

Most scenarios to meet the Paris Agreement require negative emissions technologies. The EU has assumed a global leadership role in mitigation action and low-carbon energy technology development and deployment, but carbon dioxide removal presents a serious challenge to its low-carbon policy paradigm and experience.

An interdisciplinary assessment of climate engineering strategies
Type Article de revue
Auteur D.F. Cusack
Auteur J. Axsen
Auteur R. Shwom
Auteur L. Hartzell-Nichols
Auteur S. White
Auteur K.R.M. Mackey
URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-84903128729&doi=10.1890%2f130030&partnerID=40&md5=7402e55692d7ff82b1cecce12e400189
Volume 12
Numéro 5
Pages 280-287
Publication Frontiers in Ecology and the Environment
Date 2014
DOI 10.1890/130030
Résumé Mitigating further anthropogenic changes to the global climate will require reducing greenhouse-gas emissions ("abatement"), or else removing carbon dioxide from the atmosphere and/or diminishing solar input ("climate engineering"). Here, we develop and apply criteria to measure technical, economic, ecological, institutional, and ethical dimensions of, and public acceptance for, climate engineering strategies; provide a relative rating for each dimension; and offer a new interdisciplinary framework for comparing abatement and climate engineering options. While abatement remains the most desirable policy, certain climate engineering strategies, including forest and soil management for carbon sequestration, merit broad-scale application. Other proposed strategies, such as biochar production and geological carbon capture and storage, are rated somewhat lower, but deserve further research and development. Iron fertilization of the oceans and solar radiation management, although cost-effective, received the lowest ratings on most criteria. We conclude that although abatement should remain the central climate-change response, some low-risk, cost-effective climate engineering approaches should be applied as complements. The framework presented here aims to guide and prioritize further research and analysis, leading to improvements in climate engineering strategies. © The Ecological Society of America.

Public perceptions of climate geoengineering: a systematic review of the literature
Type Article de revue
Auteur Christopher L. Cummings
Auteur Sapphire H. Lin
Auteur Benjamin D. Trump
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DOI 10.3354/cr01475

Résumé Geoengineering is a set of proposed large-scale technological fixes designed to curb anthropogenic climate change mostly through the reduction or neutralization of greenhouse gas emissions. While this set of technologies may provide significant benefit to future society, it may also be controversial for a variety of reasons including values-based objections and uncertainties regarding the manageability and potential irreversibility of the technologies. Studies of public perceptions of geoengineering have begun to elicit responses to these proposed technologies, yet the findings of such work are scattered across many publications, and represent the work of a variety of scholars using many methods to collect data. This work provides a systematic review of empirical literature regarding the methods and results of public perception studies of 2 distinct geoengineering approaches: carbon dioxide removal and solar radiation management. Reviewing public opinion data regarding these sets of technologies can provide a stronger basis of understanding that can
empower anticipatory governance initiatives, future decision-making, and risk communication. We do not analyze public opinion studies regarding carbon dioxide capture and storage, as other reviews have been recently published elsewhere. Four key themes are identified and reviewed across studies: (1) support for research and use of geoengineering, (2) risk and benefit perceptions, (3) familiarity with geoengineering, and (4) trust in governing bodies. This review also discusses methodological issues pertaining to participant sampling and framing of geo-engineering technologies within the reviewed studies.

On sorption and swelling of CO2 in clays

Type Article de revue

Auteur A. Busch
Auteur P. Bertier
Auteur Y. Gensterblum
Auteur G. Rother
Auteur C. J. Spiers
Auteur M. Zhang
Auteur H. M. Wentinck

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DOI 10.1007/s40948-016-0024-4

Résumé The geological storage of carbon dioxide (CO_2) is a well-studied technology, and a number of demonstration projects around the world have proven its feasibility and challenges. Storage conformance and seal integrity are among the most important aspects, as they determine risk of leakage as well as limits for storage capacity and injectivity. Furthermore, providing evidence for safe storage is critical for improving public acceptance. Most caprocks are composed of clays as dominant mineral type which can typically be illite, kaolinite, chlorite or smectite. A number of recent studies addressed the interaction between CO_2 and these different clays and it was shown that clay minerals adsorb considerable quantities of CO_2. For smectite this uptake can lead to volumetric expansion followed by the generation of swelling pressures. On the one hand CO_2 adsorption traps CO_2, on the other hand swelling pressures can potentially change local stress regimes and in unfavourable situations shear-type failure is assumed to occur. For storage in a reservoir having high clay contents the CO_2 uptake can add

to storage capacity which is widely underestimated so far. Smectite-rich seals in direct contact with a dry CO2 plume at the interface to the reservoir might dehydrate leading to dehydration cracks. Such dehydration cracks can provide pathways for CO2 ingress and further accelerate dewatering and penetration of the seal by supercritical CO2. At the same time, swelling may also lead to the closure of fractures or the reduction of fracture apertures, thereby improving seal integrity. The goal of this communication is to theoretically evaluate and discuss these scenarios in greater detail in terms of phenomenological mechanisms, but also in terms of potential risks or benefits for carbon storage.
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A review on well integrity issues for CO2 geological storage and enhanced gas recovery
Type Article de revue
Auteur Mingxing Bai
Auteur Zhichao Zhang
Auteur Xiaofei Fu
Volume 59
Pages 920-926
Publication Renewable & Sustainable Energy Reviews
ISSN 1364-0321
Date JUN 2016
Extra WOS:000371948400064
DOI 10.1016/j.rser.2016.01.043
Résumé The world's rapid economic growth has contributed to the ever increasing demand for energy which results in the increase of fossil fuels usage. On the other hand, renewable energies, which are considered environmentally friendly, cannot replace the fossil fuels in the short term. For this, CO2 capture and storage (CCS) technologies could work as transitional technology. To ensure a meaningful underground storage, well integrity is potentially the greatest challenge. On one hand, the injected CO2 may cause severe corrosion to metallic tubulars and cement in the welibore. Identification, quantification and mitigation of this corrosion are the key to achieve satisfactory well conditions. On the other hand, the mechanical integrity loss due to cyclic and thermal loading in the well life will also occur, so to investigate and evaluate well integrity is of paramount importance to ensure a safe operation and storage. This paper presents a definition of well integrity in the scope of CSEGR as well as the mechanisms of well integrity loss. Overview on corrosion issues of
metallic and cement corrosion along with the remedial measures is discussed. Through a thorough literature review, well integrity criteria for new and old wells are introduced to provide a guidance for material selection for the usage in CSEGR. Moreover, in order to evaluate the integrity of operational and abandoned wells, this paper provides a review on the existing monitoring methods, as well as risk based methods such as FEPs analysis, Performance and Risk Management, CO2-PENS, and put forward a new concept of well integrity evaluation.

Dye Sensitized Solar Cell (DSSC) greenhouse shading: New insights for solar radiation manipulation
Type Article de revue
Auteur N. Roslan
Auteur M. E. Ya'acob
Auteur M. A. M. Radzi
Auteur Y. Hashimoto
Auteur D. Jamaludin
Auteur G. Chen
Volume 92
Pages 171-186
Publication Renewable & Sustainable Energy Reviews
ISSN 1364-0321
Date SEP 2018
Extra WOS:000437084300013
DOI 10.1016/j.rser.2018.04.095
Résumé Energy crisis is the worldwide main concern since fossil fuels are facing rapid depletion and its consumption contributes to the rise in the average global temperature. Among the challenges to be embedded lately with agricultural activities is to explore clean and renewable energy resources. Electrical energy generation via solar technology, or known also as photovoltaic (PV) technology, has been the most economical viable green resource, especially in tropical-based countries. The most notable problem revealed by conventional PV in greenhouses, however, is due to the antagonistic factor lying in both photovoltaic roofs and plants. As such, the divergence subsequently decreases the growth and productivity of the cultivated crops. The Dye Sensitized Solar Cell (DSSC) is thus of great importance to human as it possesses several attractive features. For instance, the fabrication of DSSC is cheap. It is also flexible, transparent, and sensitive to low light levels. Besides its easiness to be used in larger applications, makes DSSC an ideal candidate that could function greatly as energy buildings. This review article aims to explore the DSSC technology's potential and its effectiveness as a shading greenhouse. Further, in-depth understanding on the uniqueness and advantages of this technology is thoroughly assessed. In comparison to conventional PV, the DSSC technology especially on solar radiation manipulation through the optimum choice of photosensitizer is well described. This paper also consolidates all the
materials employed for DSSC fabrication for greenhouse shading. Detailing photosensitizer and light harvesting within PAR wavelength for sustenance growth have been provided. This technology has the potential to improve farming productivity while contribute to a significant reduction of CO2 emission.

De facto governance: how authoritative assessments construct climate engineering as an object of governance
Type Article de revue
Auteur Aarti Gupta
Auteur Ina Moller
Volume 28
Numéro 3
Pages 480-501
Publication Environmental Politics
ISSN 0964-4016
Date APR 16 2019
Extra WOS:000461042600006

Abrév. de revue Environ. Polit.
DOI 10.1080/09644016.2018.1452373
Langue English
Résumé Analyses of climate engineering (CE) governance have accelerated in the last decade. A key claim is that CE remains a largely ungoverned space, with shared norms, institutional arrangements, and formal rules to regulate CE not yet present. In contrast, here it is argued that de facto governance of CE is underway, discernible in an ordering of this nascent field of inquiry by unacknowledged sources of steering. One key source of de facto governance is analyzed: high-level 'authoritative assessments' of CE. The focus is on how these assessments are constructing CE as an object of governance through demarcating and categorizing this emerging field of inquiry, and how this contributes to normalizing and institutionalizing CE research (and CE research communities). Scrutinizing the distinct nature and political implications of de facto governance, particularly of novel and speculative technological trajectories not yet subject to formal steering, remains a key task for governance scholars.

Do climate engineering experts display moral-hazard behaviour?

Type Article de revue
Auteur Christine Merk
Auteur Gert Poenitzsch
Auteur Katrin Rehdanz
Volume 19
Numéro 2
Pages 231-243
Publication Climate Policy
ISSN 1469-3062
Date FEB 7 2019
Extra WOS:000453574100008
Abrév. de revue Clim. Policy
DOI 10.1080/14693062.2018.1494534
Langue English
Résumé Discourse analyses and expert interviews about climate engineering (CE) report high levels of reflectivity about the technologies' risks and challenges, implying that CE experts are unlikely to display moral hazard behaviour, i.e. a reduced focus on mitigation. This has, however, not been empirically tested. Within CE experts we distinguish between experts for radiation management (RM) and for carbon dioxide removal (CDR) and analyse whether RM and CDR experts display moral hazard behaviour. For RM experts, we furthermore look at whether they agree to laboratory and field research, and how they perceive the risks and benefits of one specific RM method, Stratospheric Aerosol Injection (SAI). Analyzing experts' preferences for climate-policy options, we do not find a reduction of the mitigation budget, i.e. moral hazard, for RM or CDR experts compared to climate-change experts who are neither experts for RM nor for CDR. In particular, the budget shares earmarked for RM are low. The perceptions of risks and benefits of SAI are similar for RM and climate-change experts. Despite the difference in knowledge and expertise, experts and laypersons share an understanding of the benefits, while their perceptions of the risks differ: experts perceive the risks to be larger. Key policy insights Experts surveyed all prioritize mitigation over carbon dioxide removal and in particular radiation management. In the views of the experts, SAI is not a viable climate policy option within the next 25 years, and potentially beyond, as global field-testing (which would be a precondition for long-term deployment) is widely rejected. In the case of SAI, greater knowledge leads to increased awareness of the uncertainty and complexity involved. Policy-makers need to be aware of this relationship and the potential

misconceptions among laypersons with limited knowledge, and should follow the guidelines about communicating risks and uncertainties of CE that experts have been advised to follow.

Ethics of Climate Engineering: Chemical Capture of Carbon Dioxide from Air
Type Article de revue
Auteur Dane Scott
Volume 24
Numéro 1
Pages 55-77
Publication Hyle
ISSN 1433-5158
Date OCT 2018
Extra WOS:000447915300004
Abrév. de revue HYLE
Langue English
Résumé In the coming decades, scientists will be increasingly confronted with opportunities to pursue research with implications for one or more climate engineering proposals. Now is the time for chemists to critically reflect on the controversial possibility of managing the climate and its ethical implications. The ultimate goal of this case study on ethics and climate engineering is to promote critical reflection and discussion on the ethics of climate engineering research. To fulfill its goal, this paper will investigate four questions: (1) Why should scientists and engineers consider climate engineering research? (2) What is climate engineering? (3) What is the substance of a common ethical objection to climate engineering, the moral hazard objection? (4) How might we begin to address crucial ethical concerns with climate engineering?

Organising the unthinkable in times of crises: Will climate engineering become the weapon of last resort in the Anthropocene?
Type Article de revue
Auteur Markus Lederer
Auteur Judith Kreuter
Volume 25
Numéro 4
Pages 472-490
Publication Organization
ISSN 1350-5084
Date JUL 2018
Extra WOS:000439604800002
Abrév. de revue Organization
DOI 10.1177/1350508418759186
Langue English
Résumé In this article, we ask how the approaches of climate engineering - mostly highly technological approaches to address the challenge of global climate change - might be organised in the age of the Anthropocene. We understand the term Anthropocene' to be characterised by crisis, on one hand, and by promise, on the other. In particular, we aim to raise doubts on the dominant perspective on the organisation of climate engineering, which assumes these approaches to be regulated through legalistic means. Drawing an analogy to the early development stages of nuclear weapons, we point out that,

instead of following a legalistic rationale, climate engineering organisation might pursue a logic of technical feasibility, political acceptance and bureaucratic momentum.

'Slippery slope' or 'uphill struggle'? Broadening out expert scenarios of climate engineering research and development

Type Article de revue
Auteur Rob Bellamy
Auteur Peter Healey
Volume 83
Pages 1-10
Publication Environmental Science & Policy
ISSN 1462-9011
Date MAY 2018
Extra WOS:000429511100001
Abrév. de revue Environ. Sci. Policy
DOI 10.1016/j.envsci.2018.01.021
Langue English
Résumé It is increasingly recognised that meeting the obligations set out in the Paris Agreement on climate change will not be physically possible without deploying large-scale techniques for either removing greenhouse gases already in the atmosphere or reflecting sunlight away from the Earth. In this article we report on the findings of a scenarios method designed to interrogate how far these 'climate engineering' ideas may develop in the future and under what
governance arrangements. Unlike previous studies in climate engineering foresight that have narrowly focussed on academic perspectives, a single climate engineering idea and a restricted range of issues, our approach sought to respond to theoretical imperatives for 'broadening out' and 'opening up' research methods applied to highly uncertain and ambiguous topics. We convened a one-day event with experts in climate change and climate engineering from across the sectors of government, industry, civil society and academia in the UK, with additional experts from Brazil, Germany and India. The participants were invited to develop scenarios for four climate engineering ideas: bioenergy with carbon capture and storage, direct air capture and storage, stratospheric aerosol injection and marine cloud brightening. Manifold challenges for future research were identified, placing the scenarios in sharp contrast with early portrayals of climate engineering research as threatening a 'slippery slope' of possible entrenchments, lock-ins and path dependencies that would inexorably lead to deployment. We suggest that the governance challenges for climate engineering should therefore today be thought of as less of a slippery slope than an 'uphill struggle' and that there is an increasingly apparent need for governance that responsibly incentivises, rather than constrains, research. We find that affecting market processes by introducing an effective global carbon price and direct government expenditure on research and development are incentives with broad potential applications to climate engineering. Responsibly incentivising research will involve a pluralistic architecture of governance arrangements and policy instruments that attends to collective ambitions as well as national differences and emerges from an inclusive and reflexive process.
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Marqueurs :
framework, Climate engineering, carbon capture, energy, Governance, Policy instruments, Research incentives, Scenarios, Slippery slope

A Critical Examination of Geoengineering: Economic and Technological Rationality in Social Context
Type Article de revue
Auteur Ryan Gunderson
Auteur Brian Petersen
Auteur Diana Stuart
Volume 10
Numéro 1
Pages 269
Publication Sustainability
ISSN 2071-1050
Date JAN 2018
Extra WOS:000425082600260
Abrév. de revue Sustainability
DOI 10.3390/su10010269
Langue English
Résumé Geoengineeringspecifically stratospheric aerosol injectionis not only risky, but supports powerful economic interests, protects an inherently ecologically harmful social formation, relegates the fundamental social-structural changes needed to address climate change, and is rooted in a vision of a nature as a set of passive resources that can be fully controlled in line with the demands of capital. The case for geoengineering is incomprehensible without analyzing
the social context that gave birth to it: capitalism's inability to overcome a contradiction between the need to accumulate capital, on the one hand, and the need to maintain a stable climate system on the other. Substantial emissions reductions, unlike geoengineering, are costly, rely more on social-structural than technical changes, and are at odds with the current social order. Because of this, geoengineering will increasingly be considered a core response to climate change. In light of Herbert Marcuse's critical theory, the promotion of geoengineering as a market-friendly and high-tech strategy is shown to reflect a society that cannot set substantive aims through reason and transforms what should be considered means (technology and economic production) into ends themselves. Such a condition echoes the first-generation Frankfurt School's central thesis: instrumental rationality remains irrational.
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Marqueurs :
climate engineering, solar radiation management, ethics, metaphors, aerosol, albedo modification, carbon dioxide removal, climate-change, critical theory, critique, degrowth, discourse, environmental sociology, Marcuse, science and technology studies, solar-radiation management, stratospheric aerosol injection, stratospheric sulfate injection

Regional Climate Variability Under Model Simulations of Solar Geoengineering
Type Article de revue
Auteur Katherine Dagon
Auteur Daniel P. Schrag
Volume 122
Numéro 22
Pages 12106-12121
Publication Journal of Geophysical Research-Atmospheres
ISSN 2169-897X
Date NOV 27 2017

Extra WOS:000418084500003
Abrév. de revue J. Geophys. Res.-Atmos.
DOI 10.1002/2017JD027110
Langue English
Résumé Solar geoengineering has been shown in modeling studies to successfully mitigate global mean surface temperature changes from greenhouse warming. Changes in land surface hydrology are complicated by the direct effect of carbon dioxide (CO2) on vegetation, which alters the flux of water from the land surface to the atmosphere. Here we investigate changes in boreal summer climate variability under solar geoengineering using multiple ensembles of model simulations. We find that spatially uniform solar geoengineering creates a strong meridional gradient in the Northern Hemisphere temperature response, with less consistent patterns in precipitation, evapotranspiration, and soil moisture. Using regional summertime temperature and precipitation results across 31-member ensembles, we show a decrease in the frequency of heat waves and consecutive dry days under solar geoengineering relative to a high-CO2 world. However in some regions solar geoengineering of this amount does not completely reduce summer heat extremes relative to present day climate. In western Russia and Siberia, an increase in heat waves is connected to a decrease in surface soil moisture that favors persistent high
temperatures. Heat waves decrease in the central United States and the Sahel, while the hydrologic response increases terrestrial water storage. Regional changes in soil moisture exhibit trends over time as the model adjusts to solar geoengineering, particularly in Siberia and the Sahel, leading to robust shifts in climate variance. These results suggest potential benefits and complications of large-scale uniform climate intervention schemes. Plain Language
Summary Climate change is a difficult problem and will likely require a wide range of solutions. The use of intentional climate interventions, also called solar geoengineering, could help combat the worst effects of climate change. Solar geoengineering refers to techniques that decrease the amount of sunlight reaching the Earth's surface in order to cool the planet. While this method may be helpful in some ways, we also need to understand the risks or any unintended consequences. In this work we focus on the potential impacts of solar geoengineering on extreme heat events, such as heat waves. We use a climate model to study how the frequency of these events is affected by solar geoengineering and compare with how future climate change impacts extremes. Our results show that solar geoengineering produces fewer extreme heat events than the future with global warming. However, some places show an increase in extremes relative to the climate of today. Finally, we find that water stored in the soils is an important factor in determining the local response of extreme heat events to solar geoengineering.
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Marqueurs :
atmospheric co2, climate modeling, climate variability, extreme events, global-scale, hot extremes, hydrological cycle, impact, land surface hydrology, plant-responses, radiation
management, sensitivity, soil-moisture, solar geoengineering, system model

The Paris Agreement and Climate Change Countermeasure Technologies
Type Article de revue
Auteur Atsushi Kurosawa
Auteur Etsushi Kato
Auteur Masahiro Sugiyama
Auteur Kooiti Masuda
Volume 43

Numéro 4
Pages 171-177
Publication Kagaku Kogaku Ronbunshu
ISSN 0386-216X
Date JUL 2017
Extra WOS:000411151300002
Abrév. de revue Kag. Kog. Ronbunshu
DOI 10.1252/kakoronbunshu.43.171
Langue Japanese
Résumé Knowledge of climate change research has influenced international politics. The Kyoto Protocol in the United Nations Framework Convention on Climate Change obliges developed economic parties to reduce greenhouse gas emissions, while the Paris Agreement requests all parties to join the reduction framework. Climate change countermeasure technology is categorized into mitigation, adaptation, and climate engineering. Research organizations internationally have analyzed mitigation scenarios such as new energy technology feasibility and greenhouse gas emission pathways utilizing integrated assessment models. An inventory of model results contributed meta-analyses in the fifth assessment reports of the intergovernmental panel on climate change. Consideration of the energy system should include viewpoints of both supply and demand. For example, the net zero energy building is proposed as a new concept in which net annual energy consumption of a building is almost zero; and this could lead to zero emission in the building sector in combination with low CO2 energy carriers. Summation of nationally determined contribution greenhouse gas emission numbers would not reach the level required to achieve the long-term temperature rise target adopted in the Paris Agreement. Some scientists consider climate engineering, namely, human intervention in the climate, as an option. CO2 removal and solar radiation management are the options of climate engineering, and practical evaluations are under way in the area of climate-energy system modeling and social sciences. Chemical engineering-related research, development and deployment will play an important role in almost all fields of technological climate change countermeasures in the future.
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Marqueurs :
energy, Climate Change, Climate Engineering, Integrated Assessment Model, Mitigation, model, option, Zero Energy Building

Geoengineering: rights, risks and ethics

Type Article de revue
Auteur Sam Adelman
Volume 8
Numéro 1
Pages 119-138
Publication Journal of Human Rights and the Environment
ISSN 1759-7188
Date MAR 2017
Extra WOS:000413507100007
Abrév. de revue J. Hum. Rights Environ.
DOI 10.4337/jhre.2017.01.06
Langue English

Résumé This article discusses arguments that manipulating the Earth's climate may provoke unforeseen, unintended and uncontrollable consequences that threaten human rights. The risks arise from both main types of geoengineering: solar radiation management (SRM) techniques and carbon dioxide removal (CDR). SRM creates particular risks because it is difficult to test on a wide scale and may not be capable of being recalled after deployment. Adequate, enforceable
governance structures do not currently exist to assess and regulate the risks of climate engineering, not least whether such technologies can be terminated in the absence of significant emissions reductions. This article is divided into six sections. After the opening introductory section, section 2 discusses the links between climate change and human rights. It briefly outlines the range of rights, including procedural rights, that might be violated by geoengineering. This is followed, in section 3, by an evaluation of the risks of SRM and CDR. The fourth section discusses debates on the ethics of geoengineering. Section 5 critiques hubristic faith in technological solutions. The final section examines the governance of geoengineering and the extent to which international environmental law and human rights law might be used to regulate the research and deployment of geoengineering.
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carbon dioxide removal, geoengineering, science, solar radiation management, moral hazard, risk, aerosols, climate, human rights

Research for assessment, not deployment, of Climate Engineering: The German Research Foundation's Priority Program SPP 1689

Type Article de revue
Auteur Andreas Oschlies
Auteur Gernot Klepper
Volume 5
Numéro 1
Pages 128-134
Publication Earths Future
ISSN 2328-4277
Date JAN 2017
Extra WOS:000395001800011
Abrév. de revue Earth Future
DOI 10.1002/2016EF000446
Langue English
Résumé The historical developments are reviewed that have led from a bottom-up responsibility initiative of concerned scientists to the emergence of a nationwide interdisciplinary Priority Program on the assessment of Climate Engineering (CE) funded by the German Research Foundation (DFG). Given the perceived lack of comprehensive and comparative appraisals of different CE methods, the Priority Program was designed to encompass both solar radiation management (SRM) and carbon dioxide removal (CDR) ideas and to cover the atmospheric, terrestrial, and oceanic realm. First, key findings obtained by
the ongoing Priority Program are summarized and reveal that, compared to earlier assessments such as the 2009 Royal Society report, more detailed investigations tend to indicate less efficiency, lower effectiveness, and often lower safety. Emerging research trends are discussed in the context of the recent Paris agreement to limit global warming to less than two degrees and the associated increasing reliance on negative emission technologies. Our results show then when deployed at scales large enough to have a significant impact on atmospheric CO_2, even CDR methods such as afforestation-often perceived as "benign"-can have substantial side effects and may raise severe ethical, legal, and governance issues. We suppose that before being deployed at climatically relevant scales, any negative emission or CE method will require careful analysis of efficiency, effectiveness, and undesired side effects.
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Marqueurs :
mitigation, carbon-dioxide removal, land, ocean iron fertilization, responses, trade-offs, world

Contrasting medium and genre on Wikipedia to open up the dominating definition and classification of geoengineering

Type Article de revue
Auteur Nils Markusson
Auteur Tommaso Venturini
Auteur David Laniado
Auteur Andreas Kaltenbrunner
Volume 3
Numéro 2
Publication Big Data & Society

ISSN 2053-9517
Date SEP 2 2016
Extra WOS:000418159500001
Abrév. de revue Big Data Soc.
DOI 10.1177/2053951716666102
Langue English
Résumé Geoengineering is typically defined as a techno-scientific response to climate change that differs from mitigation and adaptation, and that includes diverse individual technologies, which can be classified as either solar radiation management or carbon dioxide removal. We analyse the representation of geoengineering on Wikipedia as a way of opening up this dominating, if contested, model for further debate. We achieve this by contrasting the dominating model as presented in the encyclopaedic article texts with the patterns of hyper-link associations between the articles. Two datasets were created tracing the geoengineering construct on Wikipedia, shedding light on its boundary with its context, as well as on its internal structure. The analysis shows that the geoengineering category tends to be associated on Wikipedia primarily with atmospheric solar radiation management rather than land-based carbon dioxide removal type technologies. The results support the notion that the dominant model of defining and classifying geoengineering technology has been beneficial for solar radiation management type technologies more than for land-based carbon dioxide removal ones. The article also demonstrates that controversy mapping with Wikipedia data affords analysis that can open up dominating definitions and classifications of technologies, and offer resistance to their frequent naturalising and decontextualising tendencies. This work is in line with recent work on digital sociology, but the article contributes a new methodology and reports on the first empirical application of controversy mapping using Wikipedia data to a technology.
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Marqueurs :
climate engineering, geoengineering, science, climate-change, classification, controversies, definition, digital methods, participation, power, technology, web, Wikipedia

Can We Have It Both Ways? On Potential Trade-Offs Between Mitigation and Solar Radiation Management

Type Article de revue
Auteur Christian Baatz
Volume 25
Numéro 1
Pages 29-49
Publication Environmental Values
ISSN 0963-2719
Date FEB 2016
Extra WOS:000369779700003
Abrév. de revue Environ. Values
DOI 10.3197/096327115X14497392134847
Langue English
Résumé Many in the discourse on climate engineering agree that if deployment of solar radiation management (SRM) technologies is ever permissible, then it must be accompanied by far-reaching mitigation of greenhouse gas (GHG) emissions. This raises the question of if and how both strategies

interact. Although raised in many publications, there are surprisingly few detailed investigations of this important issue. The paper aims at contributing to closing this
research gap by (i) reconstructing moral hazard claims to clarify their aim, (ii) offering one specific normative justification for far-reaching mitigation and (iii) investigating in greater detail different mechanisms that could potentially cause a trade-off between mitigation and SRM. I conclude that the empirical evidence questioning the trade-off hypothesis is inconclusive. Moreover, theoretical reflections as well as economic model studies point to a trade-off. In
our current epistemic situation these findings must be taken seriously. They caution against researching and developing SRM technologies before measures to avoid or minimise a trade-off are implemented.
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Marqueurs :
mitigation, moral hazard, ethics, climate engineering, economics, climate-change, irradiance reduction, Solar radiation management, trade-off

Using decision pathway surveys to inform climate engineering policy choices
Type Article de revue
Auteur Robin Gregory
Auteur Terre Satterfield
Auteur Ariel Hasell
Volume 113
Numéro 3
Pages 560-565
Publication Proceedings of the National Academy of Sciences of the United States of America
ISSN 0027-8424
Date JAN 19 2016
Extra WOS:000368458800041
Abrév. de revue Proc. Natl. Acad. Sci. U. S. A.
DOI 10.1073/pnas.1508896113
Langue English
Résumé Over the coming decades citizens living in North America and Europe will be asked about a variety of new technological and behavioral initiatives intended to mitigate the worst impacts of climate change. A common approach to public input has been surveys whereby respondents' attitudes about climate change are explained by individuals' demographic background, values, and beliefs. In parallel, recent deliberative research seeks to more fully address the complex value tradeoffs linked to novel technologies and difficult ethical questions that characterize leading climate mitigation alternatives. New methods such as decision pathway surveys may offer important insights for policy makers by capturing much of the depth and reasoning of small-group deliberations while meeting standard survey goals including large-sample stake-holder engagement. Pathway surveys also can help participants to deepen their factual knowledge base and arrive at a more complete understanding of their own values as they apply to proposed policy alternatives. The pathway results indicate more fully the conditional and context-specific nature of support for several "upstream" climate interventions, including solar radiation management techniques and carbon dioxide removal technologies.
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Marqueurs :

geoengineering, climate change, cognition, deliberation, engagement, pathway surveys, perceptions, support, values

Climate Engineering Economics
Type Chapitre de livre
Auteur Garth Heutel
Auteur Juan Moreno-Cruz
Auteur Katharine Ricke
Éditeur G. C. Rausser
Volume 8
Lieu Palo Alto
Éditeur Annual Reviews
Pages 99-118
ISBN 978-0-8243-4708-6
Date 2016
Extra WOS:000389634800006
Langue English
Résumé This article reviews and evaluates the nascent literature on the economics of climate engineering. The literature distinguishes between two broad types of climate engineering: solar radiation management and carbon dioxide removal. We review the science and engineering characteristics of these technologies and analyze the implications of those characteristics for economic policy design. We discuss optimal policy and carbon price, interregional and intergenerational equity issues, strategic interaction in the design of international environmental agreements, and the sources of risk and uncertainty surrounding these technologies. We conclude that climate engineering technologies, similar to mitigation and adaptation, should be a fundamental part of future domestic and global climate policy design. We propose several avenues in need of additional research. Titre du livre Annual Review of Resource Economics, Vol 8
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Marqueurs :
geoengineering, solar radiation management, capture, co2, climate change, impact, model, carbon dioxide removal, climate policy, cloud, fertilization, policy, solar

An economic evaluation of solar radiation management
Type Article de revue
Auteur Asbjorn Aaheim
Auteur Bard Romstad
Auteur Taoyuan Wei
Auteur Jon Egill Kristjansson
Auteur Helene Muri
Auteur Ulrike Niemeier
Auteur Hauke Schmidt
Volume 532
Pages 61-69
Publication Science of the Total Environment
ISSN 0048-9697

Date NOV 1 2015
Extra WOS:000360286500007
Abrév. de revue Sci. Total Environ.
DOI 10.1016/j.scitotenv.2015.05.106
Langue English
Résumé Economic evaluations of solar radiation management (SRM) usually assume that the temperature will be stabilized, with no economic impacts of climate
change, but with possible side-effects. We know from experiments with climate models, however, that unlike emission control the spatial and temporal
distributions of temperature, precipitation and wind conditions will change. Hence, SRM may have economic consequences under a stabilization of global
mean temperature even if side-effects other than those related to the climatic responses are disregarded. This paper addresses the economic impacts of
implementing two SRM technologies; strato-spheric sulfur injection and marine cloud brightening. By the use of a computable general equilibrium model,
we estimate the economic impacts of climatic responses based on the results from two earth system models, MPI-ESM and NorESM. We find that under a
moderately increasing greenhouse-gas concentration path, RCP4.5, the economic benefits of implementing climate engineering are small, and may become
negative. Global GDP increases in three of the four experiments and all experiments include regions where the benefits from climate engineering are
negative. (C) 2015 Elsevier B.V. All rights reserved.
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Marqueurs :
climate-change, sensitivity, model, irradiance reduction, albedo, Climate economics, Climate modeling, clouds, cycle, Geoengineering, impacts, injection, part 1

Dual high-stake emerging technologies: a review of the climate engineering research literature

Type Article de revue
Auteur Bjorn-Ola Linner
Auteur Victoria Wibeck
Volume 6
Numéro 2
Pages 255-268
Publication Wiley Interdisciplinary Reviews-Climate Change
ISSN 1757-7780
Date MAR-APR 2015
Extra WOS:000352721000008
Abrév. de revue Wiley Interdiscip. Rev.-Clim. Chang.
DOI 10.1002/wcc.333
Langue English
Résumé The literature on climate engineering, or geoengineering, covers a wide range of potential methods for solar radiation management or carbon dioxide
removal that vary in technical aspects, temporal and spatial scales, potential environmental impacts, and legal, ethical, and governance challenges. This

paper presents a comprehensive review of social and natural science papers on this topic since 2006 and listed in SCOPUS andWeb of Science. It adds to
previous literature reviews by combining analyses of bibliometric patterns and of trends in how the technologies are framed in terms of content,
motivations, stakes, and recommendations. Most peer-reviewed climate engineering literature does not weigh the risks and new, additional, benefits of the
various technologies, but emphasizes either the potential dangers of climate engineering or the climate change consequences of refraining from considering
the research, development, demonstration, and/ or deployment of climate engineering technologies. To analyse this polarity, not prevalent in the literature
on earlier emerging technologies, we explore the concept of dual high-stake technologies. As appeals to fear have proven ineffective in spurring public
engagement in climate change, we may not expect significant public support for climate engineering technologies whose rationale is not to achieve
benefits in addition to avoiding the high stakes of climate change. Furthermore, in designing public engagement exercises, researchers must be careful not
to steer discussions by emphasizing one type of stake framing over another. A dual high-stake, rather than risk-benefit, framing should also be considered
in analysing some emerging technologies with similar characteristics, for example, nanotechnology for pollution control. (C) 2015 The Authors. WIREs
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Laypeople's Risky Decisions in the Climate Change Context: Climate Engineering as a Risk-Defusing Strategy?
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Résumé This study explores the development of laypeople's preferences for newly emerging climate engineering technology (CE). It examines whether laypeople perceive CE to be an acceptable back-up strategy (plan B) if current efforts to mitigate CO2 emissions were to fail. This idea is a common justification for CE research in the scientific debate and may significantly influence future public debates. Ninety-eight German participants chose their preferred climate policy strategy in a quasi-realistic

scenario. Participants could chose between mitigation and three CE techniques as alternative options. We employed a think-aloud interview technique, which allowed us to trace participants' informational needs and thought processes. Drawing on Huber's risk management decision theory, the study addressed whether specific CE options are more likely to be accepted if they are mentally represented as a back-up strategy. Results support this assumption, especially for cloud whitening. This result is especially relevant considering the high prevalence of the plan B framing in
CE appraisal studies and its implications for public opinion-formation processes.
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Résumé The aim of this paper is to present a theme situated within applied ethics studies, the ethics of geoengineering. Research on this subject has gained a boost in the last few years, when the inevitable debates concerning global warming have created a practical scenario, applicable in the future, a daring and provocative scenario: climate engineering through two types of technologies (solar radiation management and carbon dioxide removal). The objective of this article is to briefly point out the main and problematic paradigms in geoengineering. I will offer certain recommendations concerning the passage from social opportunity to morality in geoengineering, based on these. First, I will offer a working definition of geoengineering, as well as a short approach of the two types of climate manipulation, to familiarize the reader with the specificity of this research domain. I will then illustrate the research paradigms (reductionism and scientific instrumentalism) which caracterise the process of laboratory development and practical implementation, trying to refer in the end to the inconsistencies and the moral principles that may be broken as a result of the introduction of such technologies in the natural world.
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geoengineering, climate change, instrumentalism, moral, reductionism, sulphate aerosol spraying

ASPECTS ÉCONOMIQUES POUR L'ATTEINTE DE LA CARBONEUTRALITÉ

Böhringer, C. and T. F. Rutherford (2008). "Combining bottom-up and top-down." Energy Economics 30(2): 574-596.

We motivate the formulation of market equilibrium as a mixed complementarity problem which explicitly represents weak inequalities and complementarity between decision variables and equilibrium conditions. The complementarity format permits an energy-economy model to combine technological detail of a bottom-up energy system with a second-best characterization of the over-all economy. Our primary objective is pedagogic. We first lay out the complementarity features of economic equilibrium and demonstrate how we can integrate bottom-up activity analysis into a top-down representation of the broader economy. We then provide a stylized numerical example of an integrated model — within both static and dynamic settings. Finally, we present illustrative applications to three themes figuring prominently on the energy policy agenda of many industrialized countries: nuclear phase-out, green quotas, and environmental tax reforms.

Chan, W. N., et al. (2016). "Assessment of CO<inf>2</inf> emission mitigation for a Brazilian oil refinery." Brazilian Journal of Chemical Engineering 33(4): 835-850.

Currently the oil refining sector is responsible for approximately 5% of the total Brazilian energy related CO2 emissions. Possibilities to reduce CO2 emissions and related costs at the largest Brazilian refinery have been estimated. The abatement costs related to energy saving options are negative, meaning that feasibility exists without specific income due to emission reductions. The assessment shows that short-term mitigation options, i.e., fuel substitution and energy efficiency measures, could reduce CO2 emissions by 6% of the total current refinery emissions. It is further shown that carbon capture and storage offers the greatest potential for more significant emission reductions in the longer term (up to 43%), but costs in the range of 64 to162 US$/t CO2, depending on the CO2 emission source (regenerators of FCC units or hydrogen production units) and the CO2 capture technology considered (oxyfuel combustion or post-combustion). Effects of uncertainties in key parameters on abatement costs are also evaluated via sensitivity analysis.

Chen, H., et al. (2017). "Costs and potentials of energy conservation in China's coal-fired power industry: A bottom-up approach considering price uncertainties." Energy Policy 104: 23-32.

Energy conservation technologies in the coal-fired power sector are important solutions for the environmental pollution and climate change issues. However, a unified framework for estimating their costs and potentials is still needed due to the wide technology choices, especially considering their economic feasibility under fuel and carbon price uncertainties. Therefore, this study has employed a bottom-up approach to analyze the costs and potentials of 32 key technologies' new promotions during the 13th Five-Year Plan period (2016–2020), which combines the conservation supply curve (CSC) approach and break-even analysis. Findings show that (1) these 32 technologies have a total coal conservation potential of 275.77 Mt with a cost of 238.82 billion yuan, and their break-even coal price is 866 yuan/ton. (2) steam-water circulation system has the largest energy conservation potential in the coal-fired power industry. (3) considering the co-benefits will facilitate these technologies' promotions, because their break-even coal prices will decrease by 2.35 yuan/ton when the carbon prices increase by 1 yuan/ton. (4) discount rates have the largest impacts on the technologies' cost-effectiveness, while the future generation level affect their energy conservation potentials most.

Christiansen, V. and S. Smith (2015). "Emissions Taxes and Abatement Regulation Under Uncertainty." Environmental and Resource Economics 60(1): 17-35.

We consider environmental regulation in a context where firms invest in abatement technology under conditions of uncertainty about subsequent abatement cost, but can subsequently adjust output in the light of true marginal abatement cost. Where an emissions tax is the only available instrument, policy faces a trade-off between the incentive to invest in abatement technology and efficiency in subsequent output decisions. More efficient outcomes can be achieved by supplementing the emissions tax with direct regulation of abatement technology, or by combining the tax with an abatement technology investment subsidy. We compare the properties of these alternative instrument combinations.

De Cian, E. and T. Massimo (2012). "Mitigation Portfolio and Policy Instruments When Hedging Against Climate Policy and Technology Uncertainty." Environmental Modeling & Assessment 17(1): 123-136.

In this paper, we use a stochastic integrated assessment model to evaluate the effects of uncertainty about future carbon taxes and the costs of low-carbon power technologies. We assess the implications of such ambiguity on the mitigation portfolio under a variety of assumptions and evaluate the role of emission performance standards and renewable portfolios in accompanying a market-based climate policy. Results suggest that climate policy and technology uncertainties are important with varying effects on all abatement options. The effect varies with the technology, the type of uncertainty, and the level of risk. We show that carbon price uncertainty does not substantially change the level of abatement, but it does have an influence on the mitigation portfolio, reducing in particular energy R&D investments in advanced technologies. When investment costs are uncertain, investments are discouraged, especially during the early stages, but the effect is mitigated for the technologies with technological learning prospects. Overall, these insights support some level of regulation to encourage investments in coal equipped with carbon capture and storage and clean energy R&D.

Delhotal, K. C., et al. (2006). "Mitigation of Methane and Nitrous Oxide Emissions from Waste, Energy and Industry." The Energy Journal Multi-Greenhouse Gas Mitigation and Climate Policy.

Traditionally, economic analyses of greenhouse gas (GHG) mitigation focused on carbon dioxide (CO2) emissions from energy sources, while nonCO2 GHGs were not incorporated into the studies, due to the lack of data on abatement costs of non-CO2 GHGs. In recent years, however, increasing attention has been dedicated to the benefits of reducing emissions of non-CO2 GHGs such as methane and nitrous oxide. Increased attention to the potential role of these gases in a GHG reduction policy increased the need for better data on the costs of non-CO2 GHG abatement for countries and regions outside of the US and the European Union (EU). Using a net present value calculation, this analysis develops regionally adjusted costs per mitigation option and marginal abatement cost curves by region for use in economic models. The result is worldwide cost estimates for methane and nitrous oxide from waste, energy and the industrial sectors. This paper also demonstrates the ability to significantly reduce greenhouse gases from these sectors with current technologies and the low cost of methane and nitrous oxide relative to CO reductions.

Gallaher, M., et al. (2009). "Estimating the potential CO2 mitigation from agricultural energy efficiency in the United States." Energy Efficiency 2(2): 207-220.

Energy efficiency in agriculture is an underanalyzed aspect of a potential climate change mitigation strategy. According to the Fourth Assessment Report, experts report only medium agreement and medium evidence that energy efficiency can provide substantial reductions (Smith et al. 2007). This paper estimates the CO2 mitigation potential achievable through improvements in energy efficiency in the US agriculture sector. The data are presented in three formats: the cost data or break-even points of each technology, a marginal abatement supply curve expressed in terms of reduction in energy use by fuel category, and a marginal abatement supply curve expressed in terms of CO2 emission reductions by fuel category. The largest sources of energy use in the sector were identified as motors used in irrigation systems or other pumping operations; farm machinery such as tractors used in daily farm operations; and space conditioning, such as HVAC systems for livestock and crop-drying systems.

Huang, S. K., et al. (2016). "The applicability of marginal abatement cost approach: A comprehensive review." Journal of Cleaner Production 127: 59-71.

The Marginal Abatement Cost (MAC) methodology is widely used in climate change policies. Policy makers rely on MAC to assess feasible strategies and related costs to achieve emission reduction goals. This paper introduces a variety of MAC methodologies, aiming at solving diverse problems, which utilizes various calculable-logic, thus producing different results and implications. This study applies a mind mapping method to capture differentiation of MAC methods, and systematically classify MAC methodologies. The applicability path analysis was proposed, based on principles such as stakeholder type, decision-making objectives, cost concept, strategy mode and information scope. Our goal is to assess the applicability of different methodologies, to reduce misuse by policy-makers, and to serve as a guide for subsequent research, which might prompt and lead to the derivation of more consequential results in future studies. The results of this study suggest that the complex method is not always better than the simplified method because policy-makers are required to select the appropriate method according to the type of information needed. It may even be suggested that MAC could be reliable by ranking relative-value of options compared with baseline, rather than focusing on the absolute value of individual measures.

Jones, A. K., et al. (2015). "Developing farm-specific marginal abatement cost curves: Cost-effective greenhouse gas mitigation opportunities in sheep farming systems." Land Use Policy 49: 394-403.

Growing demand for agricultural produce, coupled with ambitious targets for greenhouse gas emissions reduction present the scientific, policy and agricultural sectors with a substantial mitigation challenge. Identification and implementation of suitable mitigation measures is driven by both the measures' effectiveness and cost of implementation. Marginal abatement cost curves (MACCs) provide a simple graphical representation of the abatement potential and cost-effectiveness of mitigation measures to aid policy decision-making. Accounting for heterogeneity in farm conditions and subsequent abatement potentials in mitigation policy is problematic, and may be aided by the development of tailored MACCs. Robust MACC development is currently lacking for mitigation measures appropriate to sheep systems. This study constructed farm-specific MACCs for a lowland, upland and hill sheep farm in the UK. The stand-alone mitigation potential of six measures was modelled, against real farm baselines, according to assumed impacts on emissions and productivity. The MACCs revealed the potential for negative cost emissions' abatement in the sheep industry. Improving ewe nutrition to increase lamb survival offered considerable abatement potential at a negative cost to the farmers across all farms while, lambing as yearlings offered negative cost abatement potential on lowland and upland farms. The results broadly advocate maximising lamb output from existing inputs on all farm categories, and highlight the importance of productivity and efficiency as influential drivers of emissions abatement in the sector. The abatement potentials and marginal costs of other measures (e.g. reducing mineral fertiliser use and selecting pasture plants bred to minimise dietary nitrogen losses) varied between farms, and this heterogeneity was more frequently attributable to differences in individual farm management than land classification. This has important implications for the high level policy sector as no two farms are likely to benefit from a generic one size fits all approach to mitigation. The construction of further case-study farm MACCs under varying farm conditions is required to define the biophysical and management conditions that each measure is most suited to, generating a more tailored set of sector-specific mitigation parameters.

Klinge Jacobsen, H. (1998). "Integrating the bottom-up and top-down approach to energy–economy modelling: the case of Denmark." Energy Economics 20(4): 443-461.

This paper presents results from an integration project covering Danish models based on bottom-up and top-down approaches to energy–economy modelling. The purpose of the project was to identify theoretical and methodological problems for integrating existing models for Denmark and to implement an integration of the models. The integration was established through a number of links between energy bottom-up modules and a macroeconomic model. In this integrated model it is possible to analyse both top-down instruments, such as taxes along with bottom-up instruments, such as regulation of technology choices for power plants and energy standards for household electric appliances. It is shown that combining the two kinds of initiatives reduces the emission-reducing effect of each of the instruments remarkably.

Krause, F. (1996). "The costs of mitigating carbon emissions: A review of methods and findings from European studies." Energy Policy 24(10): 899-915.

Conventional wisdom has it that top-down studies of mitigation costs are too pessimistic while bottom-up studies are too optimistic. In examining mitigation cost studies for Western Europe, this paper finds this interpretation to be flawed. The paper expands the analytical framework for interpreting mitigation cost studies, evaluates the treatment of no regrets options and other input assumptions in the various studies, and includes findings from recent integrated top-down/bottom-up modeling assessments not covered in the IPCC report. Based on these new elements, it is found that mitigation costs tend to be overestimated not only in top-down studies, but also in bottom-up studies. Given this pervasive bias toward pessimism, the body of existing mitigation cost assessments for Western Europe can be read as follows. Over the next three to four decades, a combination of tax shifts, market transformation instruments and policies to reform subsidies and internalize non-climatic externalities could cut carbon emissions in Western Europe by 40–50% relative to the base year, at no loss or at a gain in GDP. Averaged over the medium term and including a phase-in period, an economically optimal rate of implementing Western Europe's no regrets potentials is found to be in the neighborhood of 2% per year relative to base year levels.

Leeson, D., et al. (2017). "A Techno-economic analysis and systematic review of carbon capture and storage (CCS) applied to the iron and steel, cement, oil refining and pulp and paper industries, as well as other high purity sources." International Journal of Greenhouse Gas Control 61: 71-84.

In order to meet the IPCC recommendation for an 80% cut in CO2 emissions by 2050, industries will be required to drastically reduce their emissions. To meet these targets, technologies such as carbon capture and storage (CCS) must be part of the economic set of decarbonisation options for industry. A systematic review of the literature has been carried out on four of the largest industrial sectors (the iron and steel industry, the cement industry, the petroleum refining industry and the pulp and paper industry) as well as selected high-purity sources of CO2 from other industries to assess the applicability of different CCS technologies. Costing data have been gathered, and for the cement, iron and steel and refining industries, these data are used in a model to project costs per tonne of CO2 avoided over the time period extending from first deployment until 2050. A sensitivity analysis was carried out on the model to assess which variables had the greatest impact on the overall cost of wide-scale CCS deployment for future better targeting of cost reduction measures. The factors found to have the greatest overall impact were the initial cost of CCS at the start of deployment and the start date at which large scale deployment is started, whilst a slower initial deployment rate after the start date also leads to significantly increased costs.

Levihn, F. (2016). "On the problem of optimizing through least cost per unit, when costs are negative: Implications for cost curves and the definition of economic efficiency." Energy 114: 1155-1163.

For society and industry alike, efficient allocation of resources is crucial. Numerous tools are available that in different ways rank available options and actions under the aim to minimize costs or maximize profit. One common definition of economic efficiency is least cost per unit supplied. A definition that becomes problematic if cost take negative values. One model, where negative costs are not uncommon, is expert based/bottom up [marginal abatement] cost curves. This model is used in many contexts for understanding the impact of economic policy as well as optimizing amongst potential actions. Within this context attention has been turned towards the ranking problem when costs are negative. This article contributes by widening the discussion on the ranking problem from the MACC context to the general definition of least cost per unit supplied. Further it discuss why a proposed solution to the ranking problem, Pareto optimization, is not a good solution when available options are interdependent. This has particular consequences for the context of energy systems, where strong interdependencies between available options and actions are common. The third contribution is a proposed solution to solve the ranking problem and thus how to define economic efficient when costs are negative.

Levihn, F., et al. (2014). "Marginal abatement cost curves and abatement strategies: Taking option interdependency and investments unrelated to climate change into account." Energy 76: 336-344.

Firms usually have optimization tools for evaluating various investment options; policymakers likewise need tools for designing economically efficient policies. One such tool is the MACC (marginal abatement cost curve), used to capture the least-cost sequence of abatement options. Such curves are also used for understanding the implications of government policies for markets and firms. This article explores dynamic path-dependent aspects of the Stockholm district heating system case, in which the performance of some discrete options is conditioned by others. In addition, it proposes adding a feedback loop to handle option redundancy when implementing a sequence of options. Furthermore, in an energy system, actions unrelated to climate change abatement might likewise affect the performance of abatement options. This is discussed together with implications for climate change policy and corporate investment optimization. Our results indicate that a systems approach coupled with a feedback loop could help overcome some of the present methodological limitations.

Liu, S., et al. (2017). "Energy Consumption and GHG Emission for Regional Aluminum Industry: A Case Study of Henan Province, China." Energy Procedia 105: 3391-3396.

Aluminum industry is a typical energy-intensive and emission-intensive industry. Henan's aluminum output occupies the first for many years until 2013 in the whole country. We analyzed 18 applicable to aluminum smelting process and 8 energy-efficiency technologies to alumina production process. The Conservation Supply Curve (CSC) is used in this paper. It is an analytical tool which selects the economically feasible technologies. Three scenarios are simulated. Under the BAU, S1 and S2 scenario, the energy consumption of the aluminum industry will decrease by 19%, 25%, and 29% compared to 2014 level respectively. The emission mitigation of GHG in S1 and S2 scenario are 3.2 Mt CO_2e and 5.4 Mt CO_2e, compared to BAU scenario in 2030. In addition, sensitivity analysis is conducted. Finally, some policy implications are proposed.

Liu, X., et al. (2016). "Carbon pricing for low carbon technology diffusion: A survey analysis of China's cement industry." Energy 106: 73-86.

This study estimates the effect of using carbon pricing to promote the diffusion of low carbon technologies based on data collected from 78 cement companies in China. The analysis confirms that they are familiar with major energy saving and low carbon technologies in the sector and have made efforts in energy saving, but are lagging in terms of carbon management. An average payback time of 3.3

years is confirmed as the threshold for cement companies to determine technology investment. The adoptions of target technologies in this survey are at different stages; WHR (waste heat recovery power generation) systems have been largely diffused and the effect of carbon pricing is highly marginal for further adoption. On the other hand, levying a moderate carbon price, i.e., 60 Yuan/t-CO2, may accelerate the diffusion of EMOS (energy management and optimisation systems), recently introduced in China's cement industry. This research goes some way to clarifying the diffusion of low carbon technologies and provides implications for climate countermeasures for the target sector in China.

Lutsey, N. and D. Sperling (2009). "Greenhouse gas mitigation supply curve for the United States for transport versus other sectors." Transportation Research Part D: Transport and Environment 14(3): 222-229.

To compare transportation greenhouse gas mitigation options with other sectors, we construct greenhouse gas mitigation supply curves of near-term technologies for all the major sectors of the US economy. Our findings indicate that motor vehicles and fuels are attractive candidates for reducing GHGs in the near and medium term. Transport technologies and fuels represent about half of the GHG mitigation options that have net-positive benefits – so-called “no regrets” strategies – and about 20% of the most cost-effective options to reduce GHGs to 10% below 1990 levels by 2030.

Moran, D., et al. (2011). "Marginal Abatement Cost Curves for UK Agricultural Greenhouse Gas Emissions." Journal of Agricultural Economics 62(1): 93-118.

Abstract This article addresses the challenge of developing a ‘bottom-up’ marginal abatement cost curve (MACC) for greenhouse gas (GHG) emissions from UK agriculture. An MACC illustrates the costs of specific crop, soil and livestock abatement measures against a ‘business as usual’ scenario. The results indicate that in 2022 under a specific policy scenario, around 5.38 Mt CO2 equivalent (e) could be abated at negative or zero cost. A further 17% of agricultural GHG emissions (7.85 Mt CO2e) could be abated at a lower unit cost than the UK Government’s 2022 shadow price of carbon [£34 (tCO2e)−1]. The article discusses a range of methodological hurdles that complicate cost-effectiveness appraisal of abatement in agriculture relative to other sectors.

Newell, R. G., et al. (2013). "Carbon Markets 15 Years after Kyoto: Lessons Learned, New Challenges." Journal of Economic Perspectives 27(1): 123-146.

Carbon markets are substantial and they are expanding. There are many lessons from market experiences over the past eight years: there should be fewer free allowances, better management of market-sensitive information, and a recognition that trading systems require adjustments that have consequences for market participants and market confidence. Moreover, the emerging market architecture features separate emissions trading systems serving distinct jurisdictions and a variety of other types of policies exist alongside the carbon markets.This situation is in sharp contrast to the top-down, integrated global trading architecture envisioned 15 years ago by the designers of the Kyoto Protocol and raises a suite of new questions. In this new architecture, jurisdictions with emissions trading have to decide how, whether, and when to link with one another. Stakeholders and policymakers must confront how to measure the comparability of efforts among markets as well as relative to a variety of other policy approaches. International negotiators must in turn work out a global agreement that can accommodate and support increasingly bottom-up approaches to carbon markets and climate change mitigation.

Nordrum, S., et al. (2011). "Assessment of greenhouse gas mitigation options and costs for California Petroleum Industry facilities: The shape of things to come." Energy Procedia 4: 5729-5737.

The California Global Warming Solutions Act of 2006 sets a goal for the state to reduce its greenhouse gas emissions to 1990 levels by 2020. In preparation for implementation of a cap and trade program under this Act, Chevron has undertaken a detailed assessment of greenhouse gas mitigation options and costs. Such an assessment is key to making compliance decisions within the constraints of a given cap and trade regime. If the cap and trade market is minimally restricted (i.e., recognizes that climate change is a global issue and thus has no geographic restrictions and no set requirement for onsite emission reductions), facilities can make the best economic (and environmental) choices of where to 'make' emission reductions inside the facility fenceline and when to 'buy' the emission reduction allowances or credits on the market. The scope of the study included Chevron's two refineries and a large heavy oil steamflood production operation in California. This paper will discuss how mitigation technologies are identified and assessed, describe some of the key greenhouse gas mitigation alternatives of interest to the Chevron California facilities and present a business-based approach to analyzing mitigation costs. Technologies studied included energy efficiency, advanced energy (solar, wind, geothermal, biomass, nuclear, low temperature heat recovery) and carbon dioxide capture and storage (CCS). For each mitigation option, a consistent methodology, based on the International Petroleum Industry Environmental Conservation Association/American Petroleum Institute (IPIECA/API) Guidelines for Evaluation of Greenhouse Gas Emission Reduction Projects was used to assess baseline or 'business as usual' emissions, net emission reductions due to the project, capital cost, operating cost and any project benefits (e.g., reduced fuel use for energy efficiency projects). These values were then entered into a business evaluation tool to calculate a Net Present Value for each option. Key conclusions: •Broad involvement of various disciplines is needed to identify new alternatives for greenhouse gas mitigation technologies.•Other than CCS, options for significant reductions of refinery and petroleum production emissions were extremely limited in the facilities studied.•Since cost-effective, feasible options are limited for refineries and petroleum production facilities, availability of sufficient allowances and offsets is an important element if state goals are to be achieved.•Although a number of energy efficiency projects were identified, the cumulative total emissions reductions available through energy efficiency projects is minimal.•Renewable and advanced energy projects that generate electricity generally have very high mitigation costs, and may not greatly benefit facilities if emission caps apply only to direct emissions, since these projects reduce the quantity of purchased electricity rather than emissions from the facility itself (and are therefore not eligible for credit under most regulatory design schemes).•Renewable and advanced energy technologies for steam generation may have significant mitigation potential for heavy oil steamflood production. Further development and demonstration is needed to determine whether these technologies will be viable.•In order to support good business decisions, it is important that greenhouse gas mitigation technology evaluation be done in a manner consistent with other business evaluation processes.

Pommeret, A. and K. Schubert (2009). "ABATEMENT TECHNOLOGY ADOPTION UNDER UNCERTAINTY." Macroeconomic Dynamics 13(4): 493-522.

New technology has been credited with solving environmental problems by mitigating the effects of pollutants. We construct a general equilibrium model in which abatement technology is a real option and pollution's (negative) amenity value alters both risk aversion and the intertemporal elasticity of substitution. We derive the tax scheme such that in a decentralized economy agents adopt the abatement technology at the time that is socially optimal. We show that the higher the greenness of preferences, the earlier the adoption and the higher the optimal tax rate. We also obtain that adoption is fostered by uncertainty if the effective intertemporal elasticity of substitution is large enough, but is not affected by uncertainty if this elasticity is low. Moreover, the optimal tax rate, which only exists if the effective intertemporal elasticity of substitution is high, is an increasing function of uncertainty.

Rehan, R. and M. Nehdi (2005). "Carbon dioxide emissions and climate change: policy implications for the cement industry." Environmental Science & Policy 8(2): 105-114.

There is growing awareness that the cement industry is a significant contributor to global carbon dioxide (CO_2) emissions. It is expected that this industry will come under increasing regulatory pressures to reduce its emissions and contribute more aggressively to mitigating global warming. It is important that the industry's stakeholders become more familiar with greenhouse gas (GHG) emission and associated global warming issues, along with emerging policies that may affect the future of the industry. This paper discusses climate change, the current and proposed actions for mitigating its effects, and the implications of such actions for the cement industry. International negotiations on climate change are summarized and mechanisms available under the Kyoto Protocol for reducing greenhouse gas emissions are explained. The paper examines some of the traditional and emerging policy instruments for greenhouse gas emissions and analyses their merits and drawbacks. The applicability, effectiveness and potential impact of these policy instruments for the global cement industry in general and the Canadian cement industry in particular are discussed with recommendations for possible courses of action.

Rehl, T. and J. Muller (2013). "CO_2 abatement costs of greenhouse gas (GHG) mitigation by different biogas conversion pathways." Journal of Environmental Management 114: 13-25.

Biogas will be of increasing importance in the future as a factor in reducing greenhouse gas emissions cost-efficiently by the optimal use of available resources and technologies. The goal of this study was to identify the most ecological and economical use of a given resource (organic waste from residential, commercial and industry sectors) using one specific treatment technology (anaerobic digestion) but applying different energy conversion technologies. Average and marginal abatement costs were calculated based on Life Cycle Cost (LCC) and Life Cycle Assessment (LCA) methodologies. Eight new biogas systems producing electricity, heat, gas or automotive fuel were analyzed in order to identify the most cost-efficient way of reducing GHG emissions. A system using a combined heat and power station (which is connected to waste treatment and digestion operation facilities and located nearby potential residential, commercial or industrial heat users) was found to be the most cost-efficient biogas technology for reducing GHG emissions. Up to (sic) 198 per tonne of CO2 equivalents can be saved by replacing the "business as usual" systems based on fossil resources with ones based on biogas. Limited gas injection (desulfurized and dried biogas, without compression and upgrading) into the gas grid can also be a viable option with an abatement cost saving of (sic) 72 per tonne of CO2 equivalents, while a heating plant with a district heating grid or a system based on biogas results in higher abatement costs ((sic) 267 and (sic) 270 per tonne CO2 eq). Results from all systems are significantly influenced by whether average or marginal data are used as a reference. Beside that energy efficiency, the reference system that was replaced and the by-products as well as feedstock and investment costs were identified to be parameters with major impacts on abatement costs. The quantitative analysis was completed by a discussion of the role that abatement cost methodology can play in decision-making.

Timilsina, G. R., et al. (2017). "Development of marginal abatement cost curves for the building sector in Armenia and Georgia." Energy Policy 108: 29-43.

Armenia and Georgia are taking climate change agenda seriously and contributing to efforts for mitigating global climate change through various ways including preparation of low carbon development strategies for their future economic growth. The improvement of energy efficiency is one of the key elements of the low carbon development strategies. This study develops a methodology to estimate marginal abatement cost (MAC) curve for energy efficiency measures and apply in the building sector in both countries. The study finds that among the various energy efficiency measures considered, the replacement of energy inefficient light bulbs (i.e., incandescent lamps) with efficient light bulbs is the most cost effective measure in saving energy and reducing greenhouse gas (GHG) emissions from the building sector. Most energy efficiency improvement options considered in the study would produce net economic benefits even if the value of reduced carbon is not taken into account. While the MAC analysis conducted demonstrates the cost competitiveness of various energy efficiency measures in Armenia and Georgia, the study also offers a caution to policy makers to have supplemental analysis before prioritizing the implementation of these measures or introducing policies to support them

Vogt-Schilb, A. and S. Hallegatte (2014). "Marginal abatement cost curves and the optimal timing of mitigation measures." Energy Policy 66: 645-653.

Abstract: Decision makers facing abatement targets need to decide which abatement measures to implement, and in which order. Measure-explicit marginal abatement cost curves depict the cost and abating potential of available mitigation options. Using a simple intertemporal optimization model, we demonstrate why this information is not sufficient to design emission reduction strategies. Because the measures required to achieve ambitious emission reductions cannot be implemented overnight, the optimal strategy to reach a short-term target depends on longer-term targets. For instance, the best strategy to achieve European's −20% by 2020 target may be to implement some expensive, high-potential, and long-to-implement options required to meet the −75% by 2050 target. Using just the cheapest abatement options to reach the 2020 target can create a carbon-intensive lock-in and make the 2050 target too expensive to reach. Designing mitigation policies requires information on the speed at which various measures to curb greenhouse gas emissions can be implemented, in addition to the information on the costs and potential of such measures provided by marginal abatement cost curves. [Copyright &y& Elsevier]

Wegener, M., et al. (2019). "Unpacking carbon accounting numbers: A study of the commensurability and comparability of corporate greenhouse gas emission disclosures." Journal of Cleaner Production 211: 652-664.

The purpose of this study is to challenge the ability of carbon accounting to work as a commensuration process by exploring the ability of quantified greenhouse gas emissions data to communicate comparable—and therefore highly commensurable—carbon performance information. Comparability and commensurability are examined through the case study of a major oil and gas firm, and an empirical comparability test of the greenhouse gases emissions reported by oil and gas facilities from 19 different corporations between 2004 and 2015. Comparability ratings between facilities are developed based on mandatorily reported emissions and production levels. We provide evidence of a lack of comparability, and therefore commensurability, in reported greenhouse gas emissions. Information related to corporate-level greenhouse gas emissions could potentially mislead users into believing the firm has lower regulatory costs and/or less regulatory risk than it actually has. This study suggests that the collection and consolidation of facility level direct greenhouse gas emissions estimation could fail to produce highly commensurable and hence meaningful greenhouse gas emissions reports. © 2018 Elsevier Ltd

Yáñez, E., et al. (2018). "Unravelling the potential of energy efficiency in the Colombian oil industry." Journal of Cleaner Production 176: 604-628.

The oil and gas sector represents 39% of the world's total industrial final energy consumption, and contributes to around 37% of total greenhouse gas (GHG) emissions. This study investigates the potential for improvements in energy efficiency, and their implications for CO2 abatement, in the Colombian oil industry value chain. It also assesses the potential cost of conserved energy and mitigated CO2-eq. A bottom-up approach was used to identify energy efficiency measures based on an assessment of specific operational data at the process unit level. In total, 20 measures and technologies were identified and applied in 48 cases throughout the chain, representing energy savings of 15.8 PJ and GHG savings of 0.75 Mt CO2-eq per year. This accounts for 25% and 19% of the total energy consumption and GHG emissions, respectively. Ninety-six percent of the total energy savings come from measures that are already cost-effective and could be implemented in the short term. The results of this study offer a better understanding of the critical stages for energy and GHG savings potentials, as well as investment cost and revenue from a full value chain perspective, based on operational data processing.