European Battery Alliance

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Industrial Policy

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Status

☒Final	
☐In Progress. Please explain:	☐ Iterative Process – This year's results have been 100% achieved.
	☐ Delay – This year's results were not fully achieved.

Tracking Changes

Level of Dissemination

☒ EIT and InnoEnergy

☐ Public

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Executive Summary

This document contains the official information regarding activities done during 2020 related to Industrial Policy for the European Battery Industry, which refers to the complete value chain from mining for raw materials and all the way through to recycling of used batteries.

In this document, there will be specific focus on the general activities analyzed on a high level to show the progress during the year 2020.

Furthermore, four examples of actions linked to industrial policy for the European Battery Industry are described.

The actions described on high level are:

- Participation in the technical work of updating the Batteries PEFCR "High energy rechargeable batteries for mobile applications"
- Information on the new regulatory framework to the European battery industry
- Creation of MEP group Friends of Batteries
- Action to accelerate the European Battery Alliance

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Abbreviations and Acronyms

Table 0-1 Acronyms

ASIDI	Average System Interruption Duration Index
BAU	Business as usual
CAPEX	Capital expenditures
CBA	Cost Benefit Analysis
DER	Distributed Energy Resources
DMS	Distribution Management System
DSO	Distribution System Operator
EC	European Commission
EEGI	European Electricity Grid Initiative
EU	European Union
FD	Fault Detection / fault detector
EBA	European Battery Alliance
EV	Electric Vehicle
EIT	European Institute of Innovation and Technology
PEFCR	Product Environmental Footprint Category Rules

1 Introduction

The European Battery Alliance (EBA) officially launched by Vice-President Maroš Šefčovič in charge of the Energy Union on October 11th 2017, intends to act as a call addressed to the European industry to seize the opportunity of a technology, namely Battery, that will be at the core of the energy transition. The main goal of the EBA is indeed to create the necessary momentum to support the European Industry in the field of safe and sustainable batteries which is estimated to an amount to 250 b€ of an annual European market by 2025 (that covers the needs all along the value chain: power, transport and industry), and make European champions emerge as a credible alternative to North American and Asian players and to eventually avoid the risk for Europe to become fully dependent of foreign batteries.

Industrial Policy has been central in creating the European Battery Industry of such strategic importance.
This project report focuses on the high-level progress of some of the actions to spread industrial policy within the European Battery industry along the whole value chain.
EBA250 housed within EIT InnoEnergy, the industrial arm of the European Battery Alliance has been instrumental in spreading and applying the Industrial Policy for the European Commission.
These examples of actions taken to do this are in line with the general goals and objectives as specific originally when defining the EBA back in 2017.

1.1 Background

Following-up the political launching of the EBA, Vice-President Šefčovič gave mandate to EIT InnoEnergy to mobilize and steer the industry towards the delivery of first recommendations on enabling framework conditions to create a pan-European and cross-sectoral batteries ecosystem, capable of converting a technological leadership into competitive products and services. These recommendations formulated by the so-called EBA250, the industrial workstream of the EBA led by EIT InnoEnergy, notably contributed to the Strategic Action Plan on Batteries issued by the European Commission in May 2018. In practice, this process thus gave birth to a reinforcing and growing industrial ecosystem of stakeholders coming from the entire battery value chain and driven by the shared ambition of making Europe one major stakeholders in the Batteries sector in the coming years (see Figure 1).

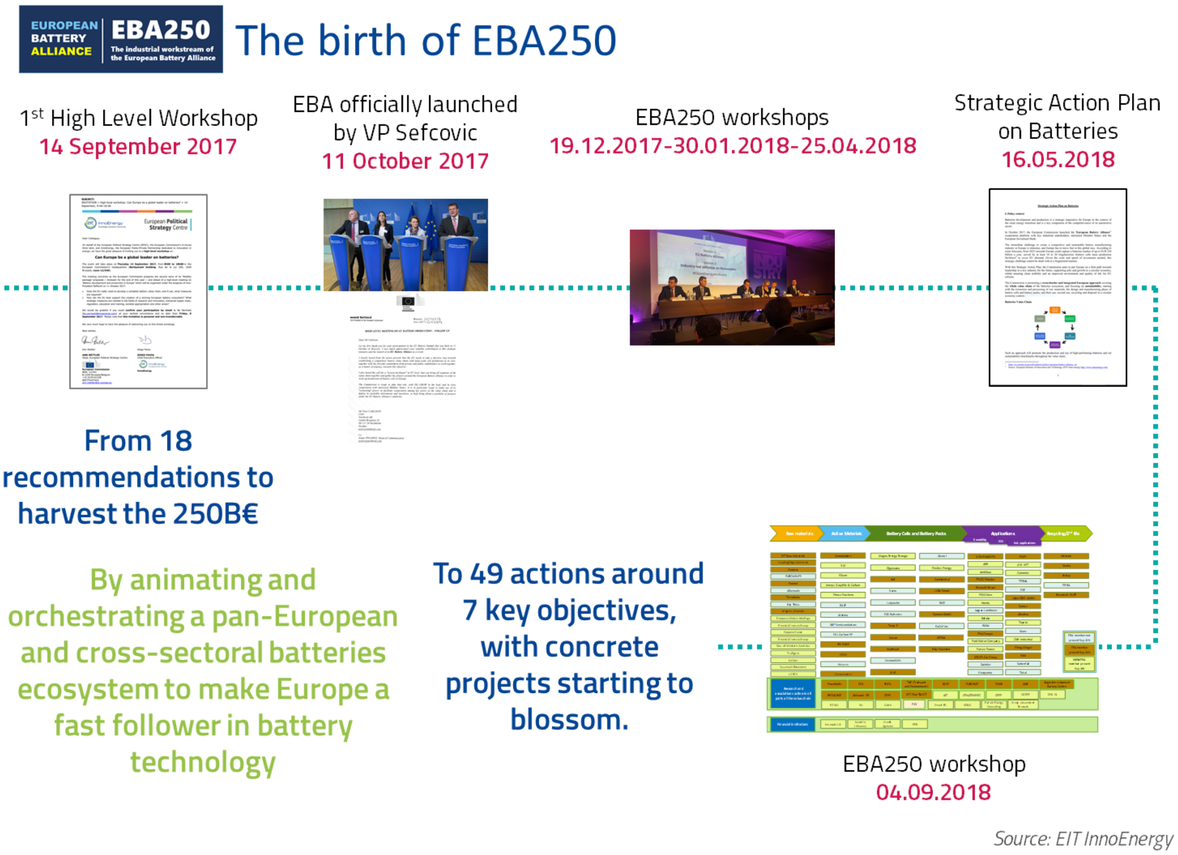

Figure 1. The birth of EBA250

The main idea behind development of EBA is to provide a framework that includes secure access to raw materials, support for technological innovation and consistent rules on battery production. The immediate objective is to create a competitive manufacturing value chain in Europe with sustainable battery cells at its core. To prevent a technological dependence on our competitors and capitalize on the job, growth and investment potential of batteries, Europe has to move fast in the global race. According to some forecasts, Europe could capture a battery market of up to €250 billion a year from 2025 onwards. Covering the EU demand alone requires at least 10 to 20 ‘gigafactories’ (large-scale battery cell production facilities), that is the reason why there is a requirement of a combined effort to address this industrial challenge.

In Figure 2, one can see the different key players for each step of the value chain when it comes to the production of batteries.

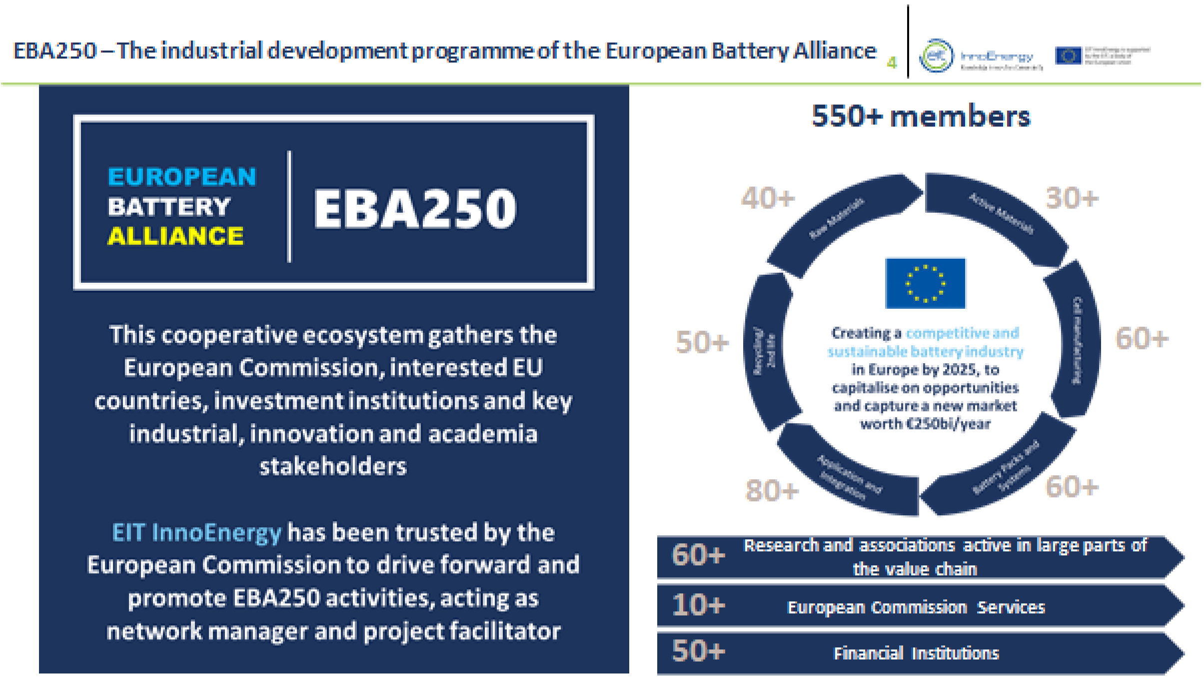

Figure 2. EBA250 and the number of members distributed over the European Battery Industry value chain (status as per October 2020. For more information on who these members are see https://www.eba250.com/about-eba250/network/

Within the strategic action plan for batteries defined by the European Commission, a comprehensive set of concrete measures were adopted to develop an innovative, sustainable and competitive battery "ecosystem" in Europe. The plan aims to:

- Secure access to raw materials for batteries from resource-rich countries outside the EU and facilitate access to European sources of raw materials, as well as access secondary raw materials by recycling in a circular economy of batteries
- Support scaled European battery cell manufacturing and a full competitive value chain in Europe. the Alliance is bringing key industry players and national authorities together and work in partnership with EU countries and the EIB to support integrated (cross-border) manufacturing projects at scale
- Strengthen industrial leadership through accelerated research and innovation support to advanced (e.g. Lithium-ion) and disruptive (e.g. solid state) technologies
- Develop and strengthen a highly skilled workforce along the whole value chain to close the skills gap. This includes providing adequate training at EU and country level, re-skilling and upskilling, and making Europe attractive for world-class experts in the field
- Support the sustainability of EU battery cell manufacturing industry with the lowest environmental footprint possible. This entails setting requirements for safe and sustainable battery production in Europe
- Ensure consistency with the broader EU regulatory and enabling framework (Clean Energy Strategy and Mobility Packages, trade policy, etc.)

See also figure below for the goals and objectives of the strategic action plan on Batteries:

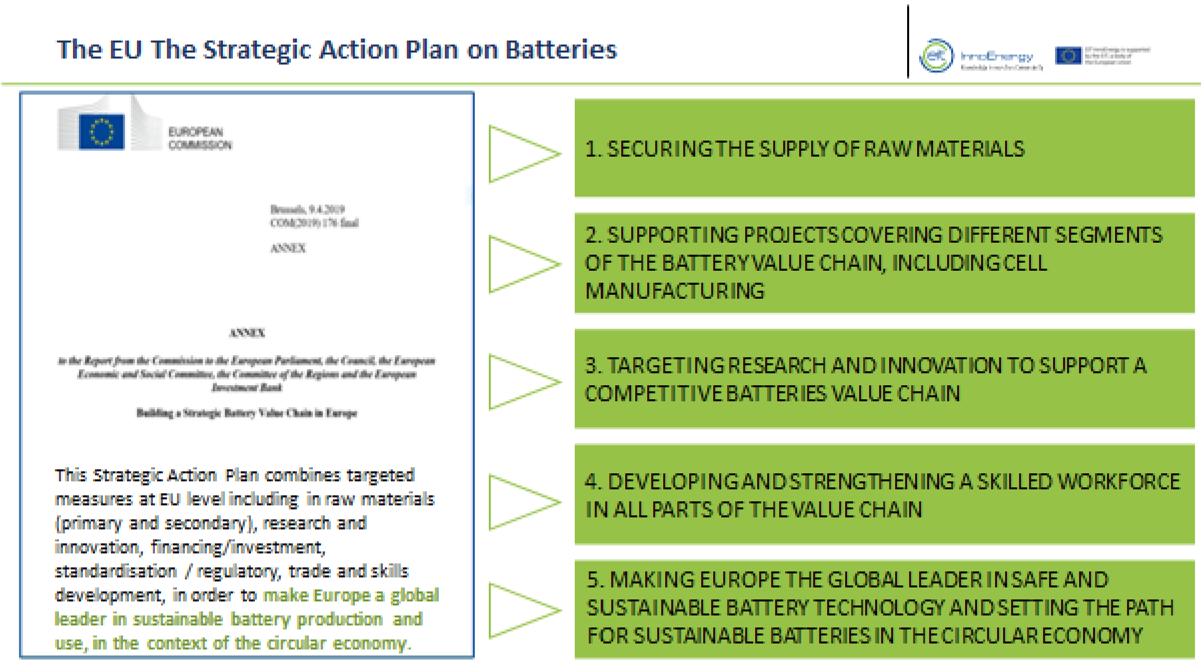

Figure 3. Goals and objectives of the strategic action plan on Batteries

1.2 Scope of the document

The main aim of this deliverable is to document the is to highlight some examples of the specific action taken by EBA250 during 2020 to spread and communicate industrial Policy within the European Battery Industry.

1.3 Structure of the document

The document comprises the following main sections:

- Participation in the technical work of updating the Batteries PEFCR “High energy rechargeable batteries for mobile applications”
- Information on the new regulatory framework to the European battery industry
- Creation of MEP group Friends of Batteries
- Action to accelerate the European Battery Alliance
- Conclusions

2 Industrial policy

Find in this section highlighted participation on behalf of the European Battery Alliance in the topic related to industrial policy.

2.1 Participation in the technical work of updating the Batteries PEFCR “High energy rechargeable batteries for mobile applications”

In 2020 EIT InnoEnergy decided to take part in the update of the Batteries PEFCR “High energy rechargeable batteries for mobile applications” that is coordinated by RECHARGE the advanced and rechargeable battery association.

The Batteries PEFCR is expected to become the reference tool for the new EU legislative instrument regulating batteries. In the revision process of the Batteries Directive 2006/66/EC conducted by DG ENV, and with the support of DG GROW for a sustainable manufacturing “ecosystem” for battery cells in the EU, the carbon footprint declaration (based on the GWP model of the batteries PEFCR) is proposed as a mandatory indicator. In addition, other indicators such as the resource depletion model may be considered by the Commission.
In parallel, DG ENV is also preparing a status change of Commission recommendation 2013/179/EU of 9 April 2013 “on the use of common methods to measure and communicate the life cycle environmental performance of products and organizations” and turn it into a regulation, making the use of the PEF mandatory for any “Green Claim” as well as for public sourcing.

In this context, it is important that the databases and models used in the PEF are updated with the support of the battery industry before being used in a legislation as the mandatory tool to compare environmental performance across products.

The aim of the Secretariat will be to provide Industry and the Commission with high-quality tools to assist in implementing the new legislative framework for batteries:

- An updated PEFCR, in a similar format to the existing one. This document should be the reference for the future “Green Claims” legislation.

- A detailed methodology (and possibly software specifications) providing a standardized calculation for the carbon footprint (and possibly other indicators) based on the models of the PEFCR and public databases, with a simple user interface enabling the transparency and auditability of the data input. This methodology would be the reference for the mandatory carbon footprint declaration of batteries placed on the EU market.

By taking actively part in this work, EIT InnoEnergy has also the possibility to engage one of our assets, Verkor directly in this work.

2.2 Information on the new regulatory framework to the European battery industry

The development of a competitive and sustainable European battery industry has been our mission since EIT InnoEnergy was trusted by the European Commission to drive the industrial workstream of the European Battery Alliance, EBA250.

The need for a supportive regulatory framework has been highlighted by our stakeholders along the entire value chain from the very start.
Already in 2019, EIT InnoEnergy has been closely following the work on the "Ecodesign preparatory study on Batteries" by the EC Commission and encouraged relevant stakeholders from the EBA250 network to take part in this important work and give their input in the design of the new regulatory framework that has been presented by the EU Commission in December 2020.

This year, the EU Commission was invited to present the ongoing work the EBA250 network in a virtual event on July 1st and to present the final proposal at another virtual meeting on December 15. This event received a lot of attention with more than 560 registered participants from the entire EBA250 network.
See agenda below.

Figure 4. Agenda Virtual Meet up – new regulation for batteries

EIT InnoEnergy welcomes this important piece of regulation that will influence the battery industry for many year to come and that will be the single most important tool that enables Europe to build a truly sustainable battery industry supporting Europe's transition to electrification.
In our opinion, there is every reason for European public bodies to embrace this regulation without further delays. A European Battery value chain based on ethically sourced raw materials, sustainable battery production and increased recycling efforts towards a circular economy is possible and supported with the measures laid out in this regulation.
We would like to highlight three key areas that we believe are of special importance to incentivize, support and ultimately steer the battery industry in the right direction.

- Declaration of a carbon footprint for industrial and EV batteries

We support the proposed measure to introduce a mandatory declaration of a carbon footprint that over time will be complemented with carbon footprint performance classes and maximum threshold values as a condition for the placement of batteries on the EU market. As stated in the regulation, such measures aim to contribute to the Union's objective of reaching climate neutrality by 2050 and fight against climate change, as stated in the new Circular Economy Action Plan, for a cleaner and more competitive Europe. Furthermore, it will be an important tool to create transparency towards the consumer.

- Sustainable batteries in a circular economy

The regulation forwards a couple of measures on that will help to increase recycling of all types of batteries, increase recycling efficiencies recovery of materials. Those measures are important to build resilient supply chains for the battery value chain as certain raw materials contained in batteries, such as cobalt, lead, lithium or nickel, are acquired from scarce resources which are not easily available in the Union, and some are considered critical raw materials by the Commission. We share the Commission's opinion that enhancing circularity and resource efficiency with increased recycling and recovery of those raw materials, will contribute to reaching that goal. An increased use of recovered materials would support the development of the circular economy and allow a more resource-efficient use of materials, while reducing Union dependency on materials from third countries. Concrete and ambitious targets for recycling efficiencies for those materials are an important step in this direction, before mandatory levels of recycled contents in batteries can be implemented, also taking into account that the amount of recycled battery material is still low and time should allowed to ramp up recycling capacities in Europe.

- Supply chain due diligence

The social and environmental risks of the extraction, processing and trading of raw materials for battery manufacturing purposes need to be addressed, especially in the view of the expected exponential growth in battery demand in the EU Assuring high ethical standards, in accordance with OECD Due Diligence Guidance, for raw materials is a key aspect to the overall sustainable profile of a battery. This measure will also help to create transparency and thereby enhance societal appropriation for the entire battery industry as a key industry in the green transition.

A summary of all the measures can be seen in the picture below:

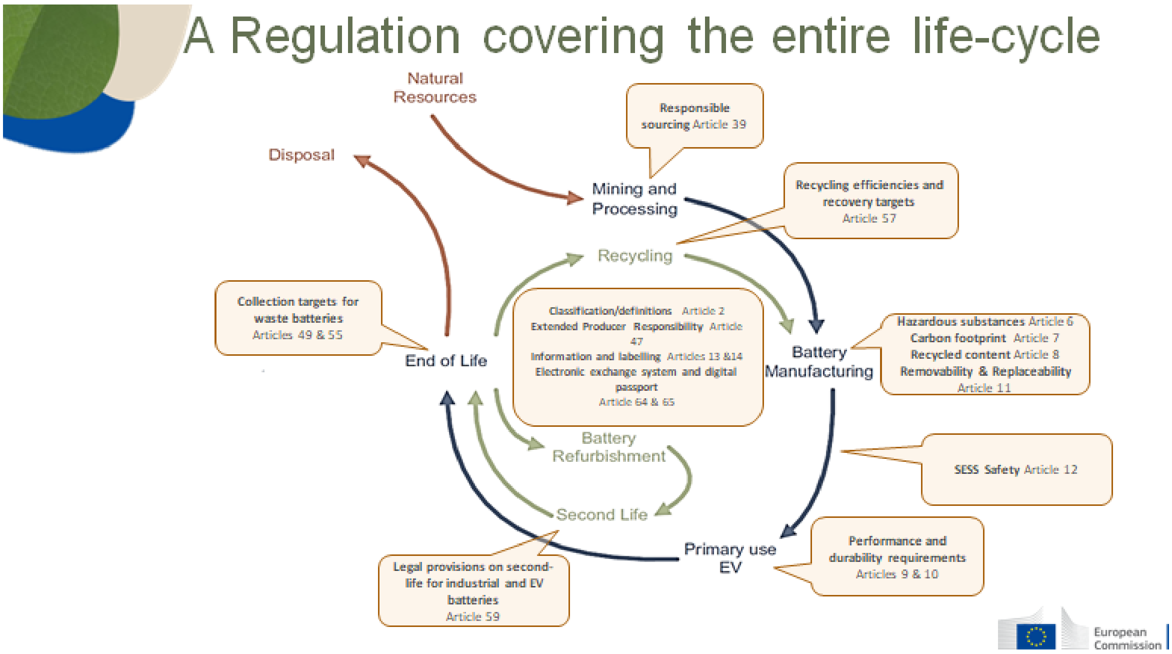

Figure 5. New battery regulation covering the entire battery value chain

In summary, EBA250 welcomes the proposed regulatory framework and is looking forward to the adoption of the preferred measures. We are convinced that this regulation will make Europe the global leader in sustainable battery production and is a important cornerstone in creating a competitive industry that will allow the European Union to capture a significant proportion of the entire value chain of the rapidly expanding global battery market, which has been estimated at 250B€ annually from 2025 onwards.
The link to the proposed documentation has been shared on the EBA250 website, as well as the link for its open consultation.

2.3 Creation of MEP group Friends of Batteries

As a joint action between the EC VP Maros Sefcovic office and EBA250 /EIT InnoEnergy the MEP (Ministers of European Parliament) group was launched and a public video conference meeting was held on the 14th of October.

Figure 6. Invitation for event Friends of Batteries

The European Battery Alliance (EBA) launched in October 2017 by Vice-President Maroš Šefčovič has provided a strong foundation for building a sustainable, competitive and resilient battery ecosystem in Europe. Attracting over 400 actors and generating investments of €100 billion, the EBA has become a unique European success story making the EU a new global hotspot for investment and bolstering our resilience.
The recovery from the COVID-19 crisis has prompted us to accelerate the work on Europe's strategic battery agenda. Given the critical importance of batteries for achieving a climate neutral, digital and more resilient Europe, and their proven potential for green growth and clean jobs (i.e. market value of €250 billion/a; up to 3-4 million new jobs), investment in batteries should be at the forefront of the recovery.

The strategic partnership with the European Parliament will be decisive for delivering on the strategic battery agenda, notably for establishing an enabling framework critical for securing priority battery investment and building a thriving ecosystem essential to their successful implementation and operation. The Friends of Batteries Group's support would notably be needed to:

- promote new regulatory solutions providing certainty and a level playing field for industry, promoting our competitive edge in sustainability and innovation, and facilitating project development (e.g. fast-track permitting). The adoption of a fit-for-future regulation for batteries (by 2022) will be key to securing batteries on the European market which are high performing, safe and sustainable and with a minimal environmental footprint;
- strengthen resilience of the EU's critical raw materials (CRM) supply chains essential for Europe's strategic sectors (e.g. e-mobility, renewables, security and defense). Implementation of the new Strategic Action Plan on CRM and strengthening of sustainable domestic sourcing and refining will be of strategic importance to reduce Europe's overdependence on its main global competitors;
- support industrial actors and Member States in boosting battery and critical raw materials-targeted investments (grants, loans and guarantees) from the European Investment Bank (which has committed to spend €1 billion in 2020) and the new recovery instruments (Cohesion Policy, Just Transition Fund, Innovation Fund), as well as support the second Important Project of Common European Interest - IPCEI for batteries (to be adopted in 2020);
- mobilise investment in research and innovation and ensure that Horizon Europe provides strong foundations for ambitious battery R&D activities, including on new generation batteries and integrating research in the industrial ecosystem to shorten the transition from laboratory to market;
- promote comprehensive educational, upskilling and reskilling programmes in the EU workforce to address

In addition, the Friends of Batteries Group could help foster implementation of battery projects on the ground, for instance by intensifying support for the Interregional Smart Specialisation Platform on Advanced Materials for Batteries, which currently encompasses 29 regions committed to developing innovative research ecosystems. Further efforts at sub-national level could include Members of the Group contributing to the preparation of local and regional strategies for recovery from the crisis and/or addressing the socio-economic challenges posed by the green transition (e.g. in the coal and carbon-intensive regions) by helping to identify battery investment projects generating high-value growth and jobs, mobilizing critical actors, seeking funding opportunities from the European funds or promoting social acceptance for sustainable industrial projects with a positive socio-economic impact.

The agenda of such event can be seen below:

Batteries: A European Success Story
Together towards a sustainable, competitive and resilient battery ecosystem in Europe
Wednesday, 14 October 2020, 15:00-16:30h
Video conference via WebEX: https://europarl.webex.com/meet/mmilosevic
Agenda
15:00 – 15:05 Welcoming words by **MEP Ismail Ertug**: S&D Vice-President for Transformation, Innovation and a Strong Digital Europe
15:05 – 15:10 **MEP Jerzy Buzek**: EPP Full Member of the ITRE Committee (ITRE Substitute)
15:10 – 15:15 **MEP Miapetra Kumpula-Natri**: Co-Chair of the EP Intergroup on "Climate Change, Biodiversity and Sustainable Development"
15:15-15:25 **Maroš Šefčovič**: Vice-President of the European Commission for Interinstitutional Relations and Foresight, in charge of the European Battery Alliance
15:25-15:35 **Representative** of the European Investment Bank (tbc)
15:35-15:45 **Questions and answers**
15:45-15:55 **Peter Carlsson**: Chief Executive Officer at Northvolt 15:55-16:05 **Diego Pavia**: Chief Executive Officer at InnoEnergy
16:05-16:15 **Julia Poliscanova**: Senior Director, Vehicles and EMobility at Transport & Environment 16:15-16:25 **Questions and answers**
16:25-16:30 Concluding remarks by the **MEP Ismail Ertug**

2.4 Action to accelerate the European Battery Alliance

Another joint action between EC VP Maros Sefcovic office and EBA250 /EIT InnoEnergy to align and boost industrial policy was taken in May of 2020.

The web-based conference was organized on 19th of May.

The main participants were:

- European Commission — VP Maros Sefcovic
- European Investment Bank EIB — VP Andrew McDowell
- EIT InnoEnergy — CEO Diego Pavia
- EIT InnoEnergy /EBA250 — Industrial Strategy Executive Bo Normark
- Top executives of 10 key industrial stakeholders in the European Battery Industry

The purpose of the event was to share insights both the intent and ambition from the EC and EIB side and in addition to listen to the needs of the industry as expressed by the top executives of key industrial stakeholders. This means in short to accelerate the European Battery Alliance.

The agenda of the event can be seen below and the complete presentations given is attached as annex I.

Welcome to the EBA@250 online meeting

2

Diego Pavia
CEO EIT InnoEnergy

InnoEnergy
Knowledge Innovation Community

Agenda

	Topic	Speaker
14:00	Welcome to the call. Housekeeping rules	Diego Pavia
14:03	Setting the frame: European recovery, potential role of Batteries/Electromobility	VP Maroš Šefčovič
14:10	The role of the EIB in the EU recovery	VP Mc Dowell
14:15	Key facts on battery industry pre and post corona	Bo Normark
14:22	7 speakers, with 3 messages each (7*3): - Mining & Conversion [2 audience] - Active materials [2 audience] - Cell Manufacturing [2 audience] - Packs and BMS for industrial/public transport	Vincent Ledoux Pedailles Francis Wedin Markus Vogt Kurt Vandeputte Peter Carlsson Ghislain Lescuyer Christophe Gurtner
14:44	First feedback from the VPs, and buffer	VPs
14:50	5 speakers, with 3 messages each: - Industry 4.0 - OEM [6 messages] - Utilities - Last Mile and 2-wheelers - Recycling	Emmanuel Lagarrigue Jens Wiese Bernard Salha Patrik Tykesson Philippe Knoche
15:15	First conclusion	Diego Pavia
15:20	Final conclusion and next steps	VPs
15:30	EOM	

Figure 7. Agenda “Action to accelerate EBA” Meetup

2.5 Competitiveness Progress Report (CPR)

The European Battery Alliance supported, throughout 2020, the European Commission with content on their first Competitiveness Progress Report and its underpinning analysis (the Clean Energy Transition – Technologies and Innovations Report), that were published on the 14^{th} of October as a part of the State of the Energy Union Package.

This important report on EU's competitiveness shows that the efforts of European Battery Alliance has led to significant progress but underlines that sustained action is needed over an extended period to ensure more investment in production capacity to capture a significant market share of the new and fast-growing rechargeable battery market.

Find the final report as well as the staff working document in Annex II.

2.6 ETIP Batteries Europe, the IWG for Batteries - Green Deal and Sector Integration Perspective

Furthermore, we also supported the SET Plan Conference in December under the umbrella of Batteries Europe. The input provided can be summarized as:

The ETIP Batteries Europe has its roots in the work done within the SET Plan Implementation Plan - action 7, and most of the experts from the SET Plan Temporary Working Group are now strongly involved in the ETIP. The platform is tasked with creating a European Strategic Research Agenda (SRA) along with corresponding Research Roadmaps covering all parts of the battery value chain, in addition to facilitating a unique forum for addressing cross-cutting topics such as education and skills, sustainability, safety and the role of digitization in battery technology.

Batteries Europe is the one-stop-shop for collaboration and information exchange for battery research in Europe, working towards a sustainable, competitive, and self-sufficient value chain and is a natural place to for different initiatives to interconnect proactively and create synergies.

Batteries as a key enabler for a low carbon -economy.

In several sectors, electrification will be a key to achieving a fossil-free society. Especially in the transition to a fossil-free energy and transport system, sustainable batteries will be a key technology. Sustainable battery production is not only an a prerequisite to achieve the ambitious climate goals of Europe but can also enable the emergence of a new, green and competitive industry that creates growth and jobs along the entire battery value chain for both new and established players.

Batteries are a variety of electrochemical energy storage technologies which allows to store energy so that it can be used at a later time or in another place- where the energy is needed, making it a true asset for energy system integration. Batteries can be used in a variety of applications, such as everyday appliances, stationary storage and mobility. Within energy system, batteries can provide a multitude of services for the electrical grid on all levels all the way to the customer behind the meter supporting. Electric vehicles as such gradually penetrate the market of flexibility services, including vehicle-to-grid services.

The ambitious Green Deal aims to make the economy sustainable and covers all sectors of the economy, including the transport and energy sectors as well as various industries and is thus relevant to the battery value chain. The Recovery communication has reconfirmed the pertinence of the Green Deal and has called for a green recovery. Carbon neutrality by 2050 and much steeper emission cuts by 2030 that will become legally binding through the European Climate Law will rise the importance of– and demand for - batteries to yet another level.

According to various Long-Term-Strategy scenarios, it is indicated that by 2050 roughly 80% of passenger cars, city busses and light-duty vehicles will have to be fully electric to achieve “net zero”. While batteries market will be driven by automotive sector, stationary storage should not be forgotten either. In energy system, the importance of stationary batteries will approach the role played by the pumped hydro storage already around 2030.

Charging is without doubt an important topic for the extended use of batteries and uptake of e-mobility – and as such addressed in the Sector Integration Strategy

The first measure is facilitation of the roll-out the necessary public charging infrastructure, starting with 1 million charging stations by 2025. To this end, the Commission will revise the Alternative Fuels Infrastructure Directive, TEN-T regulation and will mobilise financial support instruments. The second measure is accelerated installation of charging points in buildings thanks to the upcoming Renovation Wave initiative.

The Green Deal and Recovery plan will boost also stationary storage. Increased demand will be coming from the Renovation Wave and the upcoming Offshore renewable energy strategy. As batteries are easy to deploy technology, they have the best chances, at least in the nearest years.

In summary, batteries are a key enabler for the green transition – but Europe has to act fast and coordinated to continue building a domestic battery industry and develop skills to maintain this industry in Europe.

Holistic approach to supporting R&I across the Battery Value Chain

Battery research and development requires a continuous stepwise progression from concept to commercial product maturity and utilisation. To establish long term industrial technology leadership, continuous research is a prerequisite, necessary to being technologies to maturity. To build a strong "future-proof" battery value chain, a stable continuity of funding research and innovation across the entire value chain is essential.

Regional, National and European R&I funding providers grant the means to the successful creation, development and deployment of new competitive technology. Their funding mechanisms are however diverse with respect to TRL level development, segment of the value chain addressed and approach. Batteries Europe’s stakeholders recommend European, National and Regional R&I funding bodies supporting battery research, to provide information of both funded research projects and an overview of their strategic focus areas in the field, in the framework of the SET Plan reporting. This will facilitate the identification of gaps in the funding and any neglected topics, which if not addressed could lead to weakness in the value chain and thus a loss in industrial momentum.

3 Conclusions

In October 2017, InnoEnergy got the mandate from Vice-president Maroš Šefčovič of the European Commission to lead the implementation of the European Battery Alliance (EBA). The objective of the EBA is to capture the annual 250B€ new business across the battery value chain – from mining to recycling – in Europe by 2025.

Since then, the detailing of- and implementation of Industrial Policy to create this new European Battery industry has been crucial for the record-breaking industrial growth.

EBA250/ EIT InnoEnergy has been instrumental in performing actions during 2020 to spread and implement the industrial policy within the European Battery Industry.

The progress and growth achieved during the year has proven this.

This report brings up some examples of the actions taken to implement the Industrial Policy.

Annex I

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EUROPEAN BATTERY ALLIANCE | EBA250

Accelerating the European Battery Alliance (EBA)

At the core of the EU economic recovery - post Corona

Call with VP Sefcovic and VP Mc Dowell
Tuesday 19th May 14:00 to 15:30

Welcome to the EBA@250 online meeting

Diego Pavia

CEO EIT InnoEnergy

eit InnoEnergy
Knowledge Innovation Community

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European recovery, and potential role of an accelerated EBA

Maroš Šefčovič
Vice-President for Interinstitutional Relations and Foresight
European Commission

Andrew McDowell

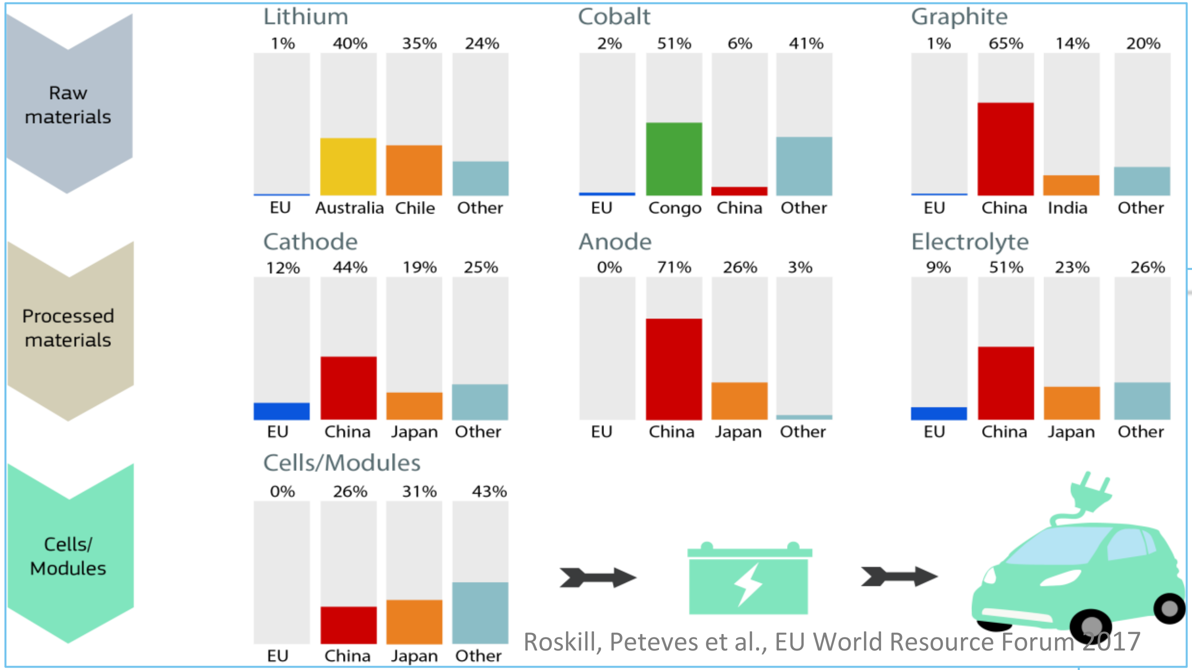
Vice-President

European Investment Bank

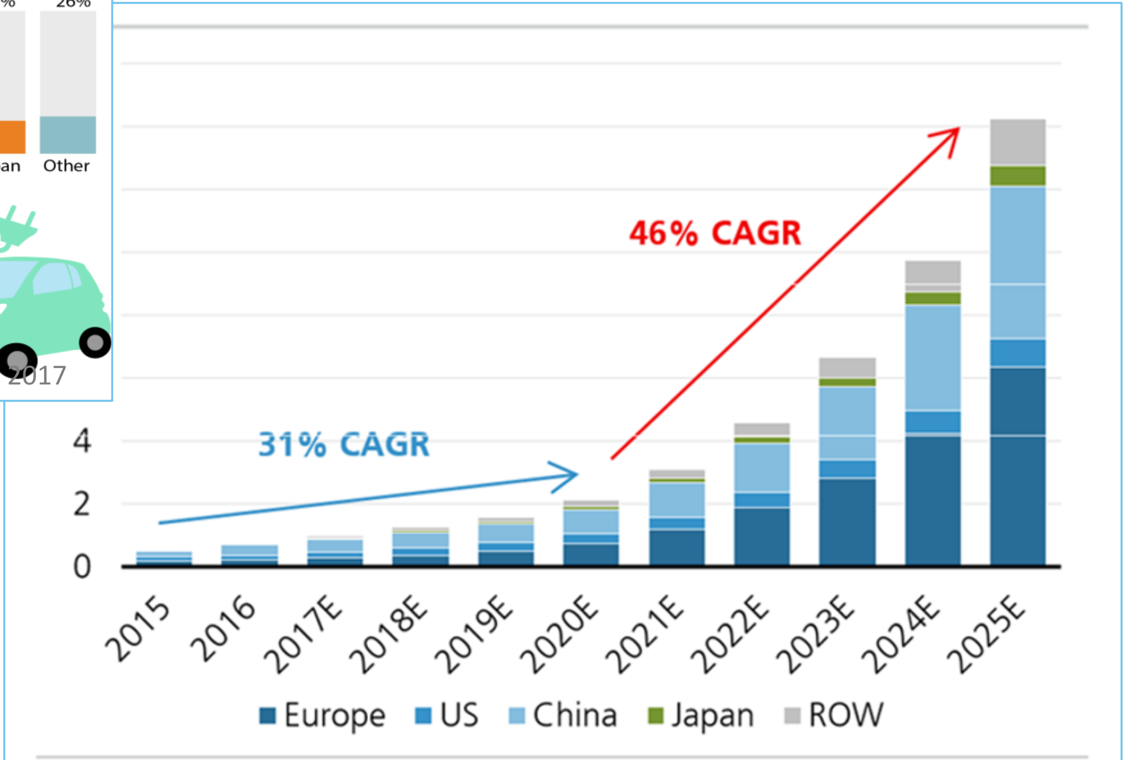
Key facts on battery industry (pre and post corona)

Bo Normark
Industrial Strategy Executive
EIT InnoEnergy

Starting point 2017

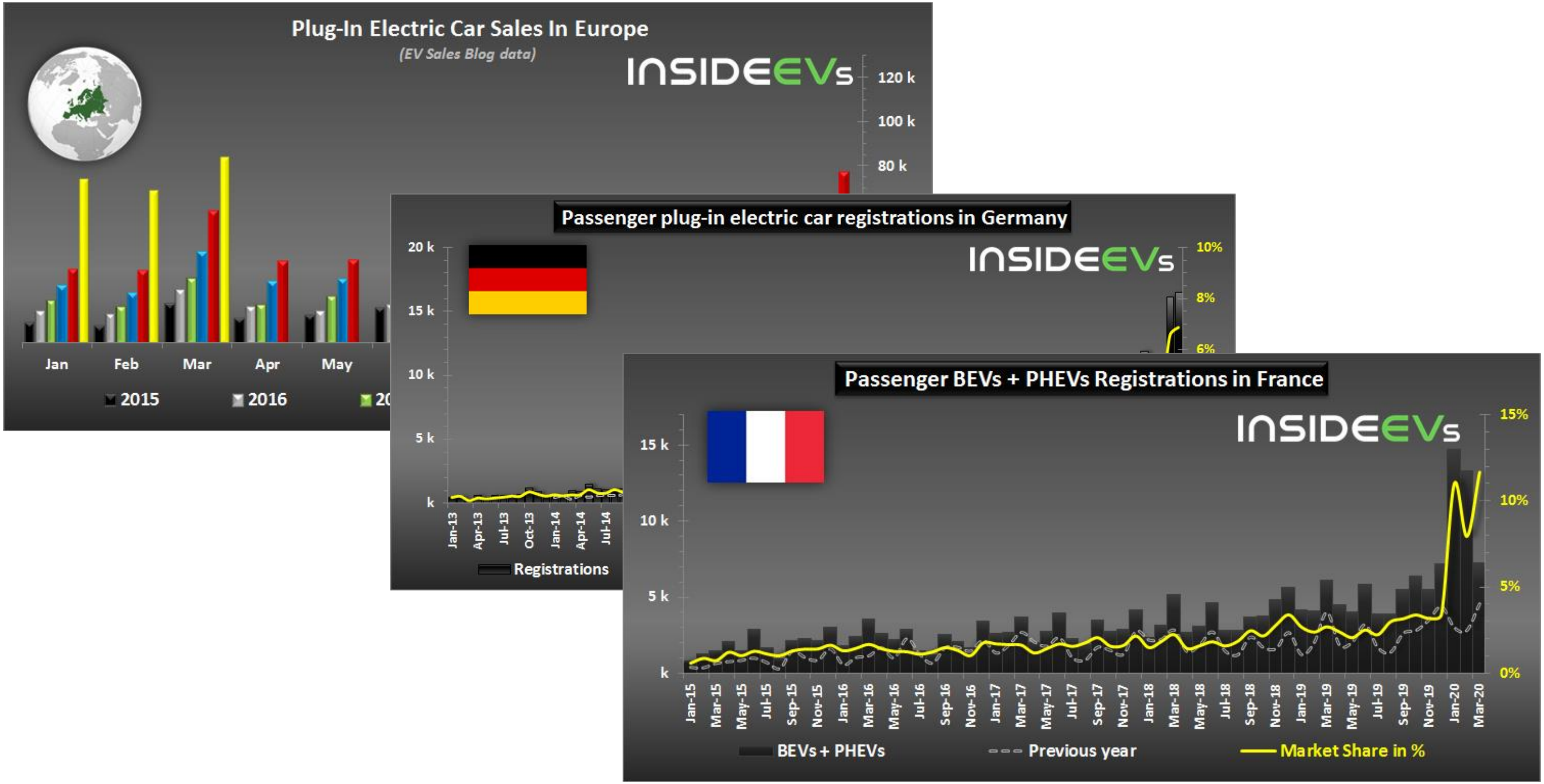


Roskill, Peteves et al., EU World Resource Forum 2017

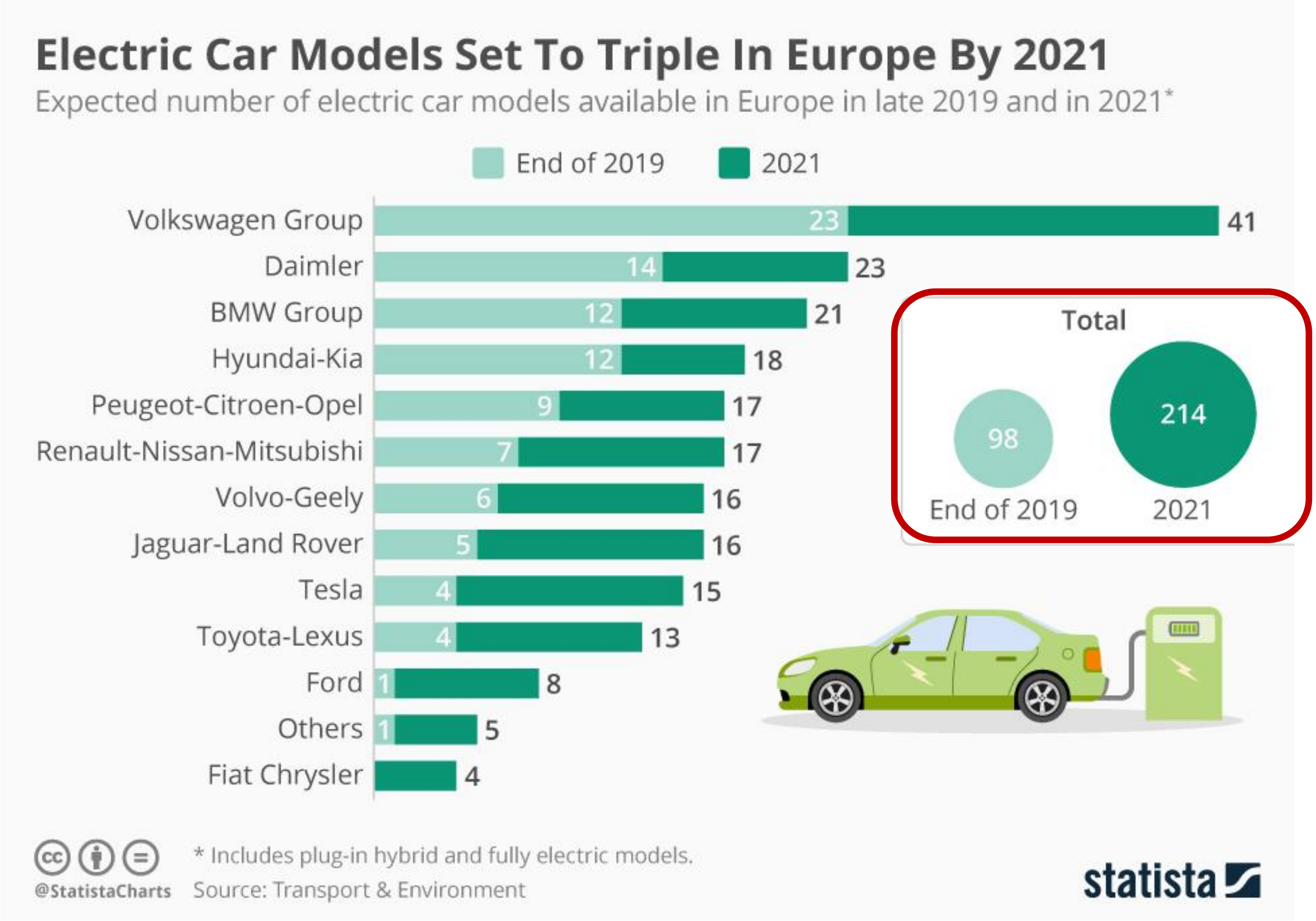


Source: UBS estimates

So what happened with the ”Tipping Point” ?

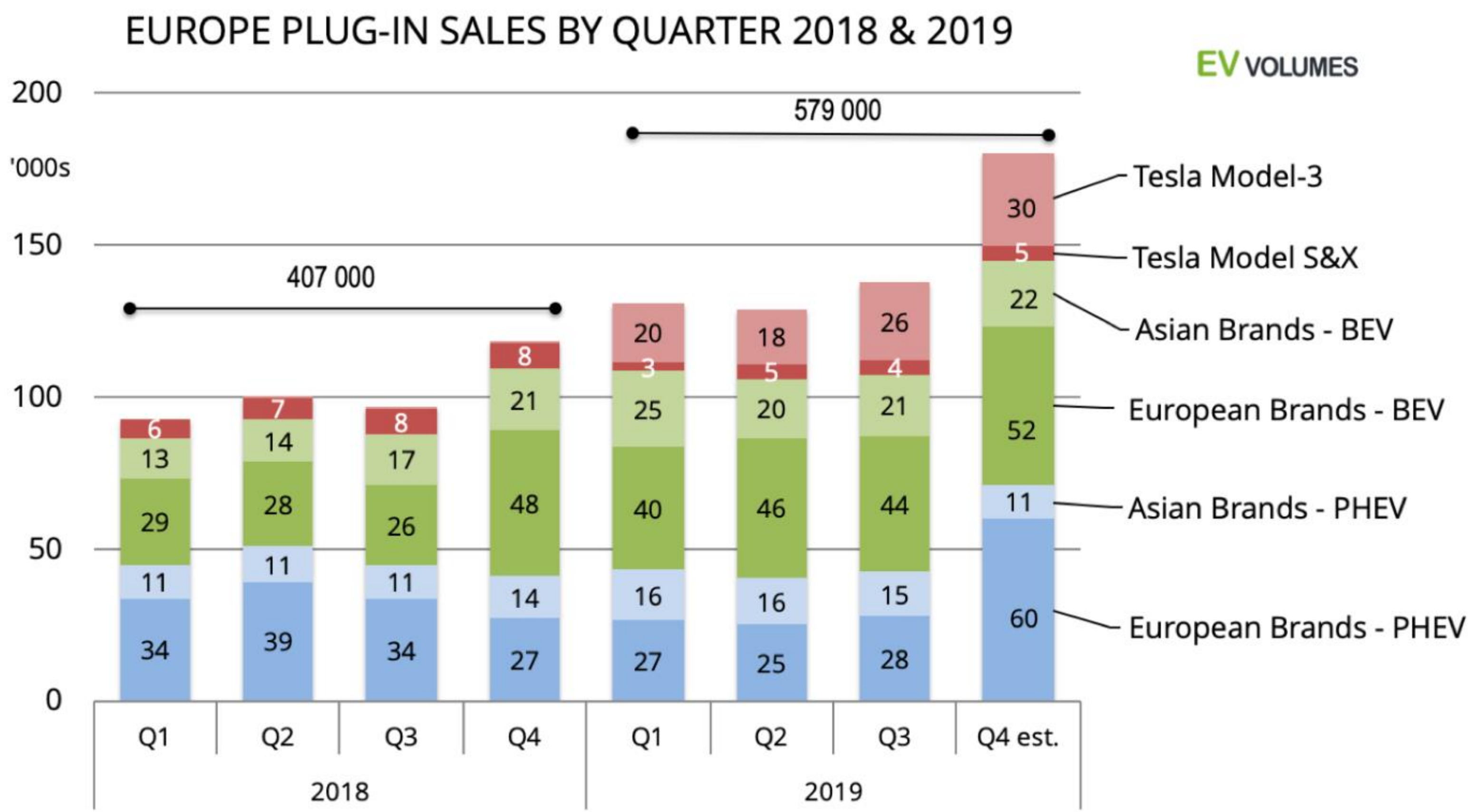


Avaliable eV models by brand: huge increase 2019 to 2021



70 %
EU Brands

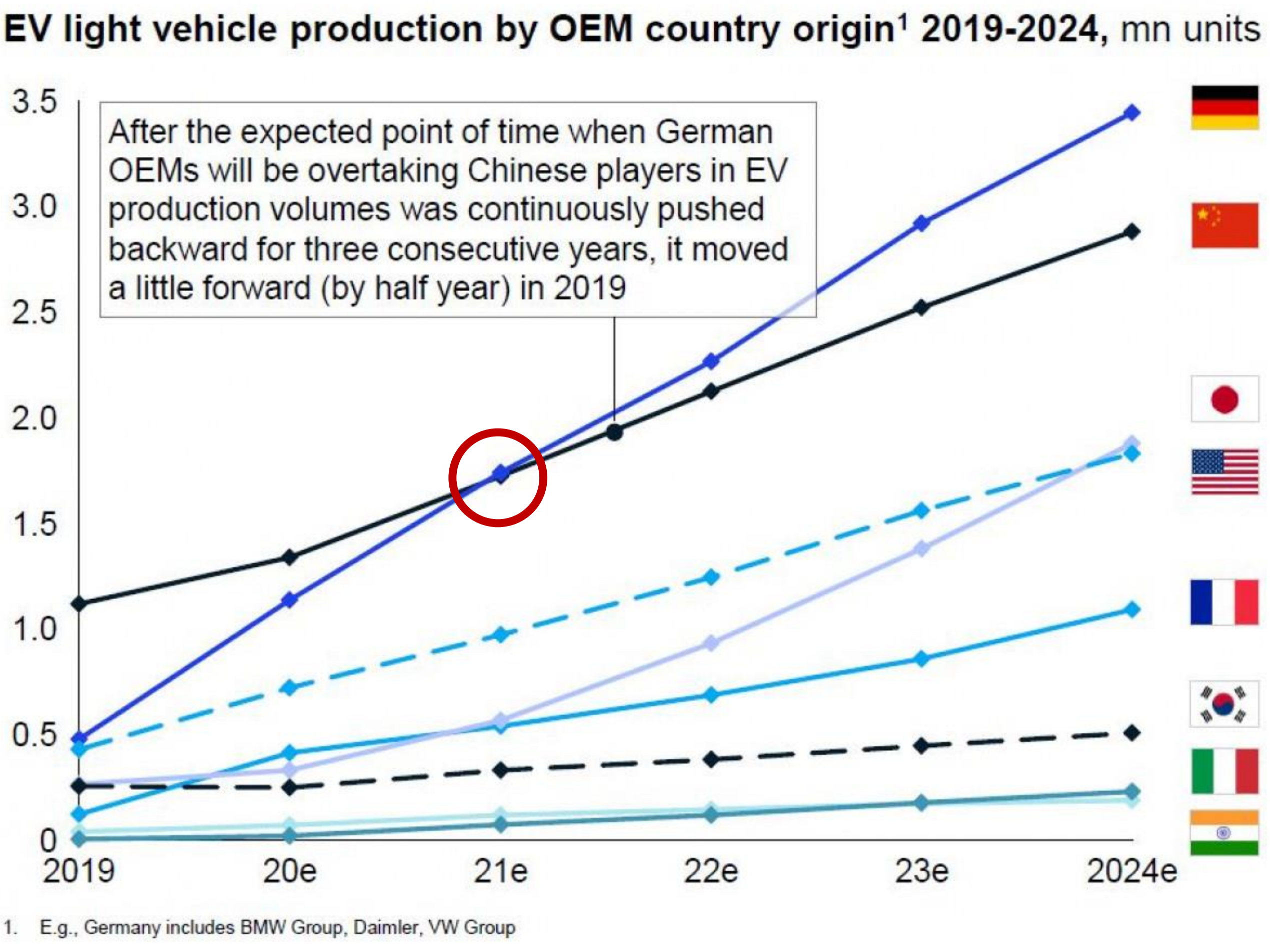
European Brands market share



65 %
EU Brands

Source: EVVolumes

Europe leading in EV manufacturing by 2023



https://www.cleanenergywire.org/news/german-carmakers-become-global-ev-market-leaders-2021-mckinsey

Europe capturing market share in cell production

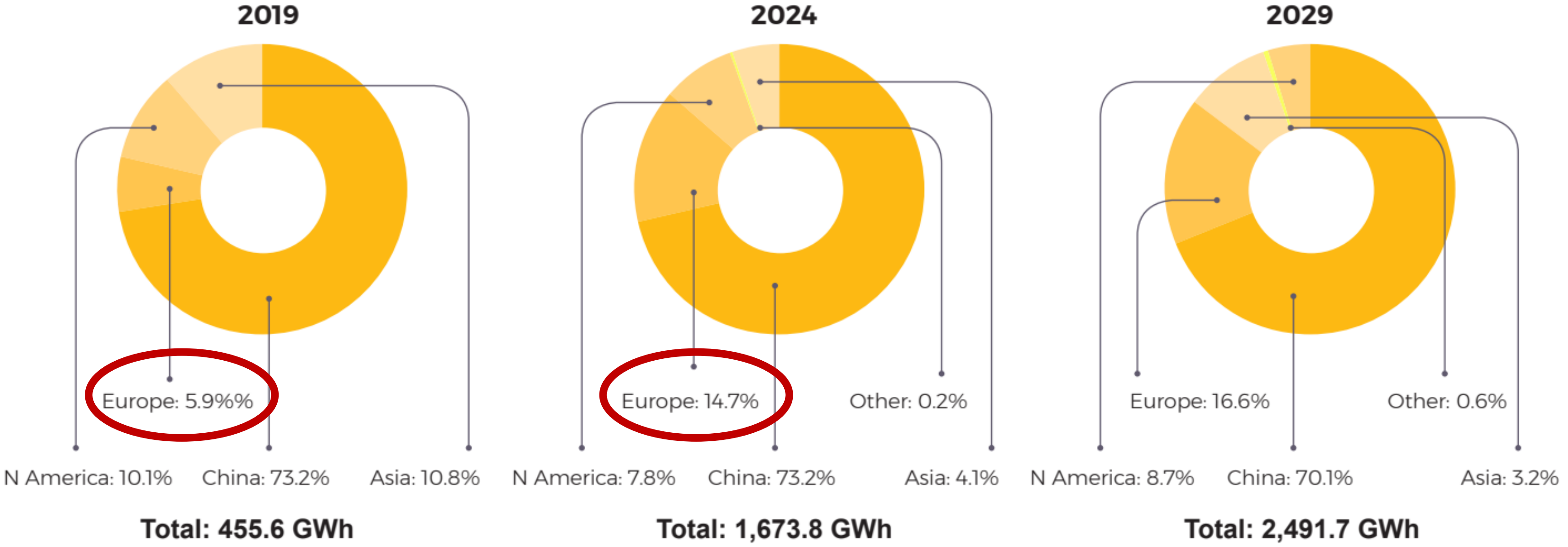
EUROPEAN BATTERY ALLIANCE EBA250

BENCHMARK | LITHIUM ION BATTERY MEGAFACTORY ASSESSMENT
APRIL 2020

BENCHMARK MINERAL INTELLIGENCE
www.benchmarkminerals.com

LITHIUM-ION BATTERY MEGAFACTORY TRACKER CONTINUED...

Megafactory Capacity by Region



Source: Benchmark Mineral Intelligence

European investments along the value chain, unaffected

Unaffected by Corona

13-Feb-2020 - BASF SE

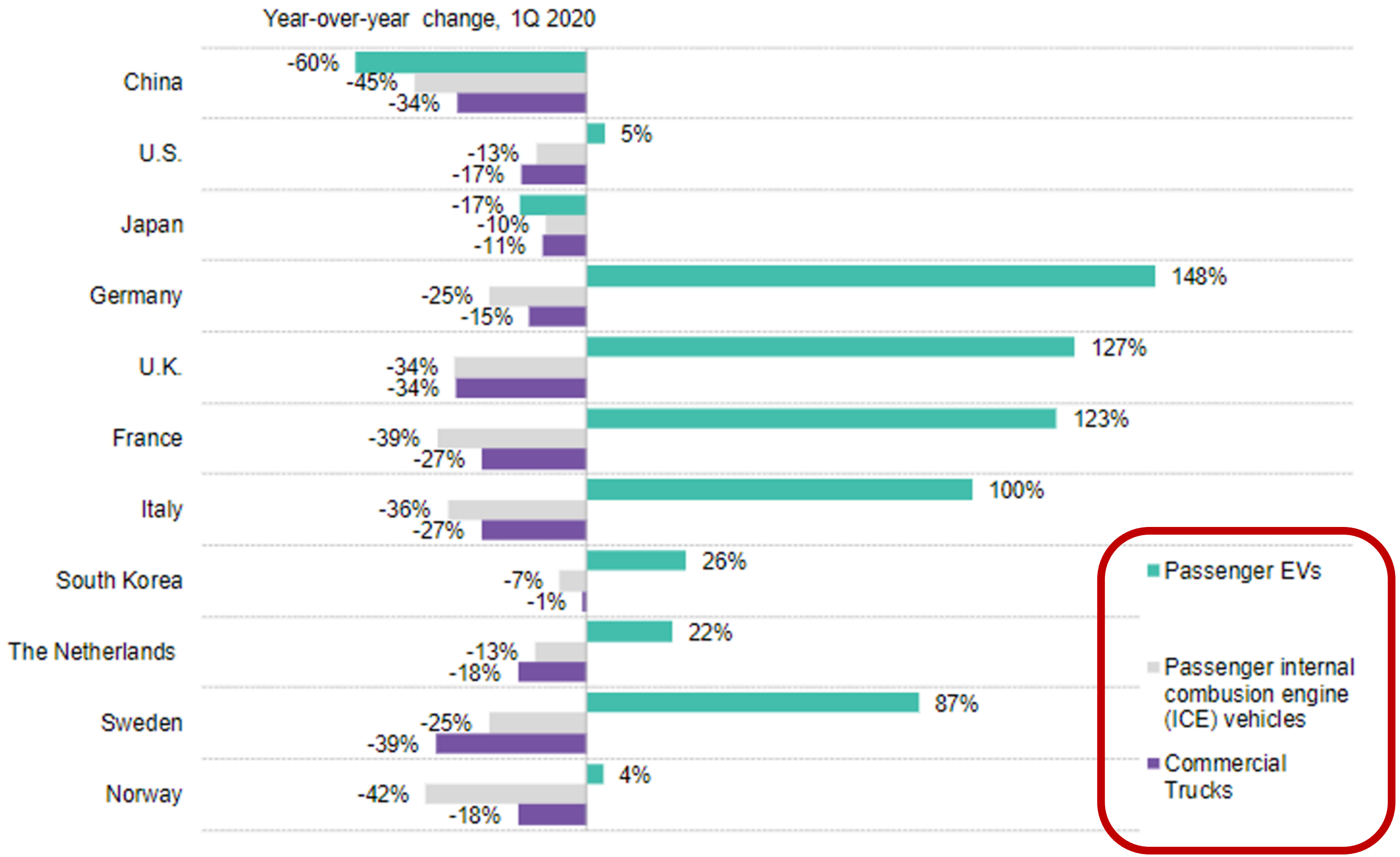
BASF announces Schwarzheide, Germany, as location for cathode active material production in Europe

Umicore completes acquisition of cobalt refining and cathode precursor activities in Finland

Infinity Lithium secures EU funding to develop Spanish San Jose lithium project

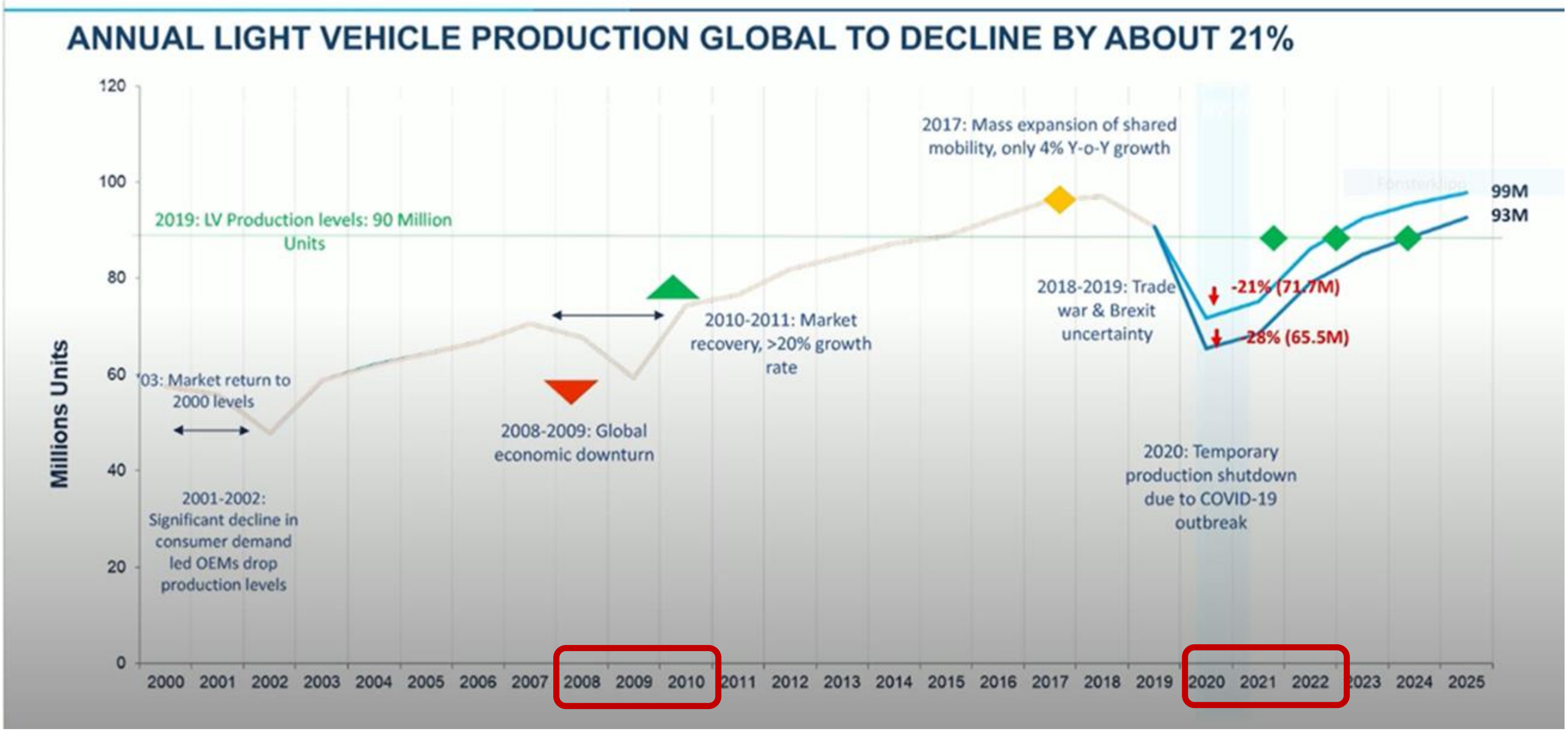
Corona effect on the automotive market Q1 2020

Year-over-year change in vehicle sales, 1Q 2019 and 1Q 2020



Source: BloombergNEF. Notes: Gasoline and diesel cars include hybrids and mild hybrids. We revised preliminary sales data in our previous Covid-19 tracker (web / terminal) with official information. The most notable change from what was previously reported was in Italy, where according to the latest EV sales data 1Q 2020 saw a 100% increase from 1Q 2019.

So the question is “How will Europe/World come out from the crisis?”



Source: Frost & Sullivan Mobility Experts April 2020

Key messages from the industry

Vincent Ledoux Pedailles
Executive Director
Infinity Lithium

1. Europe **imports 100% of Li chemicals** and is greatly **exposed to China**. New lithium industry in Europe is developing fast and **Infinity Lithium** (hard rock) could be the **first producer who helps de-risk** the battery supply chain

2. New lithium industry in Europe by **2023** is possible: **independence** from Chinese supplies, fully **environmental compliant, 20,000 jobs, €4Bn/y revenues and tax**

3. ***Need:***
   - **Fast permitting**
   - Support innovation for environmentally friendly processes
   - **Front loading financial support** (like EBA BIP by EIT InnoEnergy)

Francis Wedin
Managing Director
Vulcan Energy Resources

VULCAN ENERGY

1. EU can become the **world leader** in sustainable battery materials production by domestically producing **a world-first** battery grade **Zero Carbon Lithium hydroxide,** by 2023.

2. **Vulcan** (in the Upper Rhine Valley) will combine the extraction of lithium from sub-surface naturally heated brines, together with renewable geothermal energy production, **avoiding CO2 equivalent** to the annual emissions **of Spain**. Can represent **20%+ of EU needs. No mining required.**

3. ***Need :***
   - **Fast Permitting**
   - **Frontloaded financial support** (assist with completion of Bankable Feasibility Study).

Markus Vogt
Head of Business Management,
Battery Materials
BASF

BASF
We create chemistry

1. ***Need*** of establishing an **equal playfield for market participants in Europe**: Despite global differences in environmental standards, health and safety for workers and products, fairness in **product costing of locally manufactured vs. imported products needs to be ensured**.

2. ***Need*** of **ensuring fair competition** in line with actual regulation: Close loopholes for imports, such as Chinese goods routed via tax-exempted countries into the EU, and **react on subsidies and taxation in other countries and regions (EU: subsidies on innovations; ROW: subsidies for production).**

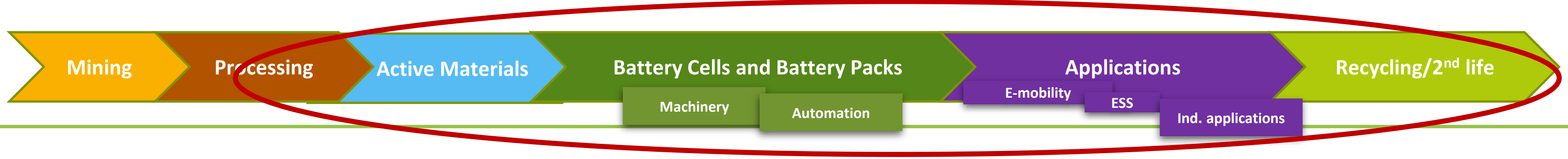
3. ***Need*** of putting clear rules and regulations in place for the e-mobility value chain: **Don’t delay CO2 targets, provide a clear basis for sustainability measures (e.g. battery passport), and a binding quota for recycling**.

Kurt Vandeputte
Senior Vice President
Umicore

1. Impact of Covid19 **on __active materials__:**
   - **Temporary** adjustment of operation levels in our Asian cathode material production plants. Product and production process innovation activities in Belgium were **marginally** affected.
   - **Continued commitment** to the planned innovation roadmap and production capacity expansion (eg. in Poland).

2. Impact of Covid19 **on __recycling__:**
   - Strong focus on **further upscaling of the recycling technology** based on the learnings of the demonstration plant in Belgium.
   - **Continued commitment** to the installation of **large-scale,** safe and lowest environmental impact **EOL-battery recycling capacity in Europe**.

3. ***__Need__*** for **fast, smart and ambitious regulatory frameworks and technologies** supporting circularity, CO_2-reduction, resource-efficiency, reciprocity, fair competition… by **introducing ambitious targets** for EOL-battery collection, recycling efficiency, environmental impact labeling, recycled content usage, traceability… to **create a cost-competitive, high-performance and sustainable European Battery Industry**.



Peter Carlsson
CEO
Northvolt

northvolt®

1. *Impact of Covid19:*
   - **After some temporary slow downs** (engineers and equipment not allowed to enter the EU), **Northvolt confirms plans** to the production capacity expansion.

2. *Important **economic and growth spill overs** of an **industrial** battery value chain:*
   - The **Northvolt Skellefteå** site has attracted **50+** new companies and businesses into the region. The region is expected to grow from **75 000 to 100 000** inhabitants and **public investments €4bn** in the region in the next 10 years. Similar development can be expected on other sites e.g. Germany, Poland and future.

3. ***Needs:***
   - Ensure **free movement workers** entering the EU - important for upscaling battery industry and ongoing construction
   - **EU green recovery:**
     1. Don't lower **political ambitions**: enforce new battery regulation and green vehicle standards
     2. Financial **investment boost and risk sharing** for large scale investments along the entire **strategic value chain**: components, machinery, raw materials etc.
     3. Use **public financial** tools to stimulate green tech i.e. public procurement

Ghislain Lescuyer
CEO
SAFT

1. *Impact of Covid:* Some temporary slowdown/shutdown in some countries, Saft is **again operating at full speed in every country** where we have factories.

2. *Contribution to accelerated EBA:* Early 2020, **Total/Saft and PSA/Opel** announced to develop EV battery manufacturing in Europe. The ambition is to **invest up to €5 billion**, in production capacity of **48 GWh** (France and Germany), which will also lead to the **creation of thousands of direct and indirect jobs** in those two countries.

3. ***Needs***:
    - Continuous **support from MS and EU**
    - Robust European regulation around the **CO2 footprint of cell manufacturing, including the upstream value chain**
    - Fair competition (**reciprocity, opening markets**) both inside and outside Europe

Mining | Processing | Active Materials | Battery Cells and Battery Packs | Applications | Recycling/2nd life

Machinery | Automation | E-mobility | ESS | Ind. applications

Christophe Gurtner
Chairman & CEO
Forsee Power

FORSEE POWER

1. *Impact of Covid:* From an **80% growth to a 30% growth**, with “gas hype” troubling the picture

2. ***Need***:
   - EU local authorities (i.e. public procurement) to accelerate **electrification of their fleet**, showing the way to the general public.
   - Stablish LEZ (Low Emission Zones) for cities.

3. ***Need:***
   - Robust European regulation around the **CO2 footprint across all the value chain**
   - Implement a **BUY EUROPEAN ACT?** (like other country are doing: China, India, US)

Emmanuel Lagarrigue
Chief Innovation Officer
ExCom member
Schneider Electric

Schneider Electric

1. Improvement of **process automation** in the cell manufacturing is a must to reach the **right yields** in such a volumetric industry. *(Let’s follow the path of semiconductors)*

2. **Schneider** has decided to strategically and heavily develop this new business area. With our **track record in industry 4.0 and energy efficiency**, we will contribute to make the European cell manufacturing industry a world leader, also as far as **manufacturing efficiency** is concerned, enabling the **right production costs**.

3. ***Need:***
   - Producing in Europe will create “green jobs”: it is the fastest and more sustainable way **to reconstruct the European economy** after the Covid crisis

Jens Wiese
Head of Group M&A, Investment Advisory and Partnerships Volkswagen

Volkswagen

1. Impact of Corona:

- Lock down of production, retail and wholesale with **significant revenue and margin drop leading to restrictive cash management**
- Planned EV sales of VW Group are **essential to reach CO2 objectives** in 2020
- **Partial relaunch of operations in Europe with focus on EV-sites**
- Very **limited market demand in EU,** with full vehicle inventories barrier restart of production:
    - **Private** customers with limited willingness to invest due to cash constraints and **uncertainty on potentially upcoming incentive schemes**
    - **Business** customers stretching leasing periods
- **China already back to business** – production restart in march with a re-strengthened market demand due to:
    - **Car buying incentives**
    - **2 years extension of EV incentives**
- **Tight capital market for long term investments**, e.g. charging infrastructure or Giga Factories

Mining | Processing | Active Materials | Battery Cells and Battery Packs | Applications | Recycling/2nd life

Machinery | Automation

E-mobility | ESS | Ind. applications

Jens Wiese

Head of Group M&A, Investment Advisory and Partnerships Volkswagen

Volkswagen

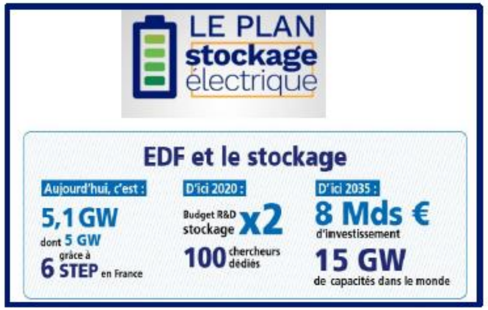
2. ***Contribution of VW to recovery*** *(of electromobility)*
   - **VW remains fully committed** to its huge EV and decarbonization – program
   - **Prioritization of EV products** for the production restart
   - **All** other business activities e.g. development of EV programs or battery R&D, on going together with our partners
   - Further commitment to **Saltzgitter**

3. ***Needs:***
   - Short Term:
     - **Stimulation of demand - EU wide incentives for new car buyers**, with focus on CO2 neutrality
     - **Enable international travels of professionals**, e.g. for factory build up
   - Coordinated **co-investments (public-private):**
     - **Direct support** for European cell manufacturing players
     - **Reinforcement of charging infrastructure** and renewable energy investments
     - Leverage EBA investment platform (BIP)
   - Reliable **regulations with certain reliefs** for the sector:
     - Strive **CO2 pricing further** and stronger incentives for **eV buyers**
     - **Harmonize / review state aid law** to accelerate procedures and support EU wide investments
     - **Streamline** technical registration procedure for eVs

Bernard Salha
CTO
EDF

EDF, following its long lasting low carbon engagement, is looking forward to support the decarbonization of the battery value chain in Europe, and forecast a large deployment of storage in the next years widely based on this industry.

1. EDF ambitious plans **for storage deployment** (2020-2035):



2. ***Need:***
   - Elaborate European regulatory frameworks to assure long term **visibility for hybrid "Renewable Energy system" + "Energy Storage System"** projects at utility scale level
   - Define common rules and standards to share data and information from EV batteries in order to facilitate smart charging (V1G & V2G) of EV
   - Ensure level playing field between storage and other flexibility solutions

Patrik Tykesson
CEO
E-bility

1. **Electric two-wheelers (and eVs based last mile logistic)** are a much underestimated force in e-mobility.Market demand for batteries from 2 wheelers and last mile is the size of a **1 Gigafab (32 GWh -> 6B€/year) in 2025, to forecasted 70+ GWh [10B€/year] in 2030.**

2. **E-bility** is providing emission-free mobility solutions **"made in Europe", hardware and software,** with domestic supply chains creating new jobs.

3. <u>**Need:**</u> Provide **subsidies and incentives** for costumers but also municipalities to purchase **locally produced, zero-emission, zero-noise electric** two/three-wheelers.

Philippe Knoche
CEO
Orano Group

orano

1. Orano positions itself on the **battery recycling value chain** (from battery dismantling up to recovery of strategic materials for cathodes production) through a **clean and efficient process with a EU footprint**

2. Recycling plants provide **500 direct jobs per 10 ktons** recycled (with potential **1 to 3 indirect**). Europe needs to recycle in the 2025 full **circular economy** scenario, around **600 ktons/year.**

3. ***Need:***
   - Continuous **support** to development of **eV vehicles**
   - Quick delivery of the battery regulation
   - Coordinated EU and national support for the financing of EU-based **low CO2 emitting recycling solutions** and batteries.

Wrap up

Diego Pavia

CEO EIT InnoEnergy

Final conclusion and next steps

Maroš Šefčovič
Vice-President for Interinstitutional Relations and Foresight
European Commission

Andrew McDowell
Vice-President
European Investment Bank

InnoEnergy
Knowledge Innovation Community

www.innoenergy.com

InnoEnergy is supported by the EIT,
a body of the European Union

Annex II

EUROPEAN
COMMISSION

Brussels, 14.10.2020
COM(2020) 953 final

REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL

on progress of clean energy competitiveness

{SWD(2020) 953 final}

CONTENTS

1. INTRODUCTION

The goal of the European Green Deal[1], Europe's new growth strategy, is to transform the European Union (EU)[2] into a modern, resource-efficient and competitive economy, which is climate neutral by 2050. The EU's economy will need to become sustainable, while making the transition just and inclusive for everyone. The Commission's recent proposal[3] to cut greenhouse gas emissions by at least 55% by 2030 sets Europe on that responsible path. Today, energy production and use account for more than 75% of the EU's greenhouse gas emissions. The delivery of the EU's climate goals will require us to rethink our policies for clean energy supply across the economy. For the energy system, this means a steep decarbonisation and an integrated energy system largely based on renewable energy. By 2030 already, the EU renewable electricity production is set to at least double from today's levels of 32% to around 65% or more[4] and by 2050, more than 80% of electricity will be coming from renewable energy sources[5].

Achieving these 2030 and 2050 targets requires a major transformation of the energy system. This however depends heavily on uptake of new clean technologies and increased investments in the needed solutions and infrastructure. However, as well as the business models, skills, and changes in behaviour to develop and use them. Industry lies at the heart of this social and economic change. The New Industrial Strategy for Europe[6] gives European industry a central role in the twin green and digital transitions. Considering the EU's large domestic market, accelerating the transition will help modernise the whole EU economy and increasing the opportunities for the EU's global clean technologies leadership.

This first annual progress report on competitiveness[7]aims to assess the state of the clean energy technologies and the EU clean energy industry's competitiveness to see if their development is on track to deliver the green transition and the EU's long-term climate goals. This competitiveness assessment is also particularly crucial for the economic recovery from the COVID-19 pandemic, as outlined in the *'Next Generation EU'* communication[8]. Improved competitiveness has the potential to mitigate the short- and medium-term economic and social impact of the crisis, while also addressing the longer-term challenge of the green and digital transitions in a socially fair manner. Both in the context of the crisis, but also in the long run, improved competitiveness can address energy poverty concerns, reducing the cost of energy production and the cost of energy efficiency investments[9].

It is possible to ascertain the clean energy technology needs for achieving the 2030 and 2050 targets on the basis of the impact assessment referred to in the European

[1] COM(2019) 640 final.
[2] For the purpose of this report, EU is to be understood as EU27 (i.e. without the UK). Whenever the UK is included, this report will refer to EU28.
[3] COM(2020) 562 final.
[4] COM(2020) 562 final.
[5] COM/2018/773 final.
[6] COM (2020) 102 final.
[7] Drawn up in accordance with the requirements of Article 35 (m) of Regulation (EU) 2018/1999 (Governance Regulation)
[8] COM(2020) 456 final
[9] See also A Renovation Wave for Europe – greening our buildings, creating jobs, improving lives COM(2020)662 accompanied by SWD(2020)550, and Energy Poverty Recommendation C(2020)9600

Commission's Climate Target Plan scenarios[10]. In particular, the EU is expected to invest in renewable electricity, notably offshore energy (in particular wind) and solar energy[11,12]. This large increase in the share of variable renewables also implies an increase in storage[13] and in the ability to use electricity in transport and industry, especially through batteries and hydrogen, and requires major investments in smart grid technologies[14]. On this basis, the present report focuses on the six technologies mentioned above[15], most of which are at the heart of the EU flagship initiatives[16,17] aimed at fostering reforms and investments to support a robust recovery based on twin green and digital transition. The remaining clean and low-carbon energy technologies included in the scenarios are analysed in the staff working document with the title 'Clean Energy Transition – Technologies and Innovations Report' (CETTIR) that accompanies this report[18].

For the purpose of this report, competitiveness in the clean energy sector[19] is defined as the capacity to produce and use affordable, reliable and accessible clean energy through clean energy technologies, and compete in energy technology markets, with the overall aim of bringing benefits to the EU economy and people.

Competitiveness cannot be captured by a single indicator[20]. Therefore, this report proposes a set of widely accepted indicators that may be used for this purpose (see table 1 below) capturing the entire energy system (generation, transmission and consumption) and analysed at three levels (technology, value chain and global market).

[10] At time horizon 2050, the 1.5 TECH from the EU 2050 Long Term Strategy (COM (2018) 773) and the Climate Target plan (COM(2020) 562 final) scenarios display no significant differences and are therefore both referred to in this report. The CTP MIX scenario achieves around 55% GHG reductions, both expanding carbon pricing and moderately increasing the ambition of policies.

[11] ASSET Study commissioned by DG ENERGY - Energy Outlook Analysis (Draft, 2020) covering LTS 1.5 Life and Tech, BNEF NEO, GP ER, IEA SDS, IRENA GET TES, JRC GECO 2C_M

[12] Tsiropoulos I., Nijs W., Tarvydas D., Ruiz Castello P., Towards net-zero emissions in the EU energy system by 2050 – Insights from scenarios in line with the 2030 and 2050 ambitions of the European Green Deal, JRC118592

[13] Study on energy storage - Contribution to the security of the electricity supply in Europe (2020): : https://op.europa.eu/en/publication-detail/-/publication/a6eba083-932e-11ea-aac4-01aa75ed71a1

[14] Between EUR 71 and 110 billion/year of power grid investments between 2031 and 2050 under the different scenarios, 'In-depth analysis in support of COM(2018) 773', table 10, p. 202.

[15] Offshore renewables (wind and ocean), solar photovoltaics, renewable hydrogen, batteries and grid technologies. This selection does not neglect the role of established renewables, in particular bioenergy and hydropower, within the EU portfolio of low-carbon energy technologies. These are covered in the CETTIR and may be covered in forthcoming annual reports on progress in competitiveness.

[16] European flagship initiatives have been presented in the latest Annual Sustainable Growth Strategy 2021 (COM(2020) 575 final) – section iv.

[17] Recent and upcoming initiatives include the upcoming offshore energy strategy and the hydrogen strategy (COM(2020) 301 final), including the Hydrogen Alliance, the European Batteries Alliance, and the energy system integration strategy (COM(2020) 299 final). These technologies are also described in a range of national energy and climate plans.

[18] SWD(2020)953 – This includes buildings (incl. heating and cooling); CCS; citizens and communities engagement; geothermal; high voltage direct current and power electronics; hydropower; industrial heat recovery; nuclear; onshore wind; renewable fuels; smart cities and communities; smart grids – digital infrastructure; solar thermal power.

[19] In this report and in the SWD, clean energy is considered as all energy technologies included in the EU Long-Term Strategy to achieve climate neutrality in 2050.

[20] Based on the conclusions of the Competitiveness Council (28.07.20).

Table 1 Grid of indicators to monitor progress in competitiveness

Competitiveness of EU clean energy industry		
1. Technology analysis Current situation and outlook	2. Value chain analysis of the energy technology sector	3. Global market analysis
Capacity installed, generation (today and in 2050)	**Turnover**	**Trade (imports, exports)**
Cost / Levelised cost of energy (LCoE) (today and in 2050)	**Gross value added growth** Annual, % change	**Global market leaders vs. EU market leaders** (market share)
Public R&I funding	**Number of companies in the supply chain, incl. EU market leaders**	**Resource efficiency and dependence**
Private R&I funding	**Employment**	**Real Unit Energy Cost**
Patenting trends	**Energy intensity / labour productivity**	
Level of scientific Publications	**Community Production**[21] Annual production values	

Analysis of competitiveness of the clean energy sector can be further developed and deepened over time, and future competitiveness reports may focus on different angles. For example by looking in more detail at policies and instruments to support R&I and competitiveness at the Member State level, how these contribute to the Energy Union and the Green Deal objectives, looking at competitiveness at subsector[22], national or regional level, or by analysing the synergies and trade-offs with environmental or social impacts, in line with the European Green Deal objectives.

Given the lack of data for a wide range of competitiveness indicators[23,24], some approximations of a more indirect nature are used (e.g. the level of investment). The Commission calls on Member States and stakeholders to work together in the context of the National Energy and Climate Plans (NECPs)[25] and the Strategic Energy Technology plan to continue developing a common approach to assessing and boosting the competitiveness of the Energy Union. This is also important for the national recovery and resilience plans that will be prepared under the Recovery and Resilience Facility.

2. Overall competitiveness of the EU clean energy sector

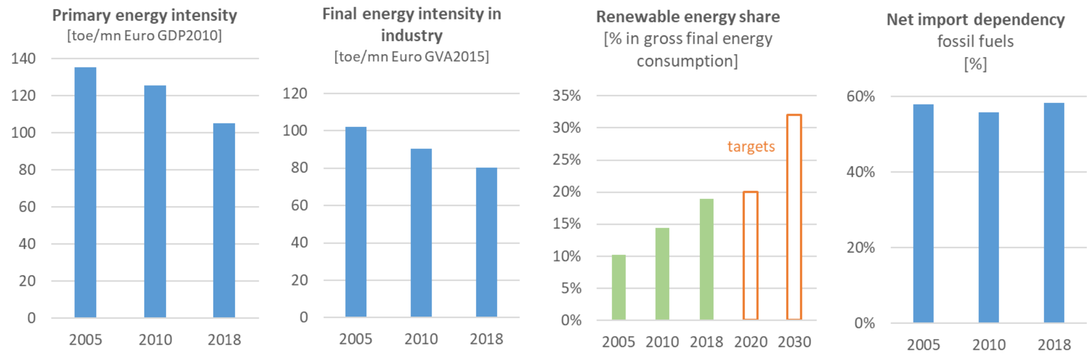
2.1 Energy and resource trends

Over 2005-2018, primary energy intensity in the EU decreased at an average annual rate of nearly 2%, demonstrating the decoupling of energy demand from economic growth. Final energy intensity in industry and construction followed the same trend, albeit at a

[21] This abbreviation means Production Communautaire (PRODCOM dataset).
[22] Eg. the scope and role of alternative business models, as well as the role of SMEs and local actors.
[23] For an overall mapping of competitiveness definitions, refer to JRC116838, Asensio Bermejo, J.M., Georgakaki, A, Competitiveness indicators for the low-carbon energy industries - definitions, indices and data sources, 2020.
[24] For an overview of missing data, see CETTIR (SWD(2020)953) chapter 5
[25] This report builds on and complements the assessment and country-specific guidance of the NECPs (COM/2020/564 final), which include the topic of 'research, innovation and competitiveness'.

slightly slower annual average rate of 1.8%, reflecting the sector's efforts to reduce its energy footprint. Enabled by energy policy, the share of renewable energy in final energy consumption rose from 10% towards the 2020 target of 20%. The share of renewable energy in the electricity sector rose to just over 32%. It increased to just over 21% in the heating and cooling sector, while the figure for the transport sector was slightly over 8%. This shows that the energy system has been shifting gradually towards clean energy technologies (see Figure 1).

Figure 1 EU primary energy intensity, final energy intensity in industry, renewable energy share and targets, and net import dependency (fossil fuels)[26]



Source 1 EUROSTAT

During the last decade, industrial electricity prices in the EU[27] have remained relatively stable, and are currently lower than Japan's, but double those of the US and higher than those of most non-EU G20 countries. Though industrial gas prices[28] have fallen, and are lower than those in Japan, China and Korea, they remain higher than those of most non-EU G20 countries. Relatively high non-recoverable taxes and levies in the EU and price regulation and/or subsidies in the non-EU G20 play an important role in this difference.

Despite a short-term improvement and reduction in energy import dependency between 2008 and 2013, the EU has since experienced an increase[29]. In 2018, net import dependency was 58.2%, just over the 2005 level, and almost equalling the highest values over the period. Resource efficiency and economic resilience are key in being competitive and enhancing the open strategic autonomy[30] of the EU in the clean energy technology market. While clean energy technologies reduce dependence on imports of fossil fuels, they risk replacing this dependence with on raw materials. This creates a new type of supply risk[31]. However, unlike fossil fuels, raw materials have the potential to stay in the economy through the implementation of circular economy approaches[32], like extended value chains, recycling, reuse and design for circularity, affecting the capital expenditures and decreasing the energy need for extraction and processing of virgin materials but not the operational expenditures of energy production. The EU is very dependent on third countries for raw and processed materials. For some technologies, however, it has a leading position in the manufacture of components and final products,

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[26] Energy Union indicators EE1-A1, EE3, DE5-RES, and SoS1.
[27] EU weighted average (see COM(2020)951).
[28] EU weighted average (see COM(2020)951).
[29] Plausible reasons include the exhaustion of EU gas sources, weather variability, the economic crises and fuel shift.
[30] COM(2020) 562 final.
[31] COM(2020) 474 final and Critical Raw Materials for Strategic Technologies and Sectors in the EU - A Foresight Study, https://ec.europa.eu/docsroom/documents/42882
[32] The Circular Economy Action Plan puts in focus the creation of a secondary raw material market and design for circularity (COM/2015/0614 final and COM/2020/98 final)

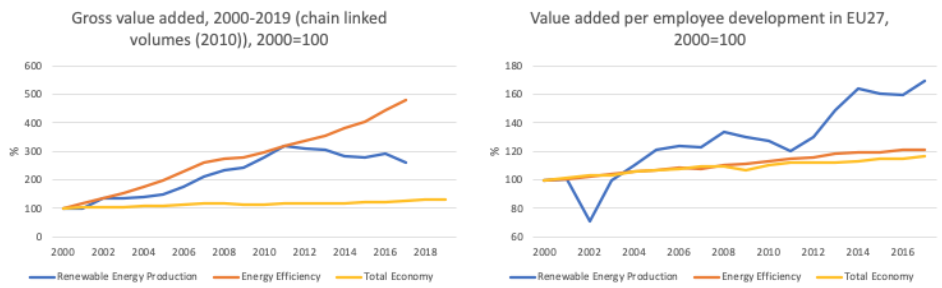
or high technology components. Specific, often high-tech materials show high supply concentration in a handful of countries. (For instance, China produces over 80% of the available rare earths for permanent magnet generators)[33].

2.2 Share of EU energy sector in EU GDP

The turnover of the EU energy sector[34] was EUR 1.8 trillion in 2018, nearly the same level as in 2011 (EUR 1.9 trillion). The sector contributes 2% of total gross value added in the economy, a figure that has remained largely constant since 2011. The turnover of the fossil fuel sector shrank from 36% (EUR 702 billion) of the overall energy sector turnover in 2011 to 26% (EUR 475 billion) in 2018. At the same time, the turnover from renewables increased over the same period from EUR 127 billion to EUR 146 billion[35,36]. The value added of the clean energy sector (EUR 112 billion in 2017) was more than double that of fossil fuel extraction and manufacturing activities (EUR 53 billion), having tripled since 2000. The clean energy sector thus generates more value added that stays within Europe than the fossil fuel sector.

Over 2000-2017, annual growth in the gross value added of renewable energy production averaged 9.4%, while that of energy efficiency activities averaged 22.3%, far outpacing the rest of the economy (1.6%). The labour productivity of the EU (gross value added per employee) has also improved significantly in the clean energy sector, especially in the renewable energy production sector, where it has risen by 70% since 2000.

Figure 2 Gross value added and value added per employee, 2000-2019, 2000=100



Source 2 JRC based on Eurostat data: [env_ac_egss1], [nama_10_a10_e], [env_ac_egss2], [nama_10_gdp.

2.3 Human capital

Clean energy technologies and solutions provide direct full-time employment for 1.5 million people in Europe[37], of which more than half million[38] in renewables (growing to

[33] D. T. Blagoeva, P. Alves Dias, A. Marmier, C.C. Pavel (2016) Assessment of potential bottlenecks along the materials supply chain for the future deployment of low-carbon energy and transport technologies in the EU. Wind power, photovoltaic and electric vehicles technologies, time frame: 2015-2030; EUR 28192 EN; doi:10.2790/08169

34 This is based on Eurostat's Structural Business Statistics Survey. The following codes are included: B05 (mining of coal and lignite), B06 (extraction of crude petroleum and natural gas), B07.21 (mining uranium and thorium ores), B08.92 (extraction of peat), B09.1 (support activities for petroleum and natural gas extraction), C19 (manufacture of coke and refined petroleum products), and D35 (electricity, gas, steam and air conditioning supply).

35 Eurostat [sbs_na_ind_r2]

[36] EurObserv'ER

[37] To give some perspective, direct employment in fossil fuel extraction and manufacturing (NACE B05, B06, B08.92, B09.1, C19) was 328,000 in the EU27 in 2018, while it was 1.2 million in the electricity, gas, steam and air

1.5 million when indirect jobs are also included) and almost 1 million in energy efficiency activities (in 2017)[39]. Direct jobs in renewable energy production for the EU grew from 327,000 in 2000 to 861,000 in 2011, falling to 502,000 in 2017. As Figure 3 shows, there was a decrease after 2011[40], probably explained by the effect of the financial crisis, including the subsequent relocation of manufacturing capacity, as well as by increased productivity and a decrease in job intensity. The number of direct jobs in energy efficiency increased steadily from 244,000 in 2000 to 964,000 in 2017. Direct jobs in these sectors (RES and EE) represent about 0.7% of total employment in EU,[41] but their growth has outpaced the rest of the economy, with average annual growth of 3.1% and 17.4% respectively[42].

conditioning sector (NACE D35), which supplies electricity from both renewable and fossil energy sources. The total figure for the broad energy sector has remained largely stable, although employment has fallen by about 80,000 in the mining of coal and lignite and by about 30,000 in the extraction of crude petroleum and natural gas. See: JRC120302, Employment in the Energy Sector Status Report 2020, EUR 30186 EN, Publications Office of the European Union, Luxembourg, 2020.

[38] If indirect jobs are also taken into account, the renewable energy sector employs nearly 1.4 million people in the EU27, according to EurObserv'ER. EurObserv'ER includes in its estimate both direct and indirect employment. Direct employment includes renewable equipment manufacturing, renewable plant construction, engineering and management, operation and maintenance, biomass supply and exploitation. Indirect employment refers to secondary activities, such as transport and other services. Induced employment is outside the scope of this analysis. EurObserv'ER uses a formalised model to assess employment and turnover.

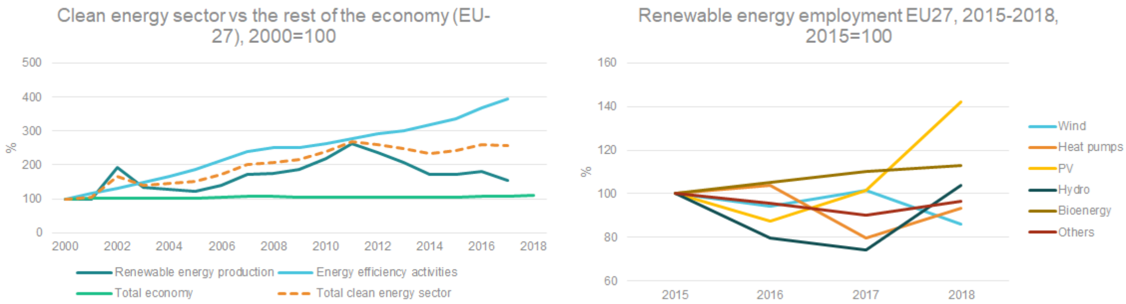
[39] Eurostat Environmental Goods and Services Sector (EGSS) data is estimated by combining data from different sources (SBS, PRODCOM, National Accounts). In EGSS, information is reported on the production of goods and services that have been specifically designed and produced for the purpose of environmental protection or resource management. The unit of analysis in EGSS is the establishment. The establishment is an enterprise or part of an enterprise that is situated in a single location and in which a single activity is carried out or in which the principal productive activity accounts for most of the value added. It is also tracked across all NACE codes. We use CREMA 13A Production of energy from renewable sources and CREMA 13B for Heat/energy saving and management.

[40] This decrease can probably be explained by the effect of the financial crisis, including the subsequent relocation of manufacturing capacity, as well as by increased productivity and a decrease in job intensity (Sources: JRC120302 Employment in the Energy Sector Status Report, 2020). The decrease was led by solar PV and by geothermal energy to a lesser extent. The effect of the crisis was seen in the drop in solar PV installations and relocation of manufacturing to Asia. For the onshore and offshore wind energy sector, increased productivity and thus decreased job intensity can be particularly observed. Comparing direct employment with the cumulative installed capacity in the last decade unveils a decrease of 47% and 59% in specific employment for the onshore and offshore wind sector, respectively (sources: GWEC 2020, Global Offshore Wind Report, 2020; WindEurope 2020, Update of employment figures based on WindEurope, Local Impact Gl). Based on EurObserv'ER, job intensity (jobs/MW) fell by 19% in wind and by 14% in solar PV over 2015-2018. Dynamics in the energy efficiency sector are different (e.g. energy saving and efficiency has a direct positive impact through reduced costs), and the growth in EE jobs can partially be explained by strong growth of jobs in the heat pump sector since 2012 (EurObservER). Overall, we can see from EurObserv'ER, which accounts for direct and indirect jobs, an increasing trend for RES employment in the EU27.

[41] Eurostat, EGSS.

[42] In the rest of the economy, average annual growth has been 0.5%.

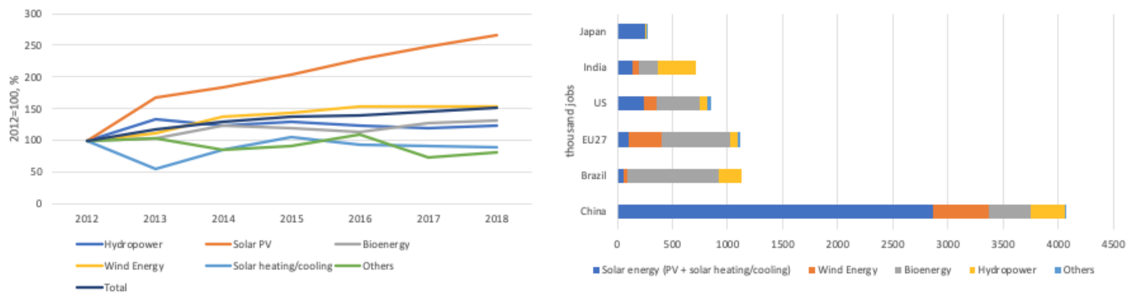
Figure 3 Direct employment in the clean energy sector vs the rest of the economy over 2000-2018, 2000=100, and Renewable energy employment per technology, 2015-2018



Source 3 (JRC based on Eurostat data [env_ac_egss1], [nama_10_a10_e][43] and EurObserv'ER)

The growing trend of employment in the clean energy sector is global, although the technologies that offer more employment opportunities vary by region. In general, jobs have been created mainly in the solar PV and wind energy sectors. China, which has almost 40% of all global jobs in renewables, employs most in solar PV, solar heating and cooling, and wind energy; Brazil's employment is in the bioenergy sector; and the EU employ most people in bioenergy (about half of all RES jobs) and wind energy (about a quarter), see Figure 4.

Figure 4 Global employment in renewable energy technology (2012-2018)[44]



Source 4 (JRC based on IRENA, 2019[45])

The clean energy technology sector continues to face challenges, in particular availability of skilled workers at the locations where they are in demand.[46,47] The skills concerned include, in particular, engineering and technical skills, IT literacy and ability to utilise new digital technologies, knowledge of health and safety aspects, specialised skills in carrying out work in extreme physical locations (for example at height or at depth), and soft skills like team work and communication, as well as knowledge of the English language.

As regards gender, women accounted for an average of 32% of the workforce in the renewables sector in 2019[48]. This figure is higher than in the traditional energy sector

[43] Renewable energy production refers to Eurostat EGSS code CREMA13A and energy efficiency activities to CREMA13B.
[44] The employment figures per country are for 2017.
[45] IRENA. 2019. Renewable Energy and Jobs – Annual Review 2019.
[46] Strategy baseline to bridge the skills gap between training offers and industry demands of the Maritime Technologies value chain, September 2019 - MATES Project. https://www.projectmates.eu/wp-content/uploads/2019/07/MATES-Strategy-Report-September-2019.pdf
[47] Alves Dias et al. 2018. EU coal regions: opportunities and challenges ahead. https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/eu-coal-regions-opportunities-and-challenges-ahead.
[48] IRENA 2019: https://www.irena.org/publications/2019/Jan/Renewable-Energy-A-Gender-Perspective

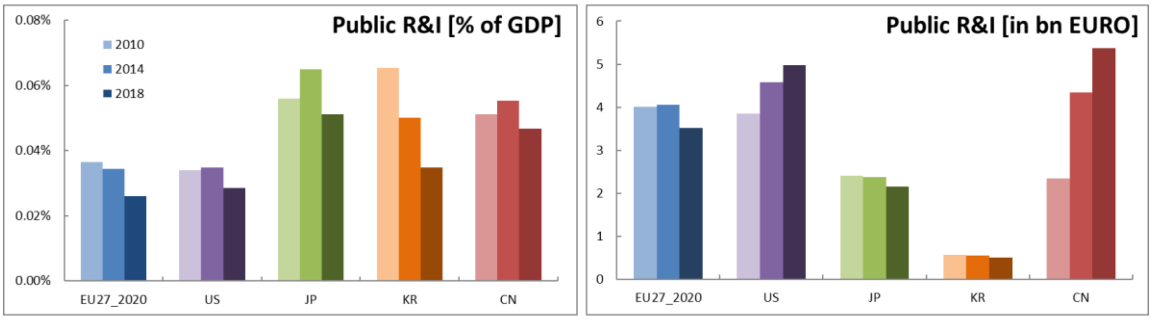
(25%[49]) but lower than the share across the economy (46.1%[50]) and furthermore gender balance differs to a higher extend for certain job profiles.

2.4 Research and innovation trends

In recent years, the EU has invested an average of nearly EUR 20 billion a year on clean energy R&I prioritised by the Energy Union[51,52]. EU funds contribute 6%, public funding from national governments accounts for 17%, and business contributes an estimated 77%.

The R&I budget allocated to energy in the EU represents 4.7% of total spending on R&I[53]. In absolute terms, however, Member States have reduced their national R&I budgets for clean energy (Figure 5); in 2018 the EU spent half a billion less than in 2010. This trend is global. Public sector R&I spending on low-carbon energy technologies was lower in 2019 than in 2012, while countries continue to allocate large amounts of R&I funding to fossil fuels[54]. This is the opposite of what is needed: R&I investments in clean technologies need to increase if the EU and the world want to meet their decarbonisation commitments. Today the EU has the lowest investment rate of all major global economies measured as a share of GDP (Figure 5). EU research funds have been contributing a larger share of public funding and have been essential in maintaining research and innovation investment levels over the last four years.

Figure 5 Public R&I financing of Energy Union R&I priorities[55]



Source 5 JRC[49] based on IEA[56], MI[57].

[49] Eurostat (2019), retrieved from https://ec.europa.eu/eurostat/web/equality/overview

[50] Eurostat [lfsa_egan2], 2019.

[51] COM(2015)80; renewables, smart system, efficient systems, sustainable transport, CCUS and nuclear safety.

[52] JRC SETIS https://setis.ec.europa.eu/publications/setis-research-innovation-data;
JRC112127 Pasimeni, F.; Fiorini, A.; Georgakaki, A.; Marmier, A.; Jimenez Navarro, J. P.; Asensio Bermejo, J. M. (2018): SETIS Research & Innovation country dashboards. European Commission, Joint Research Centre (JRC) [Dataset] PID: http://data.europa.eu/89h/jrc-10115-10001, according to:
JRC Fiorini, A., Georgakaki, A., Pasimeni, F. and Tzimas, E., Monitoring R&I in Low-Carbon Energy Technologies, EUR 28446 EN, Publications Office of the European Union, Luxembourg, 2017.
JRC117092 Pasimeni, F., Letout, S., Fiorini, A., Georgakaki, A., Monitoring R&I in Low-Carbon Energy Technologies, Revised methodology and additional indicators, 2020 (forthcoming).

[53] Eurostat, Total GBAORD by NABS 2007 socio-economic objectives [gba_nabsfin07]. The energy socioeconomic objective includes R&I in the field of conventional energy. The Energy Union R&I priorities would also fall under other socioeconomic objectives.

[54] IEA ETP https://www.iea.org/reports/clean-energy-innovation/global-status-of-clean-energy-innovation-in-2020#government-rd-funding

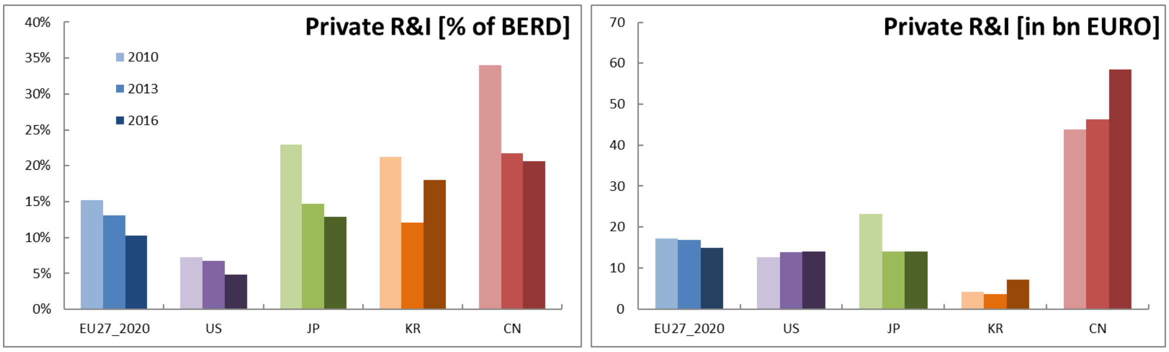
[55] Excludes EU funds.

[56] Adapted from the 2020 edition of the IEA energy technology RD&D budgets database.

[57] Mission Innovation Tracking Progress http://mission-innovation.net/our-work/tracking-progress/

In the private sector, only a small share of revenue is currently being spent on R&I in the sectors most in need of large-scale adoption of low-carbon technologies[51]. The EU have estimated that private investment in Energy Union R&I priorities has been decreasing: it currently amounts to around 10% of businesses' total expenditure on R&I[58]. This is higher than the US and comparable to Japan, but lower than China and Korea. A third of this investment goes on sustainable transport, while renewables, smart systems and energy efficiency receive about a fifth each. While the distribution of private R&I in the EU has changed only slightly in recent years, there has been a more significant shift globally towards industrial energy efficiency and smart consumer technologies[59].

Figure 6 Estimates of private R&I financing of Energy Union R&I priorities[60]



Source 6 JRC[49], Eurostat/OECD[55]

On average, major listed companies and their subsidiaries make up 20-25% of the main investors, but account for 60-70% of patenting activity and investments. In the EU, the automotive sector is the biggest private R&I investor in absolute terms in the Energy Union R&I priorities[61], followed by biotechnology and pharmaceuticals. Figure 7 shows that among the energy industries, the oil and gas sector is the largest investor in R&I. Other energy sectors, such as electricity or alternative energy companies, have much lower budgets for R&I, although they spend more of it on clean energy. It is worrying that a major share of the private budget for R&I in the energy sector is not spent on clean energy technologies. According to the IEA, less than 1% of oil and gas companies' total capital expenditure has been outside their core business areas, on average[62,63], and only 8% of their patents are in clean energy[64].

Figure 7 EU R&I investment in Energy Union R&I priorities, by industrial sector[65]

[58] Contrasted with BERD statistics: *Eurostat/OECD* business expenditure on R&D (BERD) by NACE Rev. 2 activity and source of funds [rd_e_berdfundr2]; The utilities sector includes water collection, treatment and supply services; data not available for all countries.

[59] JRC118288 input to Mission Innovation (2019) 'Mission Innovation Beyond 2020: challenges and opportunities'.

[60] Estimates for China are particularly challenging and uncertain, given differences in intellectual property protection (see also https://chinapower.csis.org/patents/), and the difficulties faced in mapping company structures (e.g. state-backed companies) and financial reporting.

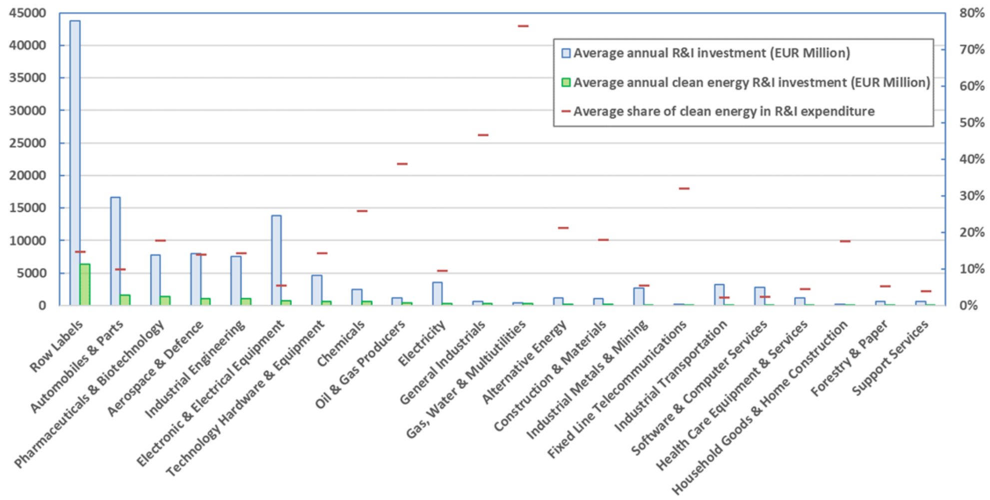
[61] This is a wider definition of what clean energy technology includes than that used in this report. For example, this broader definition includes R&I in energy efficiency in industry.

[62] With some leading individual companies spending around 5% on clean energy.

[63] The oil and gas industry in energy transitions, world energy outlook special report, IEA, January 2020, https://www.iea.org/reports/the-oil-and-gas-industry-in-energy-transitions

[64] The Energy Transition and Oil Companies' Hard Choices – Oxford Institute for Energy Studies, July 2019; Rob West, Founder, Thundersaid Energy & Research Associate, OIES and Bassam Fattouh, Director, OIES, page 4.

[65] Top contributing sectors. Five-year average (2012-2016) per sector; a third of companies (non-listed, smaller investors) cannot be allocated to a specific sector.



Source 7 JRC[49]

Venture capital (VC) investment in clean energy had been increasing in recent years, but remains low (just over 6-7%) compared with private-sector investment in R&I. So far, 2020 marks a significant global slowdown in VC investment in clean energy technologies[66].

Patenting activity in clean energy technologies[67] peaked in 2012, and has been in decline since.[68] Within this trend, however, certain technologies that are increasingly important for the clean energy transition (e.g. batteries) have maintained or even increased their levels of patenting activity.

The EU and Japan lead among international competitors in high-value[69] patents on clean energy technologies. Clean energy patents account for 6% of all high-value inventions in the EU. The EU's share is similar to that of Japan, and higher than China (4%), the US and the rest of the world (5%), and second only to Korea (7%) in terms of competing economies. The EU host a quarter of the top 100 companies in terms of high-value patents in clean energy. The majority of inventions funded by multinational firms headquartered in the EU are produced in Europe and, for the most part, by subsidiaries located in the same country.[70] The US and China are the main IPO offices – and by extension markets – targeted for protection of EU inventions.

2.5 Covid-19 Recovery[71]

During the pandemic, the European energy system has proved to be resilient to shocks stemming from the pandemic[72] and a greener energy mix has emerged, with coal power generation in the EU falling by 34% and renewables providing 43% of power generation

[66]JRC[52]and JRC analysis based on Pitchbook, and IEA data on CleanTech VC investments.
[67] Low-carbon energy technologies under the Energy Union's R&I priorities.
[68] With the exception of China, where local applications keep increasing, without seeking international protection. (See also: Are Patents Indicative of Chinese Innovation? https://chinapower.csis.org/patents/)
[69] High-value patent families (inventions) are those containing applications to more than one office i.e. those seeking protection in more than one country / market.
[70] Incentives, language and geographical proximity explain major exceptions.
[71] Based on JRC work on the impacts of Covid-19 on the energy system and value chain.s
[72] SWD(2020) 104 - Energy security: good practices to address pandemic risks

in Q2 2020, the highest share to date[73]. At the same time, the stock market performance of the clean energy sector has seemed less affected and recovered more quickly than fossil-fuel sectors. Digitalisation has helped companies and sectors respond successfully to the crisis, also boosting the emergence of new digital applications.

Although the EU energy value chains are recovering, the crisis has brought to the forefront the question of optimising and potentially regionalising supply chains, to reduce exposure to future disruptions and improve resilience. In response, the Commission aims to identify the critical supply chains for energy technologies, analyse potential vulnerabilities and improve their resilience[74]. The key energy priorities in recovery are energy efficiency in particular through the renovation wave, renewable energy sources, hydrogen and energy system integration. There is a further concern that the pandemic is affecting investments in and resources available for R&I, as has demonstrably happened in previous economic crises.

Recovery measures can take advantage of the job creation potential offered by energy efficiency and renewable energy[75], including that of the R&I sector, to boost employment while also moving towards sustainability. Support for R&I investment, including corporate R&I, has a greater positive impact on employment in medium- to high-technology sectors such as cleaner energy technology[76]. At the same time, breakthrough low-carbon technologies are needed, for instance in energy-intensive industries, which will require faster R&I investment for their demonstration and deployment.

3. FOCUS ON KEY CLEAN ENERGY TECHNOLOGIES AND SOLUTIONS

In the section below, the most relevant competitiveness values for each of the six technologies analysed above, and *the status, value chain and global market* are analysed, based on the indicators outlined in Table 1. The EU's performance is compared as far as possible with other key regions (e.g. USA, Asia). A more detailed assessment of other important clean and low carbon energy technologies needed to reach climate neutrality is set out in the accompanying Clean Energy Transition – Technologies and Innovation Report[77].

3.1 Offshore renewables – wind

<u>Technology</u>: the EU cumulative installed capacity of offshore wind (OW) amounted to 12 GW in 2019[78]. At the 2050 time horizon, EU scenarios foresee approximately 300 GW of wind offshore capacity in the EU[79]. Globally, costs have fallen steeply in recent years, and demand has been stimulated by new tenders implemented worldwide and the building of subsidy-free wind parks. OW has benefited considerably from onshore wind developments, especially economies of scale (e.g. material developments and common

[73] Quarterly Report on European Electricity Markets, Volume 13, Issue 2. https://ec.europa.eu/energy/data-analysis/market-analysis_en?redir=1

[74] The analysis is supported by a study planned to deliver its conclusions in April 2021.

[75] It is estimated that the same level of spending will generate nearly three times as many jobs as in fossil-fuelled industries Source: Heidi Garrett-Peltier, Green versus brown: Comparing the employment impacts of energy efficiency, renewable energy, and fossil fuels using an input-output model, Economic Modelling, Volume 61, 2017, 439-447

[76] EC work for MI Tracking Progress: The Economic Impacts of R&D in the Clean Energy Sector and COVID-19, 2020, MI Webinar, May 6, 2020

[77] SWD(2020)953

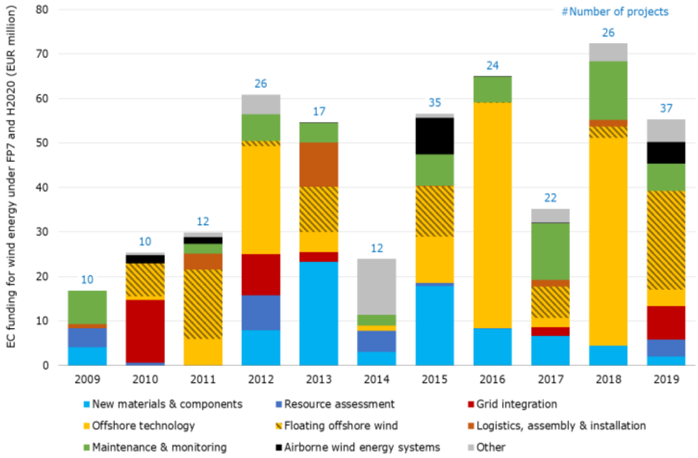
[78] GWEC, Global Wind Energy Report 2019 (2020).

[79] According to the CTP-MIX scenario from COM(2020) 562 final.

components), thereby allowing efforts to focus on the technology's most innovative segments (such as floating offshore wind, new materials and components). Recent offshore wind projects have observed much increased capacity factors. The average power capacity of the turbines has increased from 3.7 MW (2015) to 6.3 MW (2018), thanks to sustained R&I efforts.

R&I in offshore wind revolves mainly around increased turbine size, floating applications (particularly substructure design), infrastructure developments, and digitalisation. About 90% of EU R&I funding for wind comes from the private sector[80]. At EU level, offshore wind R&I has been supported since the 1990s. Offshore wind, in particular floating, have received substantial funding in recent years (*Figure 8*). These R&I patterns highlight that through the development of new market segments the EU could establish a competitive edge. For example, a fully-fledged EU OW supply chain (extended also to untapped EU sea basins), leadership in floating offshore industry targeting markets with deeper waters or new emerging concepts e.g. airborne wind systems or the development of a port infrastructure capable to deliver the ambitious targets (and synergies to other sectors e.g. hydrogen production in ports). Patenting trends confirm Europe's competitiveness in wind energy. EU players are leading in high value inventions[81] and they protect their knowledge in other patent offices outside their home market.

Figure 8 Evolution of EC R&I funding, categorised by R&I priorities for wind energy under FP7 and H2020 programmes and the number of projects funded over 2009-2019.



Source 8 JRC 2020[82]

Other recent innovations target the logistics/supply chain, e.g. the development of wind turbine gearboxes compact enough to fit into a standard shipping container[83] as well as applying circular economy approaches along the life-cycle of installations. Further innovations and trends expected to increase most over the next ten years include superconducting generators, advanced tower materials and the added value of offshore wind energy (system value of wind). The SET Plan Group on OW identified most of

[80] JRC Technology Market Report – Wind Energy (2019).

[81] This means that the patents are protected in other patent offices outside the issuing country and refer to patent families that include patent applications in more than one patent office. About 60% of all EU wind-related inventions were protected in other countries (by way of a comparison, only 2% of Chinese inventions were protected in other patent offices outside China).

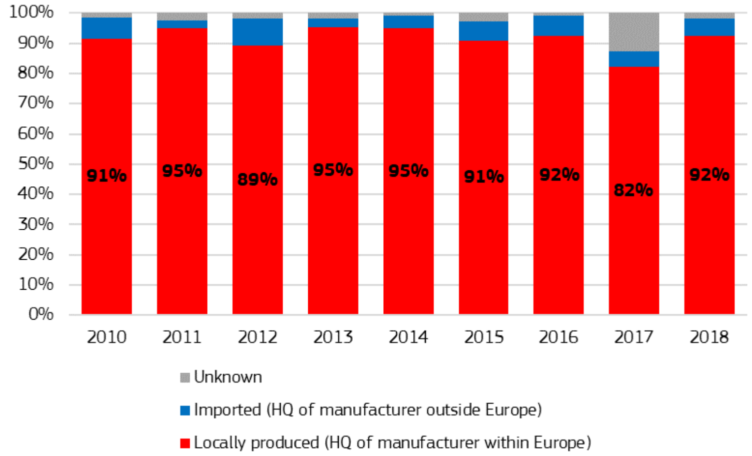
[82] JRC 2020, Low Carbon Energy Observatory, Wind Energy Technology Development Report 2020, European Commission, 2020, JRC120709.

[83] SET-Plan, Offshore Wind Implementation Plan (2018).

these areas as key for Europe to remain competitive in the future. Currently, Europe is leading in all parts of the value chain of sensing and monitoring systems for OW turbines, including research and production[84].

Value chain: On the market side, EU companies are ahead of their competitors in providing offshore generators of all power ranges, reflecting a well-established European offshore market and the increasing size of newly installed turbines[85]. Currently, about 93% of the total offshore capacity installed in Europe in 2019 is produced locally by European manufacturers (Siemens, Gamesa Renewable Energy, MHI Vestas and Senvion[86]).

Figure 9 Newly installed wind capacity (onshore & offshore) - local vs imported, assuming an European single market



Source 9 JRC 2020[87]

Global market: the EU[88] share of global exports increased from 28% in 2016 to 47% in 2018, and 8 out of the top 10 global exporters were EU countries, with China and India being the key global competitors. Between 2009 and 2018, the EU[89] trade balance remained positive, showing a rising trend.

In terms of global markets projections, within Asia (including China), offshore wind capacity is expected to reach around 95 GW by 2030 (out of a projected global capacity of almost 233 GW by 2030)[90]. Nearly half of global offshore wind investment in 2018 took place in China[91]. At the same 2030 time horizon, the CTP-MIX scenario projects 73 GW of wind offshore capacity in the EU. Currently, the NECPs project 55 GW of offshore wind capacity by 2030.

Floating applications seem to become a viable option for EU countries and regions lacking shallower waters (floating OW farms for depths between 50 and 1000 metres) and could open up new markets based on areas such as the Atlantic Ocean, the

[84] ICF, commissioned by DG Grow – Climate neutral market opportunities and EU competitiveness study (2020)
[85] JRC Technology Market Report – Wind Energy (2019).
[86] An even stronger market concentration can be expected following the insolvency of Senvion and the closure of its Bremerhaven turbine manufacturing plant at the end of 2019.
[87] JRC 2020, Facts and figures on Offshore Renewable Energy Sources in Europe, JRC121366 (upcoming).
[88] EU including UK.
[89] EU including UK.
[90] GWEC 2020, Global Offshore Wind Report, 2020.
[91] IRENA – Future of wind (2019, p. 52).

Mediterranean and, potentially, the Black Sea. A number of projects are planned or underway that will lead to the installation of 350 MW of floating capacity in European waters by 2024. Moreover, the EU wind industry aims to install floating OW farms with 150 GW of capacity by 2050 in European waters with a view to achieving climate neutrality[92]. The global market for energy from floating OW farms represents a considerable commercial opportunity for EU companies. A total of about 6.6 GW from this source are expected by 2030, with significant capacities in certain Asian countries (South Korea and Japan), in addition to the European markets (France, Norway, Italy, Greece, Spain) between 2025 and 2030. Since China has abundant wind resources in shallow waters, it is not expected to build floating wind farms with significant capacity in the medium term[93]. Floating applications can also reduce under-water environmental impacts, notably during the construction phase.

Offshore wind is a competitive industry on the global market. Emerging global market demands, such as that for energy generated by floating wind farms, may become key to EU industry if it is to be competitive in the growing offshore wind industry, and remain so. A key consideration is whether Member States will commit to wind energy. The current mismatch between the 2030 NECP projection (55 GW of offshore wind) and the EU's scenario (73 GW[94]) means that investment must be stepped up. The positive impact of offshore wind development on supply chains in sea basins is relevant to regional development (location of manufacturing, assembly of turbines close to the market, impact on port infrastructure). The offshore renewable energy strategy[95] will define a set of measures to overcome challenges and boost offshore prospects.

3.2 Offshore renewables – Ocean energy

<u>Technology:</u> tidal and wave energy technologies are the most advanced of the ocean energy technologies, with significant potential located in a number of Member States and regions[96]. Tidal technologies can be considered as being at the pre-commercial stage. Design convergence has helped the technology develop and generate a significant amount of electricity (over 30 GWh since 2016[97]). A number of projects and prototypes have been deployed across Europe and worldwide. Most of the wave energy technological approaches, however, are at technology readiness level (TRL) 6-7, with a strong focus on R&I. Most improvements in wave energy results stem from ongoing projects in the EU. Over the past five years, the sector has shown resilience[98] and significant technology progress has been achieved thanks to the successful deployment of demonstration and first-of-a-kind farms.[99]

The LTS scenarios foresee limited uptake of ocean energy technology. The high cost of wave and tidal energy converters and the limited information available on the performance limit the capture of ocean energy in the model[100]. At the same time, the

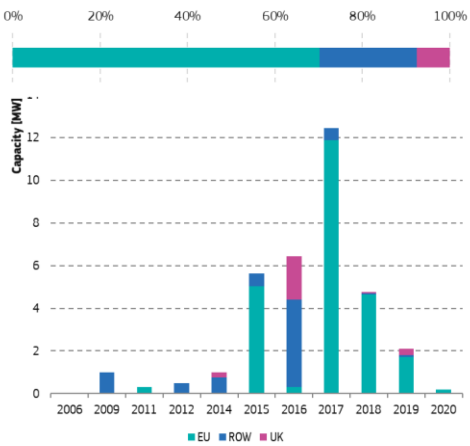
[92] ETIPWind, Floating Offshore Wind. Delivering climate neutrality (2020).
[93] GWEC 2020, Global Offshore Wind Report, 2020.
[94] The CTP-MIX scenario from COM(2020) 562 final.
[95] It is anticipated that this will be published later in 2020.
[96] There is significant potential to develop tidal energy in France, Ireland and Spain, and localised potential in other Member States. As regards wave energy, high potential is to be found in the Atlantic, localised potential in the North Sea, the Baltic, the Mediterranean, and the Black Sea.
[97] Ofgem Renewable Energy Guarantees Origin Register. https://www.renewablesandchp.ofgem.gov.uk/
[98] European Commission (2017) Study on Lessons for Ocean Energy Development, EUR 27984.
[99] Magagna & Uihllein (2015) 2014 JRC Ocean Energy Status Report.
[100] In the years to come, EU energy modelling results can be expected to reflect the validation and cost reduction of these technologies.

European Green Deal emphasises the key role marine renewable energy will play in the transition to a climate-neutral economy, with a significant contribution expected under the right market and policy conditions (2.6 GW by 2030[101] and 100 GW in European waters by 2050[102]). Ongoing demonstrations show that costs can be reduced fast: data from Horizon 2020 projects indicate that the cost of tidal energy fell by over 40% between 2015 and 2018[103,104].

Value chain: European leadership spans the whole ocean energy supply chain[105] and innovation system[106]. The European cluster formed by specialised research institutes, developers and the availability of research infrastructure has enabled Europe to develop and maintain its current competitive position.

Global market: the EU maintains global leadership despite the UK's withdrawal from the bloc and changes in the market for wave and tidal energy technologies. 70% of global ocean energy capacity has been developed by EU-based companies[107]. Over the next decade it will be vital for EU developers to build on their competitiveness position. Global ocean energy capacity is expected to increase to 3.5 GW within the next five years, and an increase of up to 10 GW can be expected by 2030[108].

Figure 10 Installed capacity by origin of technology



Source 10 JRC 2020[109]

Within the EU[110], 838 companies in 26 countries filed patents or were involved in the filing of patents to do with ocean energy between 2000 and 2015[111]. The EU has long maintained technological leadership in developing ocean energy technologies, thanks to

[101] European Commission (2018) Market study on ocean energy.2.2GW of tidal stream and 423MW of wave energy.
[102] European Commission (2017) Ocean energy strategic roadmap: building ocean energy for Europe.
[103] JRC (2019) Technology Development Report LCEO: Ocean Energy.
[104] In addition, R&I in the fields of advanced and hybrid materials, new manufacturing processes and additive manufacturing employing innovative 3D technologies could enable costs to be reduced further. It could also help reduce energy consumption, shorten lead times and improve quality associated with the production of large cast components.
[105] JRC (2017) Supply chain of renewable energy technologies in Europe.
[106] JRC (2014) Overview of European innovation activities in marine energy technology.
[107] JRC (2020) - Facts and figures on Offshore Renewable Energy Sources in Europe, JRC121366 (upcoming).
[108] EURActive (2020) https://www.euractiv.com/section/energy/interview/irena-chief-europe-is-the-frontrunner-on-tidal-and-wave-energy/
[109] JRC (2020) - Facts and figures on Offshore Renewable Energy Sources in Europe, JRC121366 (upcoming).
[110] EU including UK.
[111] JRC (2020) Technology Development Report Ocean Energy 2020 Update.

the sustained support provided for R&I. Between 2007 and 2019, total R&I expenditure on wave and tidal energy amounted to EUR 3.84 billion, most of which (EUR 2.74 billion) came from private sources. In the same period, national R&I programmes contributed EUR 463 million to the development of wave and tidal energy, while EU funds supported R&I to the tune of almost EUR 650 million (including NER300 and Interreg projects (co-funded by the European Regional Development Fund))[112]. On average, EUR 1 billion of public funding (EU[113] and national) leveraged EUR 2.9 billion of private investments in the course of the reporting period.

Significant cost reduction is still needed for tidal and wave energy technologies to exploit their potential in the energy mix, for which intensified (i.e. increased rate of projects in the water) and continued (i.e. continuity of projects) demonstration activities are necessary. Despite advances in technology development and demonstration, the sector faces a struggle in creating a viable market. National support appears low, reflected by the limited commitment to ocean energy capacity in the NECPs compared to 2010 and the lack of clear dedicated support for demonstration projects or for the development of innovative remuneration schemes for emerging renewable technologies. This limits scope for developing a business case and for identifying viable ways to develop and deploy the technology. Specific business cases for ocean energy therefore need more focus, in particular when its predictability can enhance its value, as well its potential for decarbonising small communities and EU islands[114]. The upcoming offshore renewable energy strategy offers an opportunity to support the development of ocean energy and enable the EU to exploit its resources across the EU to the full.

3.3 Solar photovoltaics (PV)

Technology: solar PV has become the world’s fastest-growing energy technology, with demand for solar PV spreading and expanding as it becomes the most competitive option for electricity generation in a growing number of markets and applications. This growth is supported by the decreasing cost of PV systems (EUR/W) and increasingly competing cost of electricity generated (EUR/MWh).

The EU[115] cumulative PV installed capacity amounted to 134 GW in 2019, and it is projected to grow to 370 GW in 2030, and to 1051 GW in 2050[116]. Given the significant projected growth of PV capacity in the EU and globally, Europe should have a sizeable role in the whole value chain. At the moment, European companies perform differently across the various segments of the PV value chain (Figure 11).

Figure 11 European players across the PV industry value chain

[112] JRC calculation, 2020.
[113] EU funds awarded up to 2020 included UK recipients.
[114] European Commission (2020), The EU Blue Economy Report, 2020.
[115] EU including UK.
[116] According to the projections in the Impact Assessment supporting the Climate Target Plan (COM(2020) 562 final.)

	Equipment for PV manufacturing	Solar PV panels (Silicon, Cells, Modules)	Monitoring & Controls	Balance of system	EPC	Deployment
Key activities	• PV manufacturing equipment • New PV technology development	• Manufacturing of silicon ingots, cells and PV modules	• Developing hardware and software to improve the performance of solar farm	• All non-module hardware (Inverters, Trackers, Steel structures, cabling, etc.)	• Engineering design • Construction • Lease & Insurance • Commissioning	• Development • Finance • O&M
Market Size (M€)	Global 1.329 EU 66	Global 57.842 EU 7.368	Global 2.694 EU 678	Global 25.707 EU 3.275	Global 17.995 EU 2.292	Global 26.993 EU 3.438
Market Growth Outlook	EU: Global: R&D directed to HJT	EU: Global: Focus on increasing cell efficiency	EU: Global: Focus diagnostics and optimisation	EU: Global: Increasing warranties and cost reduction	EU: Global: Focus on factory vs field work	EU: Global: Access to low cost capital and leading technology is key
Key players EU	• Valoe • Centrotherm • SCHMID	• Hanwha Q-cells (Partially EU) • Wacker Chemie • 3Sun	• GreenPower Monitoring • AlsoEnergy (partially EU) • Solar-log • Meteo&Control	**Inverters** • SMA **Trackers** • Soltec	Highly fragmented market dominated by local players	• Enel Green Power • Engie • BayWa.re
Key players Rest of the World	• Meyer Burger	• Trina Solar • Jinko Solar • GCL-Si • Hanwha Q-cells (Partially KR) • JA Solar • Longi • Tongwei	• AlsoEnergy (Partially US) • Inaccess	**Inverters** • Huawei • SunGrow **Trackers** • Nextracker • Array Tech	Highly fragmented market dominated by local players	• Nexterra • BP Lightsource
Critical materials	None	Silver, Copper	None	None	None	None

Legend: (10 year CAGR) >15% >10% >5% >0%

Source 11 ASSET study on competitiveness

Value chain: EU companies are competitive mainly in the downstream part of the value chain. In particular, they have managed to remain competitive in the monitoring, control and balance of system (BoS) segments, hosting some of the leaders in inverter manufacturing and in solar trackers. EU companies have also maintained a leading position in the deployment segment, where established players like Enerparc, Engie, Enel Green Power or BayWa.re have been able to gain new market share worldwide[117]. Furthermore, equipment manufacturing still has a strong base in Europe (e.g. Meyer Burger, Centrotherm, Schmid).

Global market: the EU has lost its market share in some of the upstream parts of the value chain (e.g. solar PV cell and module manufacturing). The highest value added is located both a long way upstream (in basic and applied R&D, and design) and a long way downstream (in marketing, distribution, and brand management). Even though the lowest value-added activities occur in the middle of the value chain (manufacturing and assembly), companies have an interest in being well positioned in these segments, to reduce risks and financing costs. The EU still hosts one of the leading polysilicon manufacturers (Wacker Polysilicon AG), whose production alone is sufficient to manufacture 20 GW of solar cells, and which exports a significant part of its polysilicon output to China[118]. Currently, global production of PV panels is valued at about EUR 57.8 billion, with the EU accounting for EUR 7.4 billion (12.8%) of that amount. The EU still accounts for a relatively high share of the segment's total value, thanks to the production of polysilicon ingots. However, it has fallen back dramatically in the manufacture of PV cells and modules. All the top 10 producers of PV cells and modules now produce most of their output in Asia[119].

[117] ASSET Study on Competitiveness, 2020.
[118] JRC PV Status Report, 2011.
[119] Izumi K., PV Industry in 2019 from IEA PVPS Trends Report, ETIP PV conference "Readying for the TW era, May 2019, Brussels

Capital expenditure costs for polysilicon, solar cell and module manufacturing plants fell dramatically between 2010 and 2018. Together with innovations in manufacturing, this should offer an opportunity for the EU to take a fresh look at the PV manufacturing industry and reverse the situation[120].

The EU's presence in the far upstream and far downstream parts of the value chain could well provide a basis for rebuilding the PV industry. This would require a focus on specialisation or high-performance/high-value products, such as equipment and inverter manufacturing and PV products tailored to the specific needs of the building sector, transport (vehicle integrated PV) and/or agriculture (dual land use with AgriPV), or to the demand for high-efficiency/high-quality solar power installations to optimize use of available surfaces and of resources. The modularity of the technology makes it easier to integrate PV in a number of applications, especially in the urban environment. These novel PV technologies, which are now reaching the commercial phase, could offer a new basis for rebuilding the industry[121]. The strong knowledge of the EU research institutions, the skilled labour force, and the existing and emerging industry players provide a basis for re-establishing a strong European photovoltaic supply chain[122]. To remain competitive, such industry needs to develop a global outreach. Building a sizeable EU PV manufacturing industry would also reduce the risk of supply disruptions and quality risks.

3.4 Renewable hydrogen production through electrolysis

This section focuses on renewable hydrogen production and on the competitiveness of this first segment of the hydrogen value chain[123]. Hydrogen is key to to store energy produced by renewable electricity and to decarbonise sectors that are hard to electrify. The aim of the EU hydrogen strategy is to integrate 40 GW of renewable hydrogen[124] electrolysers and the production of up to 10 Mt of renewable hydrogen in the EU energy system by 2030, with direct investment of between EUR 24 billion and EUR 42 billion[125,126].

<u>Technology</u>: the capital cost of electrolysers has fallen by 60% in the last decade, and is expected to halve again by 2030, compared to the present day, thanks to economies of

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[120] Arnulf Jäger-Waldau, Ioannis Kougias, Nigel Taylor, Christian Thiel, How photovoltaics can contribute to GHG emission reductions of 55% in the EU by 2030, Renewable and Sustainable Energy Reviews, Volume 126, 2020, 109836, ISSN 1364-0321

[121] Here are a few examples of the most relevant PV manufacturing initiatives in Europe. i) The H2020 'Ampere' project supporting the construction of a pilot line to produce heterojunction silicon solar cells and modules. The 3Sun Factory (Catania, Italy) produces one of the most efficient PV technologies based on this approach. ii) The Oxford PV initiative for manufacturing PV solar cells based on perovskite materials, receiving an EIB loan under the InnovFin EDP facility. iii) Meyer Burger's patent-protected heterojunction/SmartWire technology, which is more efficient than the current standard mono-PERC, as well as other heterojunction technologies currently available.

[122] Assessment of Photovoltaics (PV) Final Report, Trinomics (2017).

[123] On-site hydrogen production for co-located consumption in industrial applications appears to be a promising pattern which could enable the scale for the wider introduction of the carrier in the energy system to be reached fast, in line with the ambition of a climate-neutral economy and the hydrogen strategy. The competitiveness of the other supply chain segments, such as the transport of hydrogen, its storage and its conversion in end-use applications (e.g. mobility, buildings) is not dealt with in this report. The Commission has set up the European Clean Hydrogen Alliance as a stakeholder platform to bring the relevant players together.

[124] Renewable hydrogen (often referred to as 'green hydrogen') is hydrogen produced by electrolysers powered by renewable electricity, through a process in which water is dissociated into hydrogen and oxygen.

[125] A hydrogen strategy for a climate-neutral Europe, https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf

[126] In addition, from now to 2030, an amount between EUR 220bn and EUR 340bn would be required to scale up and connect 80-120 GW of solar and wind generators to the electrolysers to supply the necessary electricity.

scale[127]. The cost of renewable hydrogen[128] currently lies between EUR 3 and EUR 5.5 per kilo, making it more expensive than non-renewable hydrogen (EUR 2 (2018) per kilo of hydrogen[129]).

Today, less than 1% of world hydrogen production comes from renewable sources[130]. Projections for 2030 locate the cost of renewable hydrogen in the range of EUR 1.1-2.4/kg[131], which is cheaper than low-carbon fossil-based hydrogen[132], and nearly competitive with fossil-based hydrogen[133].

Between 2008 and 2018, the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) supported 246 projects across several hydrogen-related technological applications, reaching a total investment figure of EUR 916 million, complemented by EUR 939 million of private and national/regional investments. Under the Horizon 2020 programme (2014-2018), over EUR 90 million was allocated to developing electrolysers, complemented by EUR 33.5 million of private funds[134,135]. At national level, Germany has deployed most resources, with EUR 39 million[136] allocated to projects devoted to electrolyser development between 2014 and 2018[137]. In Japan, Asahi Kasei received a multimillion dollar grant supporting the development of their alkaline electrolyser[138].

Asia (mostly China, Japan and South Korea) dominates the total number of patents filed between 2000 and 2016 for the hydrogen, electrolyser and fuel cell groupings. Nevertheless, the EU performs very well and has filed the largest number of 'high-value' patent families in the fields of hydrogen and electrolysers. Japan, however, has filed the largest number of 'high-value' patent families in the field of fuel cells.

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[127] From the hydrogen strategy: based on cost assessments by the IEA, IRENA and BNEF. Electrolyser costs to decline from EUR 900/kW to EUR 450/KW or less in the period after 2030, and EUR 180/kW after 2040. The costs of carbon capture and storage increase the costs of natural gas reforming from EUR 810/kWH2 to EUR 1512/kWH2. For 2050, the costs are estimated at EUR 1152/kWH2 (IEA, 2019).

[128] State of art for alkaline electrolyser efficiency is around 50 kWh/kgH2 (about 67% based on hydrogen lower heating value (LHV)) and 55 kWh/kgH2 (about 60% based on hydrogen LHV) for PEM electrolysis. Energy consumption for SOE is lower (of the order of 40 kWh/kgH2), but a source of heat is required in order to provide the necessary high temperatures (>600°C). https://www.fch.europa.eu/sites/default/files/MAWP%20final%20version_endorsed%20GB%2015062018%20%28ID%203712421%29.pdf

[129] https://www.iea.org/data-and-statistics/charts/hydrogen-production-costs-using-natural-gas-in-selected-regions-2018-2 Original figure 1.7 USD - Conversation rate used: (EUR 1 = USD 1.18)

[130] International Energy Agency, Hydrogen Outlook, June 2019, p. 32 – 2018 estimates.

[131] COM(2020) 301 final

[132] Refers to fossil-based hydrogen with carbon capture' which is a subpart of fossil-based hydrogen, but where greenhouse gases emitted as part of the hydrogen production process are captured.

[133] Refers to hydrogen produced through a variety of processes using fossil fuels as feedstock COM(2020) 301 final.

[134] JRC 2020, Current status of Chemical Energy Storage Technologies', p. 63. https://publications.jrc.ec.europa.eu/repository/bitstream/JRC118776/current_status_of_chemical_energy_storage_technologies.pdf

[135] Compared with EUR 472 million for FCH JU funding overall and EUR 439 million for other sources of funding.

[136] This includes both private and public funds.

[137] JRC 2020 ,Current status of Chemical Energy Storage Technologies', p. 63 https://publications.jrc.ec.europa.eu/repository/bitstream/JRC118776/current_status_of_chemical_energy_storage_technologies.pdf

[138] Yoko-moto, K., Country Update: Japan, in 6th International Workshop on Hydrogen Infrastructure and Transportation, 2018.

Value chain: the main water electrolysis technologies are alkaline electrolysis (AEL), polymer electrolyte membrane electrolysis (PEMEL) and solid oxide electrolysis (SOEL)[139]:

- AEL is a mature technology with operational costs driven by electricity costs and high capital cost. The research challenges are high-pressure operation and the coupling with dynamic loads.
- PEMEL can reach significantly higher current densities[140] than AEL and SOEL, with the potential to further reduce capital cost. In recent years, several large (MW-scale) plants have been installed in the EU (in Germany, France, Denmark, and the Netherlands), enabling the EU to catch up on AEL. It is a market-ready technology with research mainly focused on increasing aerial power density, while guaranteeing the simultaneous reduction of critical raw material use[141] and durability performance.
- SOEL exhibits greatest efficiency. However, plants are relatively smaller, usually still in the 100 kW capacity range, require steady operation, and need to be coupled to a heat source[142]. Overall, SOEL is still in the development phase, although it is possible to order products on the market.

In 2019, the EU had around 50 MW of water electrolysis capacity installed[143] (about 30% AEL and 70% PEMEL), of which about 30 MW were located in Germany in 2018[144].

AEL has no critical components in its supply chain. Thanks to technical similarities with the chlor-alkali electrolysis industry, which deploys much larger installations, it can exploit technology overlap and benefit from well-established value chains.[145]. PEMEL and SOEL share some cost and supply risks with the respective fuel cell value chains[146]. This applies in particular to critical raw materials[147] in the case of PEMEL, and to rare earths in the case of SOEL.

PEMEL has to withstand corrosive environments and therefore requires the use of more expensive materials, such as titanium for bipolar plates. The main system-cost contributors are the electrolyser stack[148] (40-60%), followed by the power electronics (15-21%). The core components driving up the stack cost are the layers of membrane electrode assemblies (MEA), which contain noble metals[149]. Cell components based on rare earths that are used for SOEL electrodes and electrolyte are the main contributors to

[139] A novel type of high temperature electrolyser, at a very low TRL, is under development: proton ceramic Eeectrolysers (PCEL), with the potential advantage of producing pure dry pressurised hydrogen at the maximum pressure of the electrolyser, unlike other electrolyser technologies.

[140] Electrolysis is a surface-based process. Therefore, upscaling an electrolyser stack cannot take advantage of a favourable surface/volume ratio as for volume-based processes. All other things remaining equal, doubling or tripling the size of an electrolysis stack will almost double or triple the investment cost, with limited direct economies coming from the scale-up. This is why the increased areal power density allowed in the PEMEL approach is relevant. Obtaining higher hydrogen production for a given surface area of the electrolyser reduces the capital cost and the overall footprint of the installation.

[141] Mainly platinum group metals (PGMs), iridium in particular.

[142] A recently started European project[142] is currently aiming to install 2.5 MW in an industrial environment.

[143] https://iea.blob.core.windows.net/assets/a02a0c80-77b2-462e-a9d5-1099e0e572ce/IEA-Hydrogen-Project-Database.xlsx

[144] https://www.dwv-info.de/wp-content/uploads/2015/06/DVGW-2955-Brosch%C3%BCre-Wasserstoff-RZ-Screen.pdf

[145] https://www.fch.europa.eu/sites/default/files/Evidence%20Report%20v4.pdf

[146] https://publications.jrc.ec.europa.eu/repository/handle/JRC118394

[147] Iridium is currently crucial for PEM electrolysis only, but not for fuel cell systems. Since it is one of the rarest elements in the earth's crust, it is likely that any strain brought about by an increased additional demand will have strong repercussions on availability and price.

[148] A stack is the sum of all the cells.

[149] https://www.fch.europa.eu/sites/default/files/Evidence%20Report%20v4.pdf

stack cost. It is estimated that stacks account for about 35% of overall SOEL system cost[150].

Global market: European companies are well-placed to benefit from market growth. The EU has producers of all three main electrolyser technologies[151], and is the only region offering a well-defined market product for SOEL. The other players are located in the UK, Norway, Switzerland, the US, China, Canada, Russia and Japan.

The global turnover for water electrolyser systems is currently estimated to be in the range of EUR 100 to EUR 150 million per year. According to 2018 estimates, water electrolysis production could reach a capacity of 2 GW per year (globally), within a very short space of time (one to two years). European manufacturers could potentially supply about one third of this increased global capacity[152].

The aim of the EU's hydrogen strategy is to achieve a significant renewable hydrogen production capacity by 2030. This will require a tremendous effort to scale up from the 50 MW of water electrolysis capacity currently installed to 40 GW by 2030, with the setting up of the capacity required for a sustainable value chain in the EU. This effort should build on the innovation potential offered by the whole spectrum of the electrolyser technologies and on the leading position EU companies have in electrolysis in all technology approaches, along the whole value chain, from component supply to final integration capability. Important cost reductions are expected as a result of scaling up industrial scale manufacturing of electrolysers.

3.5 Batteries

Batteries are a key enabler for the transition to the climate-neutral economy we aim to reach by 2050, for the roll-out of clean mobility, and for energy storage to enable the integration of increasing shares of variable renewables. This analysis focuses on lithium ion (Li-ion) battery technology. There are several reasons for this:

- the very advanced state of this technology and its market readiness;
- its high round trip efficiency;
- its considerable projected demand; and
- its expected broader use, be it in electric vehicles, future electric (maritime and airborne) vessels, or in stationary and other industrial applications, leading to considerable market opportunities.

Technology: global demand for Li-ion batteries is projected to increase from about 200 GWh in 2019 to about 800 GWh in 2025, and to exceed 2 000 GWh by 2030. Under the most optimistic scenario, it could reach 4 000 GWh by 2040[153].

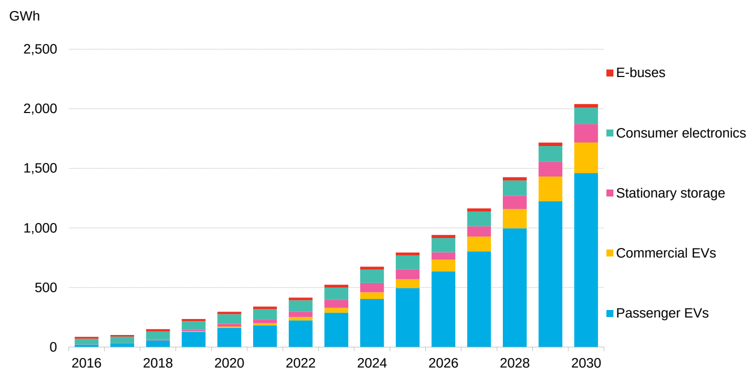
[150] https://www.hydrogen.energy.gov/pdfs/16014_h2_production_cost_solid_oxide_electrolysis.pdf

[151] *AEL* **is** provided by nine EU producers (four in Germany, two in France, two in Italy and one in Denmark), two in Switzerland and one in Norway, two in the US, three in China, and three in other countries (Canada, Russia and Japan). *PEMEL* is provided by six EU suppliers (four in Germany, one in France and one in Denmark), one supplier from the UK and one from Norway, two suppliers from the US, and two suppliers from other countries. *SOEL* are provided by two suppliers from the EU (Germany and France).

[152] https://www.now-gmbh.de/content/service/3-publikationen/1-nip-wasserstoff-und-brennstoffzellentechnologie/181204_bro_a4_indwede-studie_kurzfassung_en_v03.pdf

[153] Source: JRC Science for Policy Report: Tsiropoulos I., Tarvydas D., Lebedeva N., Li-ion batteries for mobility and stationary storage applications – Scenarios for costs and market growth, EUR 29440 EN, Publications Office of the European Union, Luxembourg, 2018, doi:10.2760/87175.

Figure 12 Historical and projected annual Li-ion battery demand, by use



Source 12 Bloomberg Long-Term Energy Storage Outlook, 2019: Bloomberg NEF, Avicenne for consumer electronics

The projected growth, mainly based on electric vehicles (especially passenger vehicles), comes from the strong technological improvements that are expected and further decreases in cost. Lithium-ion battery prices, which were above USD 1 100/kWh in 2010, have fallen 87% in real terms to USD 156/kWh in 2020[154]. By 2025, average prices are expected to be close to USD 100/kWh[155]. As regards performance, lithium-ion energy density has increased significantly in recent years, tripling since their commercialisation in 1991[151]. Further potential for optimisation is expected with the new generation of Li-ion batteries[156].

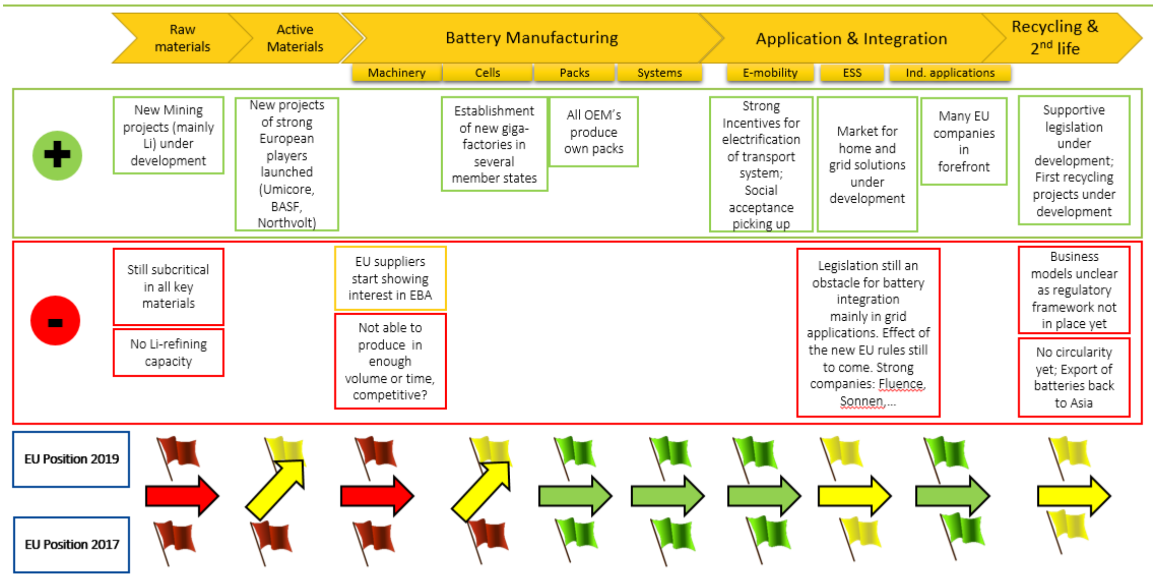
Value chain: Figure 14 shows the value chain for batteries together with the EU's position in the various segments. EU industry is investing in mining, raw and advanced materials production and processing (cathode, anode and electrolyte materials), and in modern cell, pack and battery production. The aim is to become more competitive through quality, scale and, in particular, sustainability.

Figure 13 Assessment of EU position along the battery value chain, 2019

[154] L. Trahey, F.R. Brushetta, N.P. Balsara, G. Cedera, L. Chenga, Y.-M. Chianga, N.T. Hahn, B.J. Ingrama, S.D. Minteer, J.S. Moore, K.T. Mueller, L.F. Nazar, K.A. Persson, D.J. Siegel, K. Xu, K.R. Zavadil, V. Srinivasan, and G.W. Crabtree, 'Energy storage emerging: A perspective from the Joint Center for Energy Storage Research', PNAS, 117 (2020) 12550–12557.

[155] BNEF 2019 Battery Price Survey

[156] Forthcoming JRC (2020) Technology Development Report LCEO: Battery storage.



Source 13 InnoEnergy (2019).

Global market: the global market for Li-ion batteries for electric cars is currently worth EUR 15 billion/year (of which the EU accounts for EUR 450 million/year (2017)[157]). A conservative estimate foresees that the market will be EUR 40-55 billion/year in 2025 and EUR 200 billion/year in 2040[158]. In 2018, the EU had only about 3% of the global production capacity of Li-ion cells, while China had about 66%[159]. European industry was perceived as being strong in the downstream, value-driven segments, such as battery pack manufacturing and integration and battery recycling, and generally weak in upstream, cost-driven segments such as materials, components and cell manufacturing[160,161]. The marine battery market is growing and estimated to be worth more than €800 million/year by 2025, more than half within Europe and a technological sector where Europe currently leads[162].

Recognising the urgent need for the EU to recover competitiveness in the battery market, the Commission launched the European Battery Alliance in 2017 and adopted a strategic action plan for batteries in 2018[163]. This is a comprehensive policy framework with regulatory and financial instruments to support the establishment of a complete battery

[157] https://ec.europa.eu/jrc/sites/jrcsh/files/jrc114616_li-ion_batteries_two-pager_final.pdf

[158] Bloomberg Long Term Energy Storage Outlook 2019, p55-56

[159] Manufacturing capacity; Bloomberg Long-Term Energy Storage Outlook, 2019, pp. 55-56

[160] JRC Science for Policy report: Steen M., Lebedeva N., Di Persio F., Boon-Brett L., EU Competitiveness in Advanced Li-ion Batteries for E-Mobility and Stationary Storage Applications – Opportunities and Actions, EUR 28837 EN, Publications Office of the European Union, Luxembourg, 2017 doi:10.2760/75757.

[161] JRC Science for Policy report: Lebedeva, N., Di Persio, F., Boon-Brett, L., Lithium ion battery value chain and related opportunities for Europe, EUR 28534 EN, Publications Office of the European Union, Luxembourg, 2016, doi:10.2760/6060.

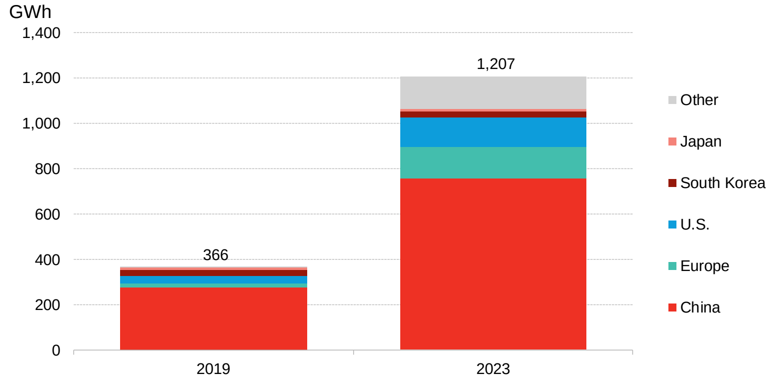
[162] https://www.marketsandmarkets.com/Market-Reports/marine-battery-market-210222319.html

[163] COM 2019 176 Report on the Implementation of the Strategic Action Plan on Batteries: Building a Strategic Battery Value Chain in Europe. https://ec.europa.eu/transparency/regdoc/rep/1/2019/EN/COM-2019-176-F1-EN-MAIN-PART-1.PDF

Actions include a) strengthening the Horizon 2020 programme through additional battery research funding, b) creating a specific technology platform, the ETIP 'Batteries Europe' tasked with coordination of R&D&I efforts at regional, national and European levels, c) preparing specific instruments for the next Research Framework Programme Horizon Europe, d) preparing new sustainability regulation, and e) stimulating investment through Important Project of Common European Interest (IPCEI). Press release IP/19/6705, 'State aid: Commission approves €3.2 billion public support by seven Member States for a pan-European research and innovation project in all segments of the battery value chain', 9 December 2019. https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6705.

value chain ecosystem in Europe. At the same time, large-scale battery and battery cell manufacturers are starting to establish new production plants (e.g. Northvolt). Currently, there have been announcements for investments in up to 22 battery factories (some of which are under construction), with a projected capacity of 500 GWh by 2030[164].

Figure 14 Li-ion cell manufacturing capacity by region of plant location



Source 14 BloombergNEF, 2019

The EU has strengths which it can build on to catch up in the battery industry, particularly in advanced materials and battery chemistries, and in recycling, where EU pioneering legislation has made it possible to develop a well-structured industry. The Batteries Directive is currently under revision. However, to capture a significant market share of the new and fast-growing rechargeable battery market, sustained action is needed over an extended period to ensure more investment in production capacity. This needs to be supported by R&I to improve the performance of batteries, while also guaranteeing that they meet EU-level quality and safety standards, as well as to guarantee the availability of raw and processed materials and the reuse or recycling and sustainability of the whole battery value chain. There also needs to be a new comprehensive EU legislative framework that sets out robust standards for performance and sustainability for batteries placed on the EU market. This will help industry to plan investments and ensure high standards of sustainability in line with the objectives of the European Green Deal. A Commission proposal will be adopted shortly.

While improving the position on Li-ion technology is likely to be a core interest stream over the next few decades, there is also a need to look into other new and promising battery technologies (such as all-solid state, post Li-ion and redox flow technology). These are important for applications whose requirements cannot be met by Li-ion technology.

3.6 Smart electricity grids

Electrification increases in all scenarios for 2050[165], so a smart electricity system is essential if the EU is to achieve its Green Deal ambitions. A smart system enables a more efficient integration of increasing shares of renewable electricity production and of increasing electricity storage and/or consuming devices (e.g. electric vehicles) in the

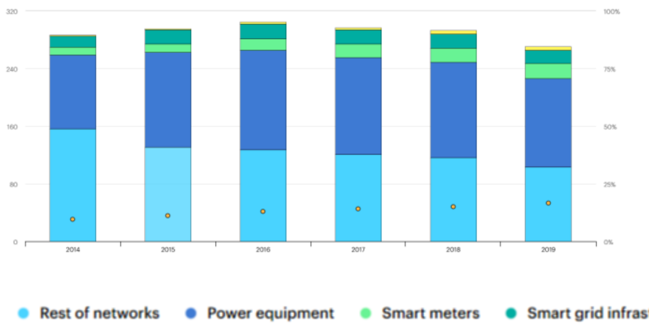
[164] EBA 2020.

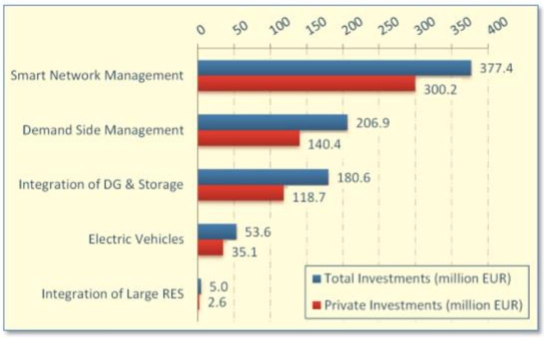
[165] 'The share of electricity in final energy demand will at least double, bringing it up to 53%, and electricity production will increase substantially to achieve net-zero greenhouse gas emissions, up to 2.5 times of today's levels depending on the options selected for the energy transition', Communication on 'A Clean Planet for all - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy', p. 9.

energy system. The same applies to the growing numbers of devices that run on electricity, such as electric vehicles. Through comprehensive control and monitoring of the grid, smart systems also create value by reducing the need for curtailment of renewables and enabling competitive and innovative energy services for consumers. According to the IEA, investment in enhanced digitalisation would reduce curtailment in Europe by 67 TWh by 2040[166]. In Germany alone, 6.48 TWh was curtailed in 2019, while grid stabilisation measures cost EUR 1.2 billion[167]. Such systems need to be cyber-secure, which requires sector-specific measures.[168]

Investments in digital grid infrastructure are dominated by hardware such as smart meters and electric vehicle chargers. In Europe, investments remained stable in 2019 at nearly EUR 42 billion[169], with a larger portion of spending allocated to upgrading and refurbishing the existing infrastructure.

Figure 15 (left) Global investment in smart grids by technology area, 2014-2019[170] (billion USD)
Figure 16 (right) Smart grid investment by European TSOs in recent years, by category (2018)[171]





The main source of support for R&I investments in smart grids at EU level is Horizon 2020, which provided almost EUR 1 billion between 2014 and 2020. EUR 100 million was invested in dedicated digitalisation projects, and many other smart grid projects assign a considerable proportion of their budget to digitalisation.[172] Figure 16 shows that public investments in smart grids, including those made through Horizon 2020, account for a significant share of total investments by transmission system operations (TSOs). It is noteworthy that budgets for R&I by TSOs are low, at around 0.5% of their annual budget[173,174].

The TEN-E Regulation also supports investments in smart electricity grids as one of the 12 priority areas, but investments in (cross-border) smart grids could benefit from higher levels of support from regulatory authorities through inclusion in national network

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[166] with demand-response accounting for 22 TWh and storage accounting for 45 TWh - https://www.iea.org/reports/digitalisation-and-energy

[167] including costs of curtailment, redispatch and procuring reserve power. These costs are higher in Germany than elsewhere in Europe, but nevertheless give a good indication of the cost of curtailment. Zahlen zu Netz- und Systemsicherheitsmaßnahmen - Gesamtjahr 2019, BNetzA, https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/Versorgungssicherheit/Netz_Systemsicherheit/Netz_Systemsicherheit_node.html, p3

[168] In particular, real-time requirements (e.g. a circuit breaker must react within a few milliseconds), cascading effects and the mix of legacy technologies with smart/state of the art technology. See the Commission's Recommendation on cybersecurity in the energy sector, C(2019) 2400 final.

[169] Source figure is US$ 50bn; https://www.iea.org/reports/tracking-power-2020

[170] https://www.iea.org/reports/tracking-energy-integration-2020/smart-grids

[171] https://ses.jrc.ec.europa.eu/sites/ses.jrc.ec.europa.eu/files/publications/dsoobservatory2018.pdf

[172] Estimated to be at least half of that total Horizon 2020 support for smart grids.

[173] This is further supported by figures on sub-markets dealt with in CETTIR (SWD(2020)953), see section 3.17.

[174] ENTSO-E RDI Roadmap 2020-2030, July 2020, p. 25.

development plans and eligibility for EU financial assistance in the form of grants for studies and works as well as innovative financial instruments under the Connecting Europe Facility (CEF). From 2014 to 2019, CEF has provided up to EUR 134 million of financial assistance related to different smart electricity grids projects across the EU.

The following two key technologies are assessed in more detail: High-voltage direct current (HVDC) systems, and digital solutions for grid operations and for the integration of renewables.

i) High-voltage direct current (HVDC) systems

Technology: higher demand for cost-effective solutions to transport electricity over long distances, particularly, in the EU, to bring power generated by offshore wind to land, increases demand for HVDC technologies. According to Guidehouse Insights, the European market for HVDC systems will grow from EUR 1.54 billion in 2020 to EUR 2.74 billion in 2030, at a growth rate[175] of 6.1%[176,177]. The global market is expected to be around EUR 12.5 billion (2020), with the main investments in HVDC taking place in Asia, where much of the market is taken up by Ultra-HVDC[178]. HVDC equipment is very costly, and projects to build HVDC connections are therefore very expensive. Given the technological complexity of HVDC systems, their installation is generally managed by manufacturers[179].

Value chain analysis: the value chain for HVDC grids can be segmented along the different hardware components needed to realise an HVDC connection[180]. The cost of HVDC systems is accounted for largely by converters (about 32%) and cables (about 30%)[181]. In the converter stations' value chain, power electronics[182] play a key role in determining the efficiency and the size of the equipment. Energy-specific applications represent only a small part of the global market in electronic components[183], but offshore grids and wind turbines depend on their functioning well under offshore conditions. R&I

[175] Growth rates in this chapter are reported as compounded annual growth rates (CAGR).

[176] Guidehouse Insights (2020) Advanced Transmission & Distribution Technologies Overview. Retrieved at https://guidehouseinsights.com/reports/advanced-transmission-and-distribution-technologies-overview

[177] EU energy models (e.g. Primes) do not model HVDC separately, so no longer-term figures are available. However, it is clear that the HVDC market is expected to grow consistently, especially given the growth of the offshore energy market.

[178] UHVDC is not used in the EU. It is of particular use in transporting electricity over very long distances, which is less important in the EU. UHVDC is also less attractive in the EU as permitting is more difficult, for example because cable towers are higher than normal high-voltage transmission cable towers. The global market for UHVDC is estimated at EUR 6.5 billion, mostly in China.

[179] By way of comparison, turnkey HVAC systems are often delivered by engineering, procurement, and construction firms.

[180] Major converter station components include the transformers, converters, breakers, and power electronics used to convert power from AC to DC and back again. Line-commutated converters (LCCs), also known as current source converters (CSCs), and voltage-source converters (VSCs) are the primary commercial HVDC converter technologies. Both LCC and VSC stations, being more complex than HVAC substations, are also more expensive[180]. Despite the integration of common technologies, HVDC transformers and converter stations are not standardised, and designs and costs are highly dependent on local project specifications.

[181] In the EU the costs of cables are typically higher: Competitiveness report by ASSET for the European Commission.

[182] Power electronics is an essential technology to integrate direct-current (DC) generation and consumption that is used in many parts of the (future) energy system, such as PV installations, windmills, batteries, and HVDC converters. Power electronics technology is based on semiconductor technology and allows control of voltage or current, for example, to manage the grid and convert electricity between AC and DC. It could, therefore, be addressed in many parts of this report, but because of a specific challenge to do with offshore wind and grids, it is dealt with here.

[183] The total market for power electronics, i.e. passive, active, electromechanical components, was estimated at EUR 316 billion in 2019: Global active electronic components market share, by end user, 2018. www.grandviewresearch.com

investments in HVDC technologies are mainly private. Public funding at EU level through Horizon 2020 is modest, but has been boosted by the recently finished Promotion project[184].

Global market: the global HVDC market is led primarily by three companies, namely Hitachi ABB Power Grids, Siemens, and GE[185]. Siemens and Hitachi ABB Power Grids have around 50% of the market in most market segments, whereas cable companies[186] make up around 70% of the market in the EU, and the main competitors are Japanese. In China, a further vendor, China XD Group, dominates the market.

So far, vendors have sold turnkey systems independently, as they were installed as point-to-point HVDC connections. In the more interconnected offshore grid of the future, HVDC systems from different manufacturers will need to be interconnected. This brings technological challenges to maintaining grid control[187] and, in particular, to ensuring the interoperability of HVDC equipment and systems. Moreover, as all components need to be installed on offshore platforms, it is important to reduce their size, and there is a need to develop power electronic solutions specifically for offshore energy applications.

ii) Digital solutions for grid operations and for the integration of renewables

Technology & value chain: the market for grid management technologies is forecast to grow very rapidly. The IEA has estimated potential savings from these specific technologies at almost USD 20 billion globally in cost reduction of operation and maintenance (O&M) and almost USD 20 billion in avoided network investment[188]. The market consists of different technologies and services in a value chain that is difficult to separate clearly, which seem to be integrating as the need increases for integrated solutions to manage storage, demand response, distributed renewables and the grid itself. This reports highlights two aspects.

Software- and data-based energy services, which are key to optimising integration of renewables, including at local level, through remote control of different technologies, in particular renewables and virtual power plants (VPP)[189]. This is a fast-growing market, forecast to increase from EUR 200 million (globally[190]) in 2020 to EUR 1 billion in 2030[191,192]. It forms the basis of a new industry that provides energy services to energy businesses (including network operators) as well as to business and household energy consumers. Thanks to a combination of increase in shares of renewables and market-supporting policies, Europe has been the driving force behind virtual power plant (VPP) markets, accounting for nearly 45% of global investments in 2020. Most of this in North-

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[184] https://www.promotion-offshore.net/

[185] Guidehouse Insights (2020) *Advanced Transmission & Distribution Technologies Overview.* Retrieved at https://guidehouseinsights.com/reports/advanced-transmission-and-distribution-technologies-overview

[186] Prysmian, Nexans, and NKT Cables are the three major European cable companies.

[187] Key technologies in this area include grid forming converters and DC circuit breakers.

[188] https://www.iea.org/reports/digitalisation-and-energy

[189] This includes Distributed energy resources management system (DERMS), Virtual Power Plant (VPP) and DER Analytics. Please see section 3.17.4 in CETTIR (SWD(2020)953) for a more detailed description.

[190] Figures for the EU are unfortunately not available.

[191] Competitiveness report by ASSET for the European Commission - Chapter 10.3.2 Grid management (Digital Technologies)

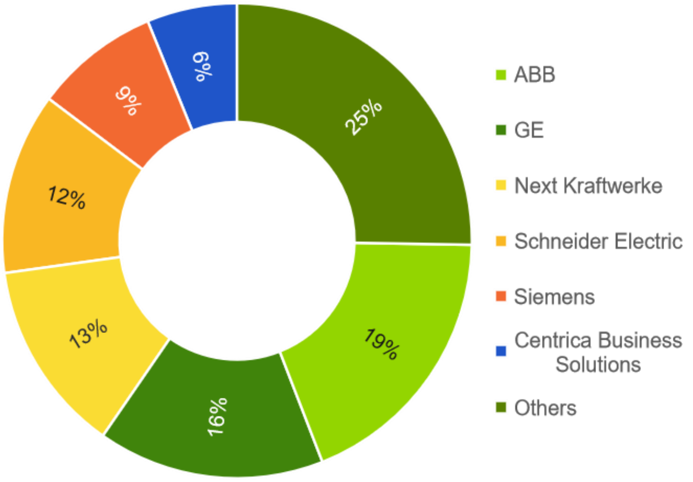
[192] These are considerable markets as is clear when comparing this to more established markets like the EU's Building Energy Management System (BEMS) market that has a size of EUR 1.2 billion in 2020 (source: Competitiveness report by ASSET for the European Commission). In CETTIR (SWD(2020)953) section 3.17.4, this technology is described together with the Home Energy Management System (HEMS) and the market of energy aggregators. These markets could also be expected to slowly integrate with the markets described here.

West Europe, including the Nordic countries. Within Europe, Germany is forecast to capture about one-third of the total VPP market's annual capacity by 2028.

Digital technologies for improved grid operation and maintenance (O&M), which is a market focused particularly on network operators. This is also a growing market, expected to reach EUR 0.2 billion in the EU by 2030 for software platforms for predictive maintenance, and EUR 1.2 billion for Internet-of-Things (IoT) sensors. The IoT market is expected to grow at 8.8% between 2020 and 2030.

Global market: the EU holds a strong position in both parts. Many of the global companies are European (Schneider Electric SE and Siemens). Competition is strongest from US companies, including several innovative start-ups. The Internet-of-Things (IOT) sensor and monitoring device hardware market consists of several major players with broad portfolios, and dozens of medium and small companies in niche markets. A handful of global companies (Hitachi ABB[193], IBM, Schneider Electric SE, Oracle, GE, Siemens, and C3.ai) dominate the market for software solutions, which it is hard for new players to enter**.** The global market for digital services is shown in figure 17.

Figure 17: Top key market players and market share for digital services, Global, 2020



Source 15 ASSET study on competitiveness

Several oil and gas and other energy providers are making strategic investments in grid management technologies, in particular services, and have invested in or acquired smaller startups in the European and US markets. Shell and Eneco have invested in the German companies Sonnen[194] and Next Kraftwerke respectively[195] and Engie has invested in the UK's Kiwi Power[196]. This trend seems to be confirmed by the fact that out of 200 recent

[193] The consequences of the divestment of ABB to Hitachi (https://new.abb.com/news/detail/64657/abb-completes-divestment-of-power-grids-to-hitachi) still need to be analysed further.

[194] Shell owns 100% of the shares of Sonnen: https://www.shell.com/media/news-and-media-releases/2019/smart-energy-storage-systems.html, 15 February 2019.

[195] Eneco owns a 34% minority share: https://www.next-kraftwerke.com/news/eneco-group-invests-in-next-kraftwerke, 8 May 2017.

[196] Engie owns just under 50% of the shares, but is the largest shareholder: https://theenergyst.com/engie-acquires-dsr-aggregator-kiwi-power/, 26 November 2018.

ventures that oil and gas companies have invested in, 65 were in the area of digitalisation, being the third sector after upstream conventional ventures and renewables[197].

While software platforms are reaching maturity, the applications for digital technologies to provide grid services continue to push innovation in the market space. Data volumes are relatively small compared to other sectors, so the innovation challenge is not in the data volumes or the data analysis technologies[198]. It lies in the availability of and access to different and distributed sources of data for the software providers to be able to provide integrated solution to their customers. Market-wide interoperable platforms for easy data access and data exchange are therefore key.

3.7 Further findings on other clean and low carbon energy technologies and solutions

As described in the accompanying Staff Working Document, the EU holds a strong competitive position in **onshore wind** and **hydropower technologies**. For onshore wind, the large scale of the market[199] and increasing capacity outside Europe offer promising prospects to a relatively well positioned EU industry in the wind value chain[200]. Similarly, for **hydropower** the importance of the market[201] and the EUs weight in global exports (48%) are key elements for a competitive industry. Yet, for both technologies, a key challenge moving forward is focus research to seize the opportunity of repowering/refurbishment of the oldest installations for increasing their social acceptance and reduced footprint. For **renewable fuels,** the key issue is to shift from first[202] to second and third generation fuels to expand the feedstock sustainability and optimise its use. To do so, scale up and demonstration projects will be important moving forward.

In the **geothermal energy technologies** (market of approx. 1 EUR billion) and **solar thermal power technologies** (market of approx. EUR 3 billion) markets, in order to increase the EU's market share, the challenge is to further deployment in existing and new heat applications for both buildings (especially for geothermal) and industry (especially for solar thermal power), and to further advance the innovation potential to integrate these technologies at scale. The development of **Carbon Capture and Storage** (CCS) technologies is currently hampered by the lack of viable business models and markets. With regard to **nuclear** energy technologies, EU companies are competitive across the whole value chain. Current competitiveness focus is set on developing and constructing on schedule, and on guaranteeing safety for the entire nuclear life cycle, with special regard to the disposal of the radioactive waste and the decommissioning of closing plants. Technological innovations such as Small Modular Reactors are being developed to maintain EU's competitiveness in the nuclear domain.

A key sector when it comes to reducing energy consumption are **buildings**, representing 40% of the EU's energy usage. The EU has a strong position in certain sectors[203] such as

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[197] The Energy Transition and Oil Companies' Hard Choices – Oxford Institute for Energy Studies, July 2019; Rob West, Founder, Thundersaid Energy & Research Associate, OIES and Bassam Fattouh, Director, OIES, p. 6.
[198] See CETTIR (SWD(2020)953) section 3.17 for more information.
[199] EU wind industry revenues in 2019: EUR 86.1 billion
[200] European manufacturers represent around 35%; Chinese manufacturers almost 50%
[201] Current EU28 market: EUR 25 billion
[202] The EU27 biofuels industry turnover was 14 billion EUR in 2017 – mostly first generation feedstocks.
[203] Not all sectors have been covered in this first report due to data availability constraints. Further sectors top be analysed include the buildings enveloppe and construction techniques/modelling/design.

prefabricated building components[204], district heating systems, heat pump technologies and home/buildings energy management systems (HEMS/BEMS). In the energy efficient lighting industry[205] the EU has a long tradition in designing and supplying innovative and high efficient lighting systems. The competitiveness challenge lies in the large scale mass production which is possible for the solid state based lighting devices. Asian suppliers are in a more favourable position because they can scale up to much higher capacity (economies of scale). Whereas, high skills in innovative design and new approaches are traditionally part of the European industrial sector.

Lastly, the energy transition is not all about technologies, but also about fitting these technologies into the system. Succeeding in moving towards net-zero economies and societies requires placing **citizens** at the heart of all actions[206] by closely looking into main motivational factors and strategies to engage them and situating the energy consumer in a broader social context. The current legal framework at the EU level represents a clear opportunity for energy consumers and citizens taking the lead and clearly benefit from the energy transition. On the basis of the observed urbanization trends, **cities** can play a key role in developing a holistic and integrated approach[207] to the energy transition, and its link with other sectors, such as mobility, ICT, and waste or water management. This, in turn, requires research and innovation in technologies as well as in processes, knowledge and capacity growth involving city authorities, businesses and citizens.

CONCLUSIONS

First and foremost, this report shows the economic potential of the clean energy sector. This outcome is also supported by the recent Impact Assessment of the 2030 Climate Target Plan[208]. It reinforces the argument how the European Green Deal has a clear potential to be the EU's growth strategy through the energy sector. In this analysis, evidence shows that the clean energy technologies sector is outperforming conventional energy sources and in comparison is creating more value-added, employment and productive labour. The clean energy sector is gaining importance in the EU economy, in line with the increased demand for clean technologies.

At the same time, public and private investments in clean energy R&I are decreasing, putting at risk the development of key technologies needed to decarbonise the economy and reach the ambitious objectives of the European Green Deal. This decline would also have a negative impact on the economic and employment growth observed until now. Furthermore, the energy sector is not investing much in R&I compared to other sectors, and within the energy industry, those investing most in R&I are oil and gas companies. Although there are positive signs, with oil and gas companies increasingly investing in

[204] EU 28 production value increased from EUR 31.85 billion (in 2009) to EUR 44.38 billion (in 2018). Within the same period, EU28 exports to the rest of the world increased from EUR 0.83 billion to EUR 1.88 billion. On the other hand, imports have been relatively stable around EUR 0.18 billion in 2009 to EUR 0.26 billion in 2018 with a low of EUR 0.15 billion in 2012-13.

[205] The European lighting market is expected to grow from EUR 16,3 billion in 2012 to EUR 19,8 billion in 2020 - CBI Ministry of Foreign Affairs, Electronic Lighting in the Netherlands, 2014

[206] The engagement strategies have to be both individual and community-oriented, aiming not only at providing economic incentives, but also at changing individual behaviours tapping into non-economic factors, such as by providing energy consumption feedback appealing to social norms.

[207] Including technologies, holistic urban planning, a combination of large-scale public and private investments, and co-creation between policy makers, economic actors and citizens

[208] COM(2020) 562 final.

clean energy technologies (e.g. wind, PV, digital), such technologies are still a minor part of their activities.

This trajectory is not sufficient for the EU to become the first climate-neutral continent and lead the global clean energy transition. A considerable increase in R&I investment, both public and private, is needed to keep the EU on its decarbonisation path. The upcoming investments in economic recovery will provide a particularly good opportunity for this. At the national level, the Commission will encourage the Member States to consider setting national targets for investments in R&I to support clean energy technologies as part of the overall call for increased public R&I investments in climate ambition. The Commission will also work with private sector to step up their R&I investments.

Second, the EU's targets for CO_2 emission reduction, renewables and energy efficiency have triggered investments in new technologies and innovations that have led to globally competitive industries. This shows that a strong home market is a key factor in industrial competitiveness in clean energy technologies and that it will drive investments in R&I. However, key characteristics of the energy market (in particular the high capital intensity, long investment cycles, new market dynamics, coupled with a low rate of return on investment) make it difficult to attract sufficient levels of investment into this sector, which affects its ability to innovate.

Experience with solar PV manufacturing in the EU shows that a strong home market alone is not enough. In addition to setting targets to create demand for new technologies, there need to be policies to support EU industry's ability to respond to this demand. This includes the development of industrial-based cooperative platforms for specific technologies (e.g. on batteries and on hydrogen). Further such actions may be needed for other technologies, in cooperation with Member States and industry.

Third, specific conclusions can be drawn from the six technologies analysed that are expected to play an increasing role in the EU's 2030 and 2050 energy mix. In the solar photovoltaic industry, considerable market opportunities exist in the segments of the value chain where specialisation or high performance/high value products are key. Similarly, for batteries, the EU's ongoing competitive recovery in the cell manufacturing segment through initiatives such as the European Batteries Alliance complements the more established European industry's position in the downstream, value-driven segments such as battery pack manufacturing and integration, and battery recycling. Regaining a competitive edge in both technologies is essential, given their projected demand, modularity and spillover potential (e.g. integration of PV in buildings, vehicles or other infrastructure).

In the ocean energy, renewable hydrogen and wind industry, the EU currently holds a first mover advantage. Nevertheless, the expected, multi-fold increase in the capacity size of the markets suggests that the industry's structure will inevitably change: expertise needs to be pooled across companies, and the Member States and the private sector have to re-structure and pool their value chains to realise the required economies of scale and positive spillovers. For instance, the EU's current leading position on the electrolysers market, along the whole value chain from component supply to final integration capability, offers significant spillover potential between batteries, electrolysers and fuel cells. The announced European Clean Hydrogen Alliance will further strengthen Europe's global leadership in this domain. As regards ocean energy, technologies have yet to become commercially viable, and financial support schemes need to be identified to maintain and expand the EU's current leading position.

The offshore wind industry, with its established innovative capacity that pushes the boundaries of the technology (e.g. floating offshore wind farms), needs the perspective of a growing home market as well as sustained R&I funding to benefit from growth in global markets. The EU smart grid and HVDC industries are also doing well, and although a small market compared to wind or solar PV, it is important as it creates value for everything connected to the grid. Given its regulated nature, governments and regulators in the EU play a key role in exploiting the benefits of this industry.

Fourth, a move towards the clean technologies also shifts the EU import-dependency from fossil fuel to increasing use of critical raw materials in energy technologies. However, their dependency is less direct than it is for the fossil fuel as these materials have the potential to stay in the economy through re-using and recycling. This can improve the resilience of clean energy technology supply chains and therewith enhance EU's open strategic autonomy. There is a clear need for R&I and investments to design the clean energy technology components to be more reusable and recyclable, in order for the materials to be kept in the economy for as long as possible at as a high value/performance as possible. Related to moving towards further circularity, the EU's engagement in international fora such as G20, Clean Energy Ministerial and Mission Innovation will allow the EU to drive the creation of environmental standards for new technologies and further strengthen its global leadership, and will mitigate the risk of supply disruptions, technologies' sustainability and quality.

Fifth, the European Commission will further develop the competitiveness assessment methodology in cooperation with the Member States and the stakeholders. The aim is to improve the macro-economic analysis of the clean energy sector, including the prerequisite of more data. An improved methodology will support designing an energy R&I policy helping to create a competitive, dynamic and resilient clean technology industry. The annual assessment of competitiveness of the clean energy sector will be complementary with the framework of the National Energy and Climate Plans, the Strategic Energy Technology Plan and the Clean Energy Industrial Forum. The aim of the continued and improved assessment is for the clean energy sector to play its full role in making the European Green Deal, an EU growth strategy in practice.

EUROPEAN
COMMISSION

Brussels, 14.10.2020
SWD(2020) 953 final

PART 3/5

COMMISSION STAFF WORKING DOCUMENT

Clean Energy Transition – Technologies and Innovations

Accompanying the document

REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL

on progress of clean energy competitiveness

{COM(2020) 953 final}

3.5. Renewable hydrogen through electrolysis

3.5.1. *State of play of the selected technology and R&I landscape*

Hydrogen offers the opportunity to be used as both an energy vector and a feedstock molecule, therefore having several potential uses across sectors (industry, transport, power and buildings sectors). Hydrogen does not emit CO_2 when used, and offers the option to decarbonise several hydrogen-based applications, provided its production is sustainable and hydrogen production is not associated to a considerable carbon footprint. Currently the most mature and promising hydrogen production technology, which can be coupled with renewable electricity, is electrolysis. Since any hydrogen-based technological chain has to rely on a hydrogen supply, it is sensible to focus first attention to technological solutions able to produce renewable hydrogen at scale and electrolysis is to be the most mature option.

In the strategic vision for a climate-neutral EU published in November 2018, the EC LTS foresees the share of hydrogen in Europe's energy mix to grow from the current less than 2% to 13-14% by 2050, amounting to 60 to 80 million tonnes of oil equivalent (Mtoe) in 2050. In terms of installed capacity, the LTS foresees up to 511 GW (1.5 TECH scenario[263]), whilst other studies suggest a 1 000 GW European market by 2050[264].

The objective of the hydrogen strategy[265] is to install at least 6 GW of renewable hydrogen electrolysers in the EU by 2024 and 40 GW of renewable hydrogen electrolysers by 2030. The Hydrogen strategy sees industry and heavy-duty transport as applications with highest added value for the EU decarbonisation ambitions.

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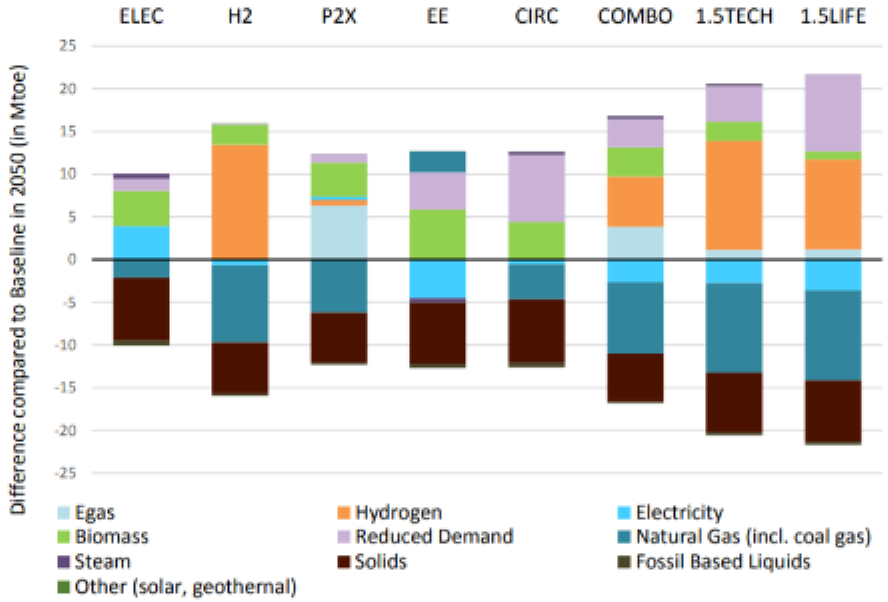
[263] European Commission (2018). IN-DEPTH ANALYSIS IN SUPPORT OF THE COMMISSION COMMUNICATION COM(2018) 773 A Clean Planet for all A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy.

[264] https://publications.jrc.ec.europa.eu/repository/bitstream/JRC115958/kjna29695enn.pdf

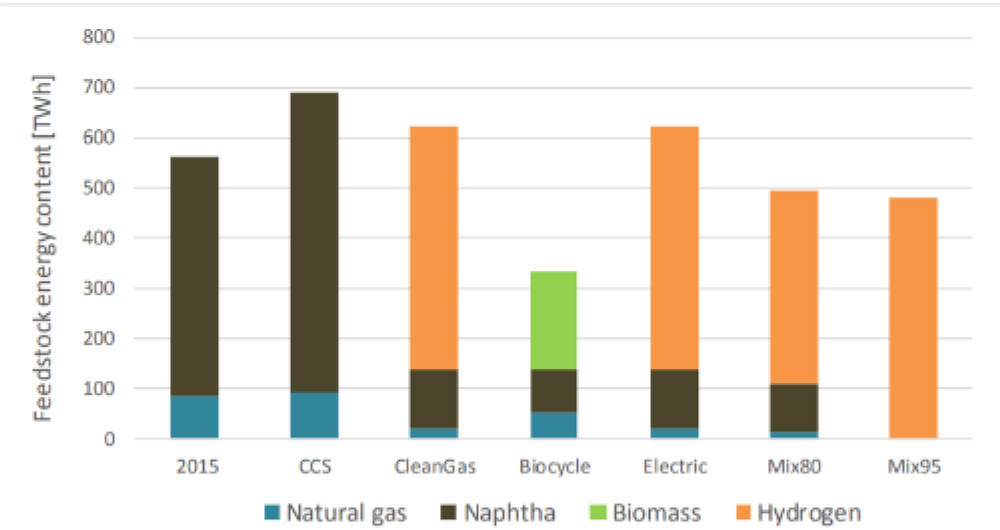
[265] https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf

Figure 79 Differences in final energy consumption in Iron & Steel compared to Baseline in 2050 by fuel and scenario



Source 80 EC PRIMES[266]

Figure 80 Energy Content of feedstock demand for ethylene, ammonia and methanol production by type of feedstock and scenario in 2050



Source 81 FORECAST[267]

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[266] European Commission (2018). IN-DEPTH ANALYSIS IN SUPPORT OF THE COMMISSION COMMUNICATION COM(2018) 773 A Clean Planet for all A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy.

Capacity installed, generation

The current hydrogen production is almost completely based on the use of fossil fuels and associated with large industrial processes. The dedicated world production of hydrogen (hydrogen as primary product) can be subdivided according to the following feedstock[268]:

- ca. 71% from natural gas (steam methane reforming), accounting for 6% of global natural gas use, and emitting around 10 tonnes of carbon dioxide per tonne of hydrogen (tCO2/tH2);
- ca. 27% from coal (coal gasification), accounting for 2% of global coal use, emitting around 19 tCO2/tH2;
- about 0.7% from Oil (reforming and partial oxidation) (emitting around 6.12 tCO2/tH2);
- less than 0.7% from renewable sources (water electrolysis powered with renewable electricity in particular)
    - About 200 MJ (55 kWh) of electricity are needed to produce 1 kg of hydrogen from 9 kg of water by electrolysis. The required water feedstock consumption is always higher than the stoichiometric value and depends on the actual process efficiency.

The total worldwide hydrogen production is mainly associated with its use as chemical feedstock in oil refining (about 33%), ammonia production (about 27%) and methanol synthesis[269] (about 10%); the remaining fractions are linked with other forms of pure hydrogen demand (e.g. chemicals, metals, electronics and glass-making industries) and use of mixtures of hydrogen with other gases (e.g. carbon monoxide) such as for heat generation.

9,9 Mt/y of hydrogen is produced today in the EU28 (9.4 Mt/y in EU27), out of about 70 Mt/y of pure hydrogen[270] globally, producing around 830 Mt of CO_2 globally[271].

In this section, the focus is on renewable hydrogen[272] production and on the competitiveness elements of this first segment of the whole hydrogen value chain. On-site hydrogen production for co-located consumption in industrial applications appears a promising option on the short-medium term to smoothly reach the scale for the larger introduction of the carrier in the energy system, in line with the ambition of a climate-neutral economy and the hydrogen strategy. The current use of hydrogen in the chemical and petrochemical industry is to be added to the future uses as fuel for the transportation sector (various modes), for cogeneration of electricity and heat or electricity alone, as a storage option for electricity and

[267] European Commission (2018). IN-DEPTH ANALYSIS IN SUPPORT OF THE COMMISSION COMMUNICATION COM(2018) 773 A Clean Planet for all A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy.

[268] International Energy Agency, Hydrogen Outlook, June 2019, p.32 – 2018 estimates

[269] In this case hydrogen is present as a component of syngas.

[270] An additional 45 MtH_2/y are used mixed with other gases.

[271] As a reference total European industrial emissions were estimated at 877 $MtCO_2$/y (around 10% of these can be associated with hydrogen production) in 2017 - https://www.eea.europa.eu/data-and-maps/indicators/greenhouse-gas-emission-trends-6/assessment-3. Industrial emissions are roughly 9% of total European emissions.

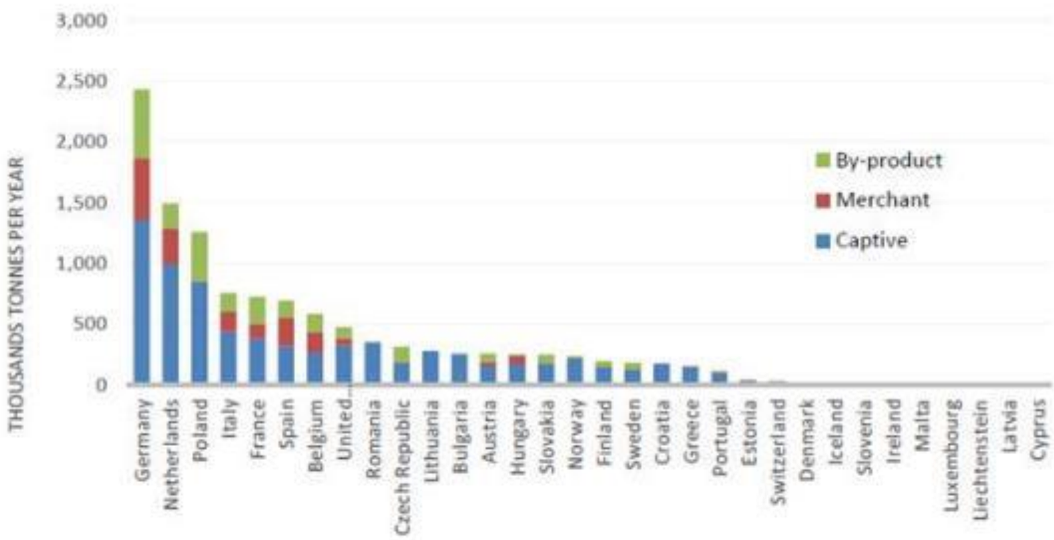
[272] Renewable hydrogen refers to hydrogen produced by electrolysers powered by renewable electricity, through a process in which water is dissociated into hydrogen and oxygen (often referred to as “green hydrogen”).

as a feedstock in the chemical industry, for direct use of hydrogen in small scale stationary end-uses. However, transport of hydrogen, its storage and its conversion in end-use applications (e.g. mobility, buildings) are not discussed here.

The recently launched “Hydrogen Strategy for a climate neutral Europe”[273] aims at fostering a significant growth in European electrolyser capacity with the objective of an expected 6 GW (producing up to one million tonne of renewable hydrogen per year) of electrolysers powered by renewable electricity deployed by 2024 and 40 GW (producing up to ten million tonnes of renewable hydrogen) deployed by 2030.

Renewable hydrogen production is still at very low capacity, but a large number of demonstration projects have been announced and it is expected to grow significantly in the coming decade. In 2019, EU27 had around 50 MW of dedicated water electrolysis capacity installed (all technologies)[274], of which around 30 MW were in Germany in 2018[275]. There are an additional 34 concrete projects already in the pipeline for an additional 1 GW capacity, requiring EUR 1.6 billion of investments[276] under construction or announced, and an additional 22 GW of electrolyser projects and would require further elaboration and confirmation. Between November 2019 and March 2020, market analysts increased the list from 3,2 GW to 8,2 GW of electrolysers by 2030 (of which 57% in Europe).

Figure 81 Hydrogen production



Source 82 Fuel Cell Hydrogen Joint Undertaking (2019 data)

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273 https://ec.europa.eu/commission/presscorner/detail/en/QANDA_20_1257

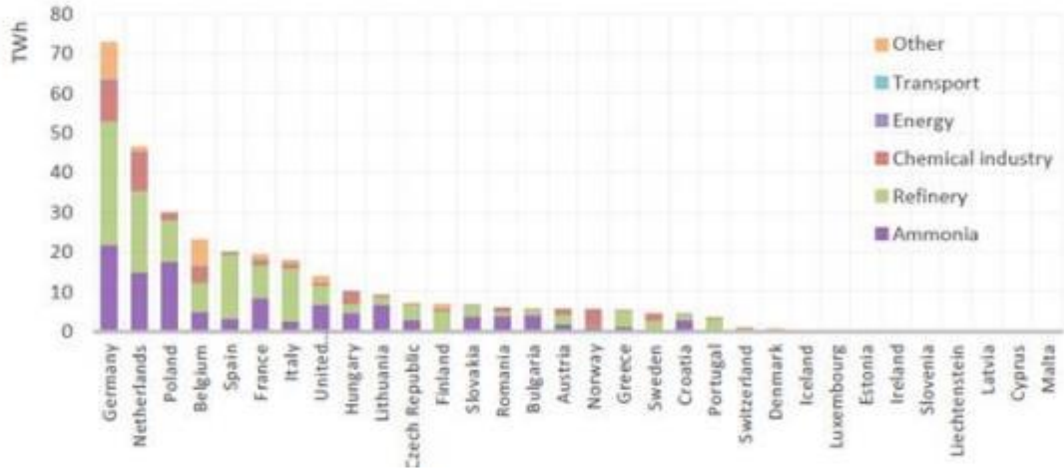
274 https://iea.blob.core.windows.net/assets/a02a0c80-77b2-462e-a9d5-1099e0e572ce/IEA-Hydrogen-Project-Database.xlsx

275 https://www.dwv-info.de/wp-content/uploads/2015/06/DVGW-2955-Brosch%C3%BCre-Wasserstoff-RZ-Screen.pdf

276 Short-term projects collected from the TYNDP ENTSOs, the IEA hydrogen project database, and presented to the ETS Innovation Fund. Future project pipeline is based on industry estimates in Hydrogen Euro

The 2018 worldwide yearly hydrogen use was about 70 Mt as pure gas, in addition 45 Mt of hydrogen were used without prior separation from other gases[277]. European hydrogen use in its pure form (both merchant and captive) accounted for about 9.7 Mt H_2 in 2015[278]; around 47% of which was used in oil refining, 40% in ammonia production, 8% in methanol production and the remaining used mainly in other chemical productions and industrial processes.

Figure 82 Hydrogen Consumption



Source 83 Fuel Cell Hydrogen Joint Undertaking (2019 data)

<u>Cost, LCOE</u>

The cost of hydrogen depends on several factors: (i) capital investment (retrofitting or greenfield); (ii) operating costs, linked with the costs of natural gas or renewable power (50-60% of overall costs for both renewable and low-carbon hydrogen); (iii) load factor[279]; and (iv) price of carbon emission (expected in the Emission Trading System), and other elements such as availability and cost of storage.

Estimated costs today for fossil-based hydrogen with carbon capture and storage are about 2 EUR/kg, and 2.5-5.5 EUR/kg for renewable hydrogen[280]. Carbon prices in the range of EUR 55-99 per tonne of CO2 would be needed to make fossil-based hydrogen with carbon capture competitive with fossil-based hydrogen today (current cost of about 1.5 EUR/kg)[281]. Today's price of 1 tonnes of CO_2 is around 25 EUR in the Emission Trading Scheme, and historically has not been higher. This means that CO_2 price will be a determining factor, together with low price of electricity, in making renewable hydrogen competitive against fossil based

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[277] International Energy Agency, Hydrogen Outlook, June 2019, p.18 and 32

[278] https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf EXHIBIT 2

[279] Amount of hours a production facility is able to run per year.

[280] IEA 2019 Hydrogen report (page 42), and based on IEA assumed natural gas prices for the EU of 22 EUR/MWh, electricity prices between 35-87 EUR//MWh, and capacity costs of 600 EUR/kW.

[281] However, at this stage, the costs can be only estimated given that no such project has started construction or operation in the EU today.

energy[282]. The relative impact of these factors will be strongly influenced by the actual natural gas prices, which changes with location, depending on the world region considered, and temporality.

Costs for renewable hydrogen are going down quickly. Electrolyser costs have already been reduced by 60% in the last ten years, and are expected to halve in 2030 compared to today thanks to economies of scale[283]. Other studies[284] indicate that the price of renewable hydrogen will depend on the location of electrolyser (on site, or "centralised" electrolyser). In regions with cost of renewable electricity, electrolysers are expected to produce hydrogen that will compete[285] with fossil-based hydrogen in 2030[286]. These elements will be key drivers of the progressive development of hydrogen across the EU economy[287].

Based on current electricity prices, the associated cost estimates for EU production range (based on IEA, IRENA, BNEF) are:

- low-carbon fossil-based hydrogen: EUR 2.2/kg;
- Renewable hydrogen: EUR 3-5.5/kg.

For 2030, the cost estimates for EU production range (based on IEA, IRENA, BNEF) are:

- low-carbon fossil-based hydrogen: EUR 2.2-2.5/kg.

For the renewable hydrogen, the cost in the range EUR 1.1-2.4/kg[288]. However, assumptions depend on a number of input factors. In countries relying on gas imports and characterised by good renewable resources, clean hydrogen production from renewable electricity can compete effectively with production that relies on natural gas[289].

Reducing the price of renewable hydrogen allows an increasing penetration of hydrogen into different sectors and applications. Usually system boundaries for hydrogen production calculations are defined by the production side, but actual competitiveness for hydrogen uses comes from the opportunity offered by business cases outside the production boundaries. Industrial competitiveness could allow certain industrial processes such as the use of hydrogen for clean steel production, to become affordable earlier than other uses which have to face more challenging competition against conventional fossil-based hydrogen (e.g.

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[282] Clean steel could be competitive as compared to coking coal, if CO2 prices are raised to 50 USD/1t CO2; clean dispatchable power can be competitive with prices of natural gas on the condition of at least 32 USD/1t CO2; green ammonia could be competitive as compared to prices of natural gas, on the condition of at least 78 USD /1tCO2.

[283] Based on cost assessments of IEA, IRENA and BNEF. Electrolyser costs to decline from 900 EUR/kW to 450 EUR/kW or less in the period after 2030, and 180 EUR/kW after 2040. Costs of CCS increases the costs of natural gas reforming from 810 EUR/kWH$_2$ to 1512 EUR/kWH$_2$. For 2050, the costs are estimated to be 1152 EUR/kWH$_2$ (IEA, 2019).

[284] Shell, Energy of the Future, 2017

[285] Currently, the dissociation of the water molecule in its constituent parts requires large amount of energy to occur (about 200 MJ - or 55 kWh - of electricity are needed to produce 1 kg of hydrogen from 9 kg of water by electrolysis). The thermodynamic limit for dissociating water at room temperature through electrolysis is around 40 kWh/kgH$_2$.

[286] Assuming current electricity and gas prices, low-carbon fossil-based hydrogen is projected to cost in 2030 between 2-2.5 EUR/kg in the EU, and renewable hydrogen are projected to cost between 1.1-2.4 EUR/kg (IEA, IRENA, BNEF).

[287] https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf

[288] IEA - The Future of Hydrogen, 2019, IRENA, Bloomberg BNEF, March 2020

[289] IEA - The Future of Hydrogen, 2019, p.55

ammonia). As an additional advantage, renewable hydrogen has a lower price volatility against hydrogen produced from fossil fuels, which follow natural gas prices.

Table 5 State of art on Electrolysis

Low temp versus/ high temp membranes	Temp (°C)	Electrolyte	Efficiency (nominal stack and nominal system)	Maturity level ([290])	Million EUR/tonne H2 out[291]	Cost in EUR/MWel of production capacity/year[292]
Alkaline Electrolysis (AEL)	60-90	Potassium hydroxide	63-71%; 51-60%	Used in industry for last 100 years	2020: 15-65 2030: 12-38 2050: 7-29	45 000[293]
Polymer Exchange Membrane (PEMEL)	50-80	Solid state membrane	60-68%; 46-60%	Commercially used for medium and small applications (less 300 kW) ([294])	2020: 42-120 2030: 26-82 2050: 8-55	69 000[295]
Solid Oxide Electrolysis – high temperature (SOEL)	700-900	Oxide ceramic	76-81%	Experiment, low TRL, pre-commercial status	2020: 36-122 2030: 27-111 2050: 13-38	
Anion Exchange Membrane ([287] (AEMEL)	60-80	Polymer membrane	N/A	Commercially available for limited applications		

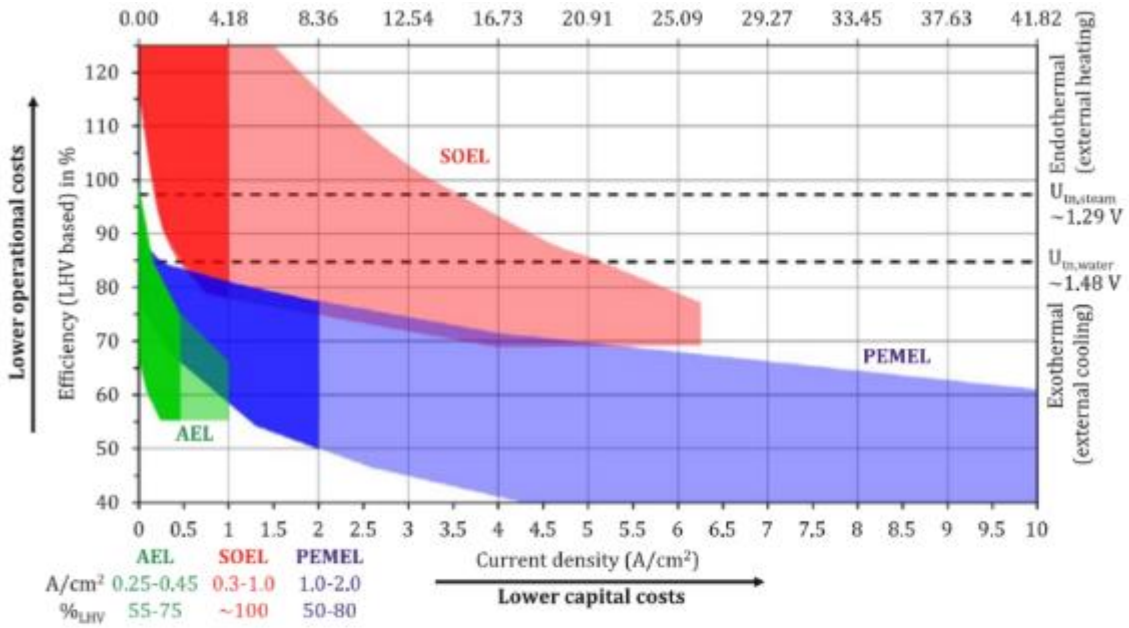
Source 84 Alexander Buttlera, Hartmut Spliethoﬀ, Renewable and Sustainable Energy Reviews 82 (2018) 2440–245

Costs of electrolysers (2019): Capital expenditure (CAPEX) account for 50% to 60% of total costs of electrolyser[296].

AEL	USD 500–1400/kWe
PEM	USD 1 100–1800/kWe
SOEC	USD 2 800–5600/kWe

[290] Shell, Energy of the Future, 2017.
[291] The total investment costs includes the costs for the electrolyser but also the ‘balance of system’ costs and the system integration costs that could add an additional 50%.
[292] Hydrogen generation in Europe: Overview of costs and key benefits (ASSET, 2020).
[293] This corresponds with 57,300 EUR/MW H_{2out} for ALK Electrolysers. ALK calculated using stack efficiency (LHV) of NEL A-series upper range 78.6% (LHV) (NEL Hydrogen, 2020).
[294] The biggest PEM electrolyser in the world(10 MW - project REFHYNE) should be about to be commissioned.
[295] This corresponds with 106 000 EUR/MW H_{2out} for PEM electrolysers (LHV). PEM calculated using stack efficiency (LHV) of 65% (Guidehouse, 2020).
[296] IEA - The Future of Hydrogen, 2019- Table 3

Figure 83 Specific Hydrogen Production per Cell Area



Source 85 A. Buttler, H. Spliethoff Renewable and Sustainable Energy Reviews 82 (2018) 2440–2454

From now to 2030, investments in electrolysers could range from EUR 24 billion to EUR 42 billion to install 40 GW of electrolysers. In addition, over the same period, from EUR 220 billion to EUR 340 billion would be required to scale up and directly connect 80-120 GW of solar and wind energy production capacity to power them. From now to 2050, investments in production capacities would amount to EUR 180-470 billion in the EU[297].

Public R&I funding

An analysis of European projects financed under horizon 2020 (2014-2018) focussing on electrolyser's development highlighted a public support of more than EUR 90 million, complemented by EUR 33.5 million of private money[298].

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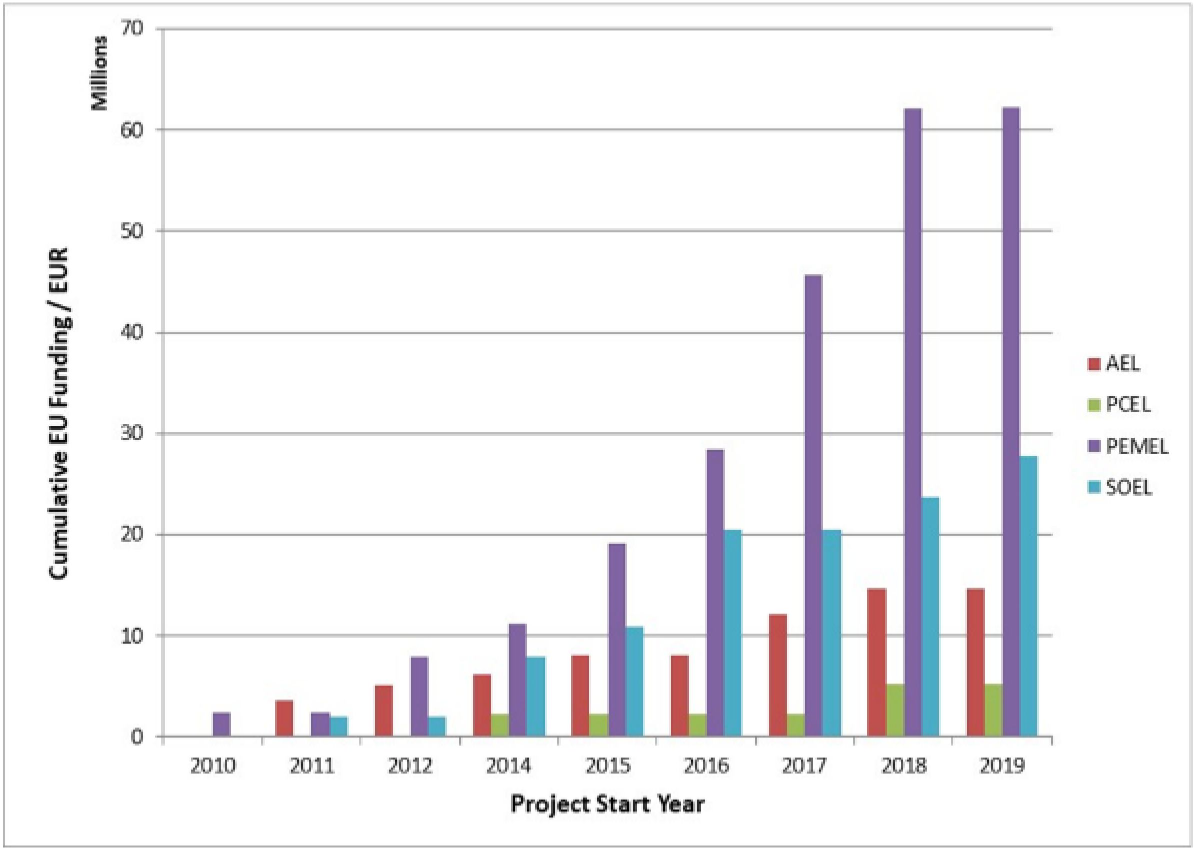
[297] Asset study (2020). Hydrogen generation in Europe: Overview of costs and key benefits. Assuming a steel production plant of 400 000 tonnes/year.

[298] JRC 2020 "Current status of Chemical Energy Storage Technologies" pag.63 https://publications.jrc.ec.europa.eu/repository/bitstream/JRC118776/current_status_of_chemical_energy_storage_technologies.pdf

Figure 84 Cumulative EU funding contribution for electrolyser technology-related projects



Source 86 JRC 2020 Current status of Chemical Energy Storage Technologies

Between 2008 and 2018, the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) supported 246 projects across several hydrogen-related technological applications, reaching a total investment of EUR 916 million, complemented by EUR 939 million of private and national/regional investments. Under the Horizon 2020 program (2014-2018 period), over EUR 90 million have been allocated to electrolyser's development, complemented by EUR 33.5 million of private funds[299,300]. At national level, Germany has deployed the largest resources with EUR 39 million[301] allocated to projects devoted to electrolyser development (2014-2018)[302]. In Japan, Asahi Kasei received a multimillion dollar grant supporting the development of their alkaline electrolyser[303].

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299 JRC 2020 "Current status of Chemical Energy Storage Technologies" pag.63 https://publications.jrc.ec.europa.eu/repository/bitstream/JRC118776/current_status_of_chemical_energy_storage_technologies.pdf

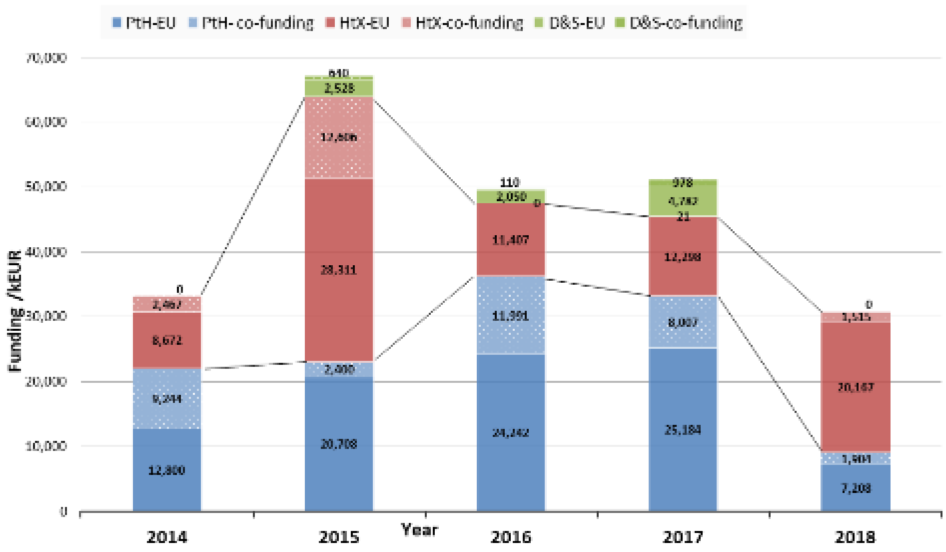
300 vs EUR 472 million for FCH JU funding overall and EUR 439 million for other sources of funding

301 This includes both private and public funds.

302 JRC 2020 "Current status of Chemical Energy Storage Technologies" pag.63 https://publications.jrc.ec.europa.eu/repository/bitstream/JRC118776/current_status_of_chemical_energy_storage_technologies.pdf

303 Yoko-moto, K., Country Update: Japan, in 6th International Workshop on Hydrogen Infrastructure and Transportation 2018

Figure 85 The funding distribution across years for chemical energy storage projects subdivided according to the methodology as defined in the Technical Report "Current status of Chemical Energy Storage Technologies", EU funding and private co-funding are separate



Source 87 JRC Technical Report Current status of Chemical Energy Storage Technologies

<u>Patenting trends</u>

Asia (mostly China, Japan and South Korea) dominates the total number of patents filed in the period from 2000 to 2016 for the hydrogen, electrolyser and fuel cell groupings. Nevertheless, the EU performs very well and has filed the most "high value" patent families in the fields of hydrogen and electrolysers. Japan, instead, filed the largest number of "high value" patent families on fuel cells.

3.5.2. *Value chain analysis*

<u>Main companies</u>

Whilst around 280 companies[304] are active in the production and supply chain of electrolysers in Europe and more than 1 GW of electrolyser projects are in the pipeline, the total European production capacity for electrolysers is currently below 1 GW per year.

The electrolysis market is very dynamic with several fusions and acquisitions recorded in recent years. An overview of the manufacturers of medium to large scale electrolysis systems reports only manufacturers of commercial systems and does not consider manufacturers of laboratory-scale electrolysers[305]. The market analysis shows that electrolysers based on

[304] 60% of EU companies active are small- and medium-size enterprises

[305] A. Buttler, H. Spliethoff Renewable and Sustainable Energy Reviews 82 (2018) 2440–2454 and https://www.fch.europa.eu/sites/default/files/Evidence%20Report%20v4.pdf

alkaline electrolysis (AEL), are provided by nine EU producers (four in Germany, two in France, two in Italy and one in Denmark), two in Switzerland and one in Norway, two in US, three in China, and three in other countries (Canada, Russia and Japan). Electrolysers based on proton exchange membrane (PEM) electrolysis, are provided by six EU suppliers (four in Germany, one in France and one in Denmark), one supplier from UK and one from Norway, two suppliers from US, and two suppliers from other countries. Electrolysers based on solid oxide electrolysis, are manufactured by three suppliers from EU (two in DE and FR) and one from the US.

Figure 86 Location of the manufacturers of large electrolysers, by technology

Electrolyser technology	EU27	CH, NO, UK	US	China	Others
Alkaline AEL	**9**	**3**	**2**	**3**	**3**
Proton Exchange Membrane PEM	**6**	2[306]	3		2
Solid Oxide Electrolysis SOEL	**3**		1		

Source 88 A. Buttler, H. Spliethoff, Renewable and Sustainable Energy Reviews 82 (2018) 2440–2454

Gross value added growth

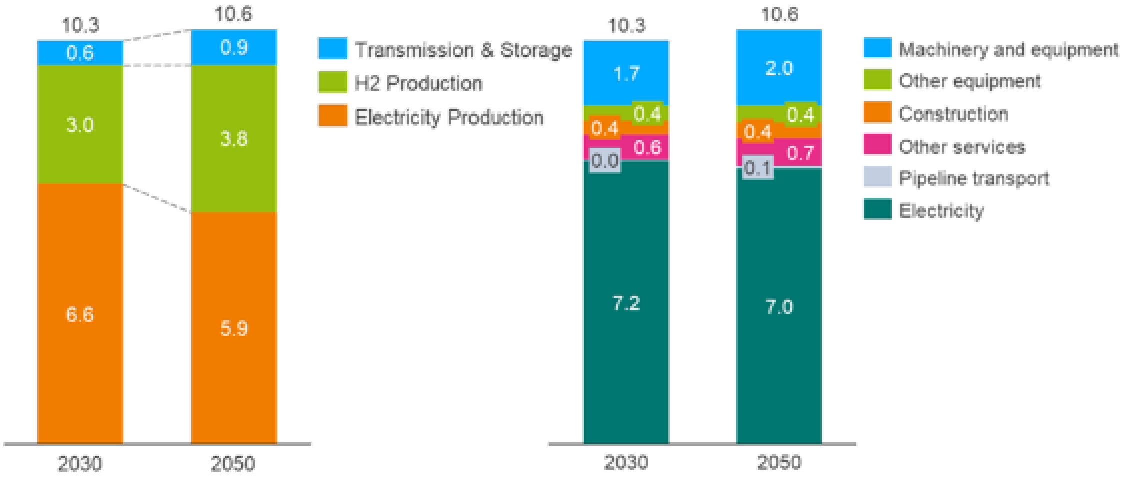
Production equipment is a significant contributor of value added in electrolyser cell production[307].

Employment figures

Currently, the entire hydrogen industry has about 16 000 employees in Europe. There are 34 concrete electrolyser projects in the pipeline for an additional 1 GW, requiring EUR 1.6 billion of investments and creating 2 000 new additional jobs. Regarding future projections, the results below should be interpreted as the number of jobs that will be created for each billion EUR invested into the hydrogen value chain in that year. Job estimates for renewable hydrogen for 2050, are around 1 milllion, of which 50% of jobs would be in the renewables sector[308].

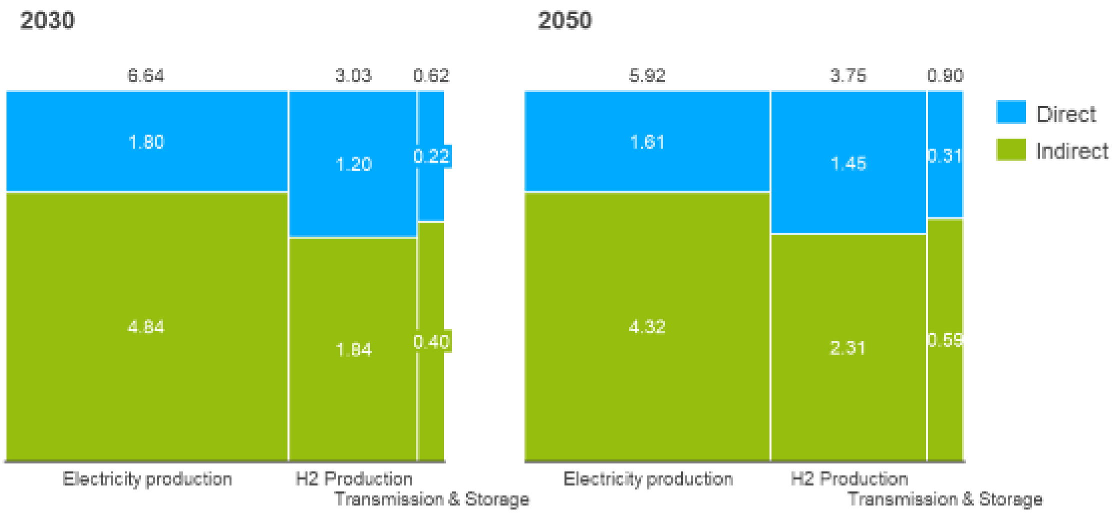
[306] The US company Proton on site was acquired by NEL (NO) in 2017.
[307] Value Added of the Hydrogen and Fuel Cell Sector in Europe summary report, FCJU September 2019.
[308] Gas for Climate study, assuming around 1500 TWh of renewable hydrogen by 2050.

Figure 87 Number of jobs (000's) created per billion EUR invested, breakdown by supply chain (left) and by sector (right)



Source 89 ASSET Study commissioned by DG ENERGY - Hydrogen generation in Europe: Overview of costs and key benefits, 2020

Figure 88 Number of jobs created per billion EUR invested, breakdown by direct vs indirect jobs



Source 90 ASSET Study commissioned by DG ENERGY - Hydrogen generation in Europe: Overview of costs and key benefits, 2020

3.5.3. *Global market analysis*

Raw materials

Europe is fully dependent on third countries for the supply of 19 of 29 raw materials relevant to fuel cells and electrolyser technologies. For the production of fuel cells alone, 13 critical raw materials namely cobalt, magnesium, REEs, platinum, palladium, borates, silicon metal, rhodium, ruthenium, graphite, lithium, titanium and vanadium are needed. The corrosive acidic regime employed by the proton exchange membrane electrolyser, for instance, requires the use of noble metal catalysts like iridium for the anode and platinum for the cathode, both of which are mainly sourced from South Africa (84%). Hydrogen production also relies on several critical raw materials for various renewable power generation technologies[309]. The biggest supply bottleneck for fuel cells is however not the raw materials, but the final product, of which the EU only produces 1%.

3.5.4. *Future challenges to fill technology gap*

Even though renewable hydrogen is commercially available, its currently high costs provide limits to its broad uptake. To ensure a full hydrogen supply chain to serve the European economy, further research and innovation efforts are required[310].

As outlined in the Hydrogen Strategy, upscaling the generation side will entail developing to larger size, more efficient and cost-effective electrolysers in the range of gigawatts that, together with mass manufacturing capabilities and new materials, will be able to supply hydrogen to large consumers. The Green Deal call (under Horizon 2020) for a 100 MW electrolyser will be the first step. Moreover, research can play a role in increasing electrolyser's performance and reducing its costs e.g.: increasing the durability of membranes for PEM, while reducing their critical raw materials content. Solutions for hydrogen production at lower technology readiness level need also to be incentivised and developed such as, for example, direct solar water splitting, or high-temperature pyrolysis processes, (cracking of methane into hydrogen, with solid carbon-black as side product). In the case of biomass based production (bio generation from bio-methane, bio-gas, vegetable oils) and from marine algae (biochemical conversion), a particular attention is to be paid to sustainability requirements.

In addition to considerations related to hydrogen production, subsequent new hydrogen technological chain should be developed. Infrastructure needs further development to distribute, store and dispense hydrogen in large volumes whether pure or mixed with natural gas should be developed. Points of production of large quantities of hydrogen and points of use (especially of large quantities) are likely not going to be close to each other. Hydrogen will have therefore to be transported over long distances.

Third, large scale end-use applications using renewable hydrogen need to be further developed, notably in industry (e.g. using hydrogen to replace coking coal in steel-making[311]

[309] https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf
[310] https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf
[311] Already today, the H2FUTURE project in Austria operates a 6MW electrolyser powered with renewable electricity that supplies hydrogen to a steel plant, while providing grid services at the same time. The HYBRIT project in Sweden is taking concrete action to become completely fossil-free steel plant by 2045, converting their production to use renewable hydrogen and electricity.

or upscaling renewable hydrogen use in chemical and petrochemical industry) and in transport (e.g. heavy duty road[312], rail, and waterborne transport and possibly aviation).

Finally, further research is needed to enable improved and harmonised (safety) standards and monitoring and assess social and labour market impacts. Reliable methodologies have to be developed for assessing the environmental impacts of hydrogen technologies and their associated value chains, including their full life-cycle greenhouse gas emissions and sustainability. Importantly, securing the supply of critical raw materials in parallel to their reduction, substitution, reuse, and recycling needs a thorough assessment in the light of the future expected increasing hydrogen technologies deployment, with due account being paid to ensuring security of supply and high levels of sustainability in Europe.

3.6. Batteries

3.6.1. *State of play of the selected technology and R&I landscape*

According to the LTS, by 2050, the share of electricity in final energy demand will double to at least 53 %[313]. By 2030, it is expected that around 55 % of electricity consumed in the EU will be produced from renewables (up from the current level of 29 %) and by 2050, this figure is expected to be more than 80%.

In a world that is increasingly electrified, batteries will become one of the key technological components of a low-carbon economy as they enable the energy transition from a mostly centralised electricity generation network towards a distributed one with increased penetration of variable renewable energy sources and "intelligent" energy flow management with smart grids and prosumers[314]. In particular, batteries cover close to half of the total need for storage within the EU energy system (more than 100 TWh[315]), bypassing by far the currently dominating pumped hydro storage technology, and followed closely by hydrogen. Stationary batteries would play a larger role, growing from 29 GW in 2030 (from negligible amounts today) to between 54 GW (1.5 LIFE) and 178 GW (ELEC)[316], in general having higher deployment in those scenarios without significant development of e-fuels[317].

Batteries are electrochemical energy storage technologies that can be found in four potential locations: associated to generation, transmission, distribution, and behind the meter (consumer, commercial and industrial). They can be divided into the categories of primary and secondary (rechargeable).

Batteries are based on a wide range of different chemistries. In the past lead acid based batteries were the main used technology, whereas nowadays Li-ion technology plays a central

[312] European bus companies have also acquired expertise in production of fuel cell busses, due to several JIVE projects funded from the Fuel Cell Joint Undertaking and from the Connecting Europe Facility (transport).

[313] COM(2018) 773 final

[314] https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf

[315] https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf (page 79)

[316] The above figures are focused only on grid scale storage and do not cover behind-the-meter storage (which might be operated differently than centralised units exposed to the wholesale electricity market), and vehicle-to-grid services. Nor do these figures cover intra-hour storage needs, but the market for this is not very big compared to the overall electricity market and will remain limited.

[317] The possibility of storing e-fuels in conventional facilities (i.e. indirect storage of electricity) allows to reduce the storage needs of the system.

role. Other, more experimental, battery technologies are Lithium-air (Li-Air), Lithium-sulphur, Magnesium-ion, and Zinc-air[318]. Li-Air technologies (also known as metal-air) have a much higher energy density than conventional lithium-ion batteries.

Figure 89 Overview of available battery technologies

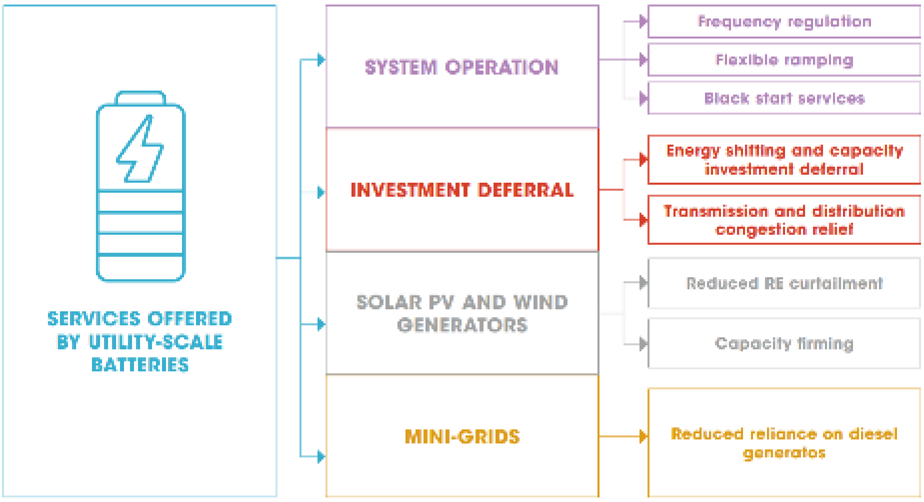
Source 91 European Association for Storage of Energy (EASE)

Secondary batteries, from an application point of view, can be broken down into:

- portable batteries (Li-based and primarily used in consumer devices);
- industrial batteries (mostly lead-based and used for industrial devices for stationery and mobile applications);
- starting-lighting ignition batteries (lead based, used in automobiles);
- "Clean Vehicles" batteries (mostly Li-based batteries, for e.g. Electric Vehicles, Plug-in Hybrid Vehicles);
- power grid batteries (different technologies, installed in residential, commercial & industrial, or grid-scale level facilities to provide a wide variety of services: balancing, system services, ancillary services).

318 Next Generation Energy Storage Technologies (EST) Market Forecast 2020-2030, Visiongain

Figure 90 Summary of services that can be provided by Energy Storage in the Power System



Source 92 IRENA Utility Scale Batteries 2019

Besides pumped hydro and compressed air with application for large power and long times , Li-ion Batteries currently dominate the rest of the market in Power System Applications. Li-ion batteries that have become a key option for electrifying transport and for lifting the penetration levels of intermittent renewable energy. Given the economies of scale, they are also increasingly used for stationary electricity storage[319].

Capacity installed

Battery development and production is largely driven by the roll out of electromobility. The future global annual market for batteries is expected to grow fast and be very substantial, increasing from about 90 GWh in 2016 to about 800 GWh in 2025, exceeding 2 000 GWh by 2030 and could reach up to 4 000 GWh by 2040 in the most optimistic scenario[320]. As the global market size increases, the EU is forecasted to develop a capacity of 207 GWh by 2023, while European demand for electric vehicle batteries alone would be around 400 GWh by 2028[321].

With respect to performance, Li-ion energy density has increased significantly in the recent years, tripling since their commercialization in 1991. Further potential for optimization is given with new generation of Li-ion batteries[322].

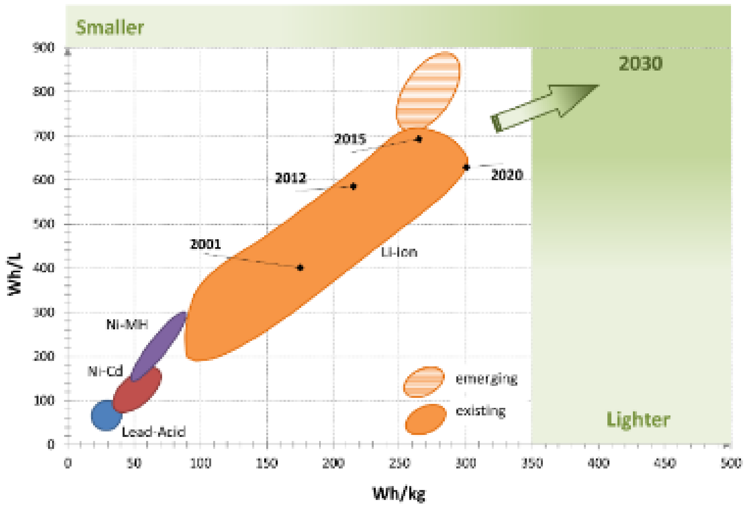
[319] Batteries for stationary storage are used for a range of applications with some being more suited to store energy and others to supply power.

[320] Source: JRC Science for Policy Report: Tsiropoulos I., Tarvydas D., Lebedeva N., Li-ion batteries for mobility and stationary storage applications – Scenarios for costs and market growth, EUR 29440 EN, Publications Office of the European Union, Luxembourg, 2018, doi:10.2760/87175.

[321] COM (2019) 176 final

[322] Forthcoming JRC (2020) Technology Development Report LCEO: Battery storage.

Figure 91 Energy density of Li-ion batteries over recent years

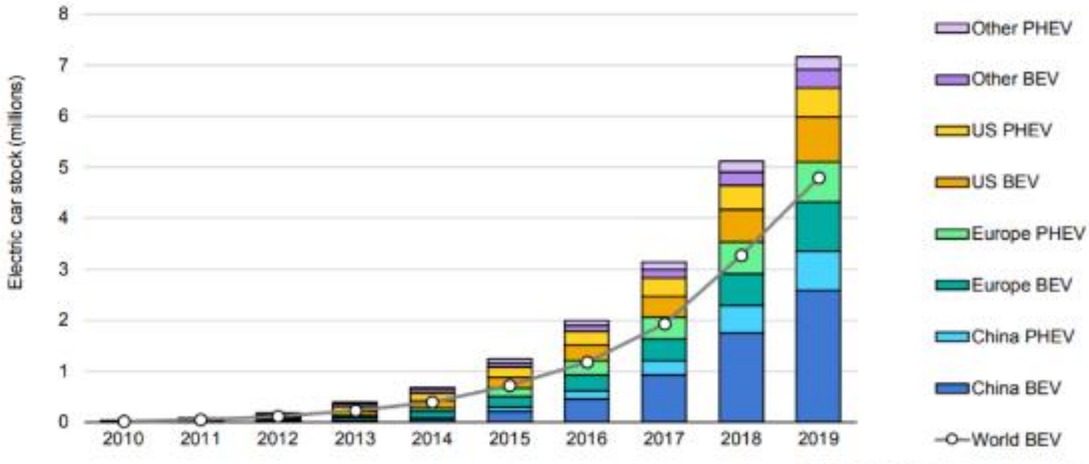


Source 93 JRC 2017[315]

EV demand has tripled global manufacturing capacity for Li-ion since 2013, given that batteries represent around 50% of the cost of an EV. By 2050, the share of battery electric and fuel cell drivetrains would reach 96% in 2050 (around 80% for battery electric and 16% for fuel cells). While only about 17 000 electric cars were on the road in 2010, there are today about 7.2 million electric cars globally[323]. Of the 4.79 million battery electric vehicles worldwide, 1 million are in Europe[324]. In particular, EVs could provide up to 20% of the flexibility to the grid required on a daily basis by 2050[325] given that appropriate interoperability solutions are in place and deployed.

[323] Both battery eletric vehicles and plug-in hybrid electric vehicles.
[324] IEA (2020), Global EV Outlook 2020, IEA, Paris https://www.iea.org/reports/global-ev-outlook-2020
[325] https://ec.europa.eu/energy/sites/ener/files/energy_system_integration_strategy_.pdf

Figure 92 Global Electric Vehicles and Plug in hybrid car stock, 2010-2019



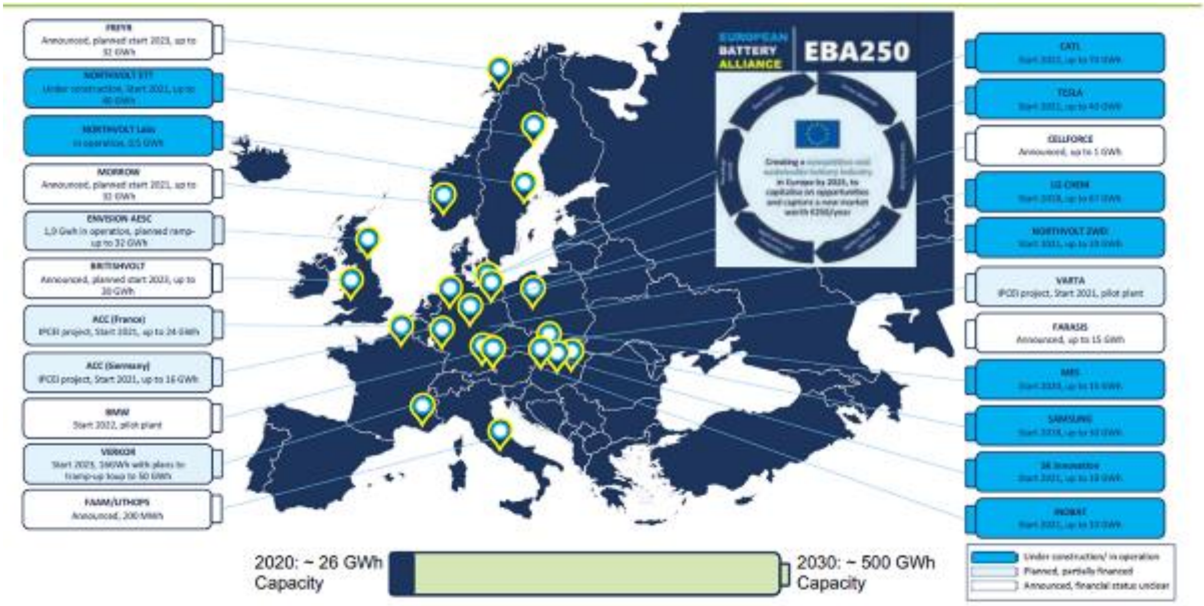
Notes: PHEV = plug-in hybrid electric vehicle; BEV = battery electric vehicle. Other includes: Australia, Brazil, Canada, Chile, India, Japan, Korea, Malaysia, Mexico, New Zealand, South Africa and Thailand. Europe includes: Austria, Belgium, Bulgaria, Croatia, Cyprus,[5, 6] Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.

Sources: IEA analysis based on country submissions, complemented by ACEA (2020); EAFO (2020c); EV-Volumes (2020); Marklines (2020); OICA (2020); CAAM (2020).

Source 94 IEA, Global electric car stock, 2010-2019, IEA, Paris https://www.iea.org/data-and-statistics/charts/global-electric-car-stock-2010-2019

Currently, there have been announcements for investments in up to 11 battery factories, with a projected capacity of 270 GWh by 2030. Whether these investments will materialise or not will depend on the establishment of a regulatory framework that will ensure fair competition for producers who take into account stricter sustainability standards.

Figure 93 Planned battery factories in EU27 + Norway and UK



Source 95 European Battery Alliance

<u>Cost, LCOE</u>

For batteries, upscaling works differently than for other technologies - at least for Li technology, the cell size and form often change while its performance increases quickly. Li-ion technology is about to take over the leading role from lead-acid batteries, both for mobile and stationary applications. Li-ion batteries are viable in short-duration applications where services can be stacked and adapted to market pricing (e.g. hourly balancing, peak shaving and ancillary services) but are less cost effective for longer duration storage (> 4 hours, > 1 MW)[326].

Electric vehicle (EV) demand is the main driver of cost reduction in Li-ion batteries. Li-ion battery prices, which were above USD 1 100/kWh in 2010, have fallen 87% in real terms to USD 156/kWh in 2020[327,328]. By 2025, average prices will be close to USD 100/kWh. The average battery pack size across electric light-duty vehicles sold (covering both battery electric vehicles and plug-in hybrid electric vehicles) continues to increase from 37 kWh in 2018 to 44 kWh in 2020, and battery electric cars in most countries are in the 50-70 kWh range[329].

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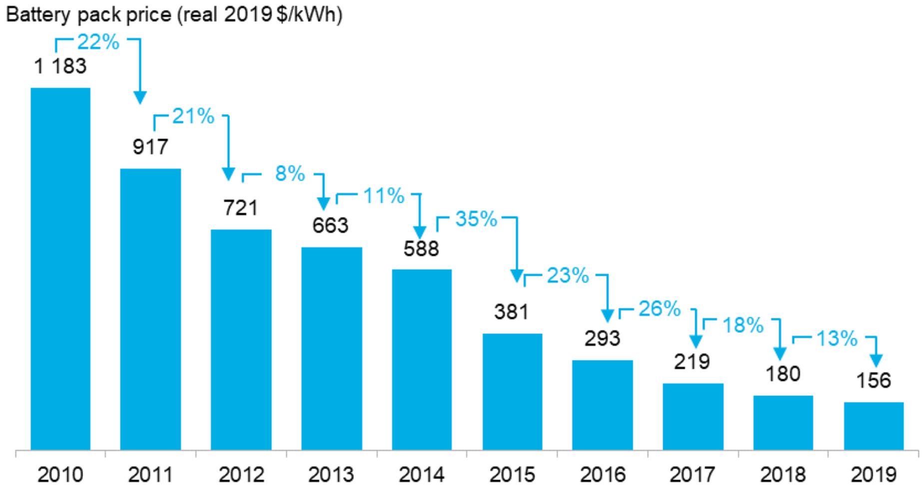
[326] ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020)

[327] L. Trahey, F.R. Brushetta, N.P. Balsara, G. Cedera, L. Chenga, Y.-M. Chianga, N.T. Hahn, B.J. Ingrama, S.D. Minteer, J.S. Moore, K.T. Mueller, L.F. Nazar, K.A. Persson, D.J. Siegel, K. Xu, K.R. Zavadil, V. Srinivasan, and G.W. Crabtree, "Energy storage emerging: A perspective from the Joint Center for Energy Storage Research", PNAS, 117 (2020) 12550–12557

[328] https://www.iea.org/reports/global-ev-outlook-2020#batteries-an-essential-technology-to-electrify-road-transport

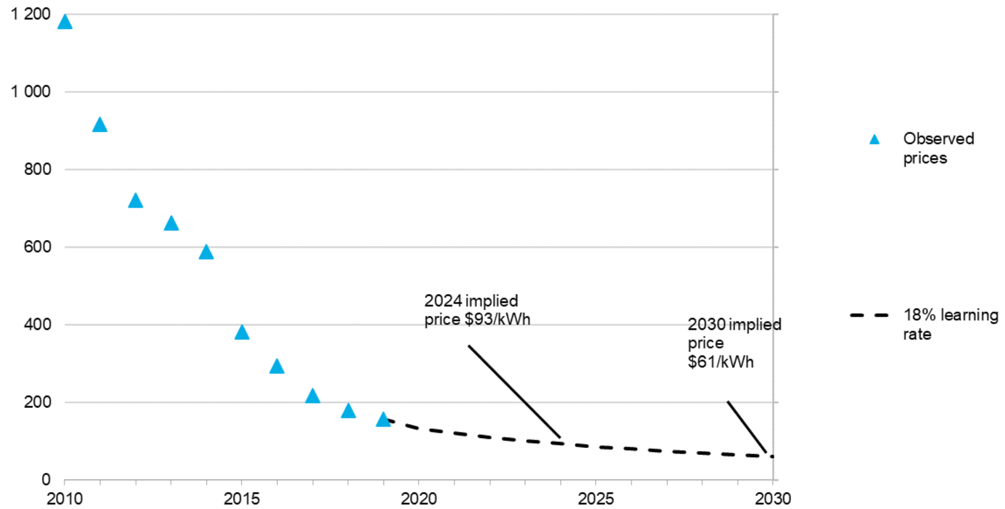
[329] https://www.iea.org/reports/global-ev-outlook-2020#batteries-an-essential-technology-to-electrify-road-transport

Figure 94 Li-ion battery price survey results: volume-weighted average



Source 96 BNEF

Figure 95 Li-ion battery pack price (real 2019 USD/kWh)



Source 97 BNEF

The prices for stationary Li-ion systems are also impressively coming down, though the cost is not the main factor for stationary systems, if compared to lifecycle. However, the cost reduction has been slower due to the contribution of other major cost components (e.g. inverters, balance of system hardware, soft costs such as engineering, procurement and construction), reduced economies of scale, and many use cases with different requirements. The benchmark costs of Li-ion stationary storage systems in 2017 were about EUR 500/kWh for energy-designed systems, about EUR 800/kWh for power-designed systems, and EUR 750/kWh for residential batteries[330]. Lowering of balance of system and other soft costs can

[330] https://publications.jrc.ec.europa.eu/repository/bitstream/JRC113360/kjna29440enn.pdf

potentially help further cost reduction of stationary energy storage systems, lifting barriers for their widespread deployment. At the same time, alternative technologies, other than Li-ion, are most promising for stationary energy storage and most probably will gain most market share in the future.

R&I

The need for cost reduction leads to innovation around four performance characteristics: energy, power, lifespan and safety[331]. Immediate innovation funding relates to succeeding with Li-ion cell mass production. In the short-term perspective this requires R&I at very high TRL level to bypass at least marginally current state of the art and start production (without waiting for break-through with solid-state technology).

While improving the performance of conventional lithium-ion batteries remains important, R&I efforts should also explore new chemistries for storing electricity at different scales[329]. The high differentiation of the market and the continuous interest in innovation are driven by multiple factors. Among the chemistries with a lower market share, currently lithium-sulphur and zinc-air batteries may be the most advanced but serious challenges will need to be overcome before commercialisation. Even though they both have significant potential, both Li-air and Mg-ion chemistries face difficulties and are dependent on technological breakthroughs for further development. Since the market for batteries is very competitive and prone to hypes, the long investment cycles, sometimes inflated expectations and reliance of some actors on government funding, can become problematic. Often, venture capital firms are reluctant to invest in projects that do not offer quick returns on investment. In addition, investors can be discouraged when innovations do not live up to the expectations. Consequently, some battery storage firms go bankrupt before reaching commercialisation[329].

The wide range of applications of batteries and the various limitations of existing chemistries continue to drive innovation in the sector[332]. Research and Innovation will benchmark the future specifications and characteristics for battery technology as such and, more important, will determine the speed and market uptake rates for mobility and energy sector electrification. The corresponding investments in research have to be substantially increased, following the trend of the last years. High performing batteries are an essential energy storage technology necessary for Europe to succeed in this transition, in particular to be competitive also in the largest Chinese market. Main technological challenges remain improving performances of batteries, at the same time guaranteeing the European-level quality and safety, as well as the availability of raw and processed materials. This can only happen through breakthrough innovations and disruptive inventions; increased digitalisation; pushing the boundaries of technological performance of battery materials and chemistries; increasing the effectiveness of manufacturing processes; ensuring smart integration in applications; interoperability with the rest of the smart energy system components at all levels; and guaranteeing reuse or recycling and sustainability of the whole battery value chain.

Materials play a very important part in the value chain, starting from the right choice of raw material that should be sustainable and easily available, over pre-processed materials, advanced value added materials and materials with low environmental and CO2 footprint up

[331] ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020)

[332] Next Generation Energy Storage Technologies (EST) Market Forecast 2020-2030, Visiongain

to materials that by nature or by design will be easily recyclable. Thus, EU should consider take up the chance to regain competitiveness by providing modern sustainable and cost competitive battery materials and basic battery components (as anode, cathode, electrolyte, separators, binders, etc.) made in Europe.

The current research trend is to develop advanced materials (e.g. silicon enriched anode, solid state electrolytes) for the currently dominant Li-ion technology rather than developing new chemistries beyond Li-ion, at least until 2025. On the battery's technical innovation side, areas include use of graphene[333], silicon anodes, solid state electrolytes, room-temperature polymer electrolytes, and big-data-driven component recycling/repurposing techniques (e.g. Circunomics)[334] paving the way for further efficiency increases. These improved technologies are speculated to transition by 2030 towards post Li-ion technologies (Li-air, Li-S, Na-ion) once their performance is proven in automotive applications. Li-ion technology is therefore expected to remain as the dominant deployed technology at least until 2025-2030[335].

The continuous pressure of improving Li-ion battery performance, especially in terms of extended life, cyclability and energy and power density as well as safety could affect the market uptake of emerging non-Li battery technology. Nevertheless, a broad range of applications requires a variety of fit-to-purpose batteries to satisfy the requirements for each application hence stimulating development of new types of batteries.

Despite only 3% of global production capacity currently being located within the EU, the sector is a very active investment space, with EU companies receiving around a third of deal volume and total investment over the 2014-2019 period[336]. One should also mention the Business Investment Platform (BIP) set up by InnoEnergy to channel private funding around innovative manufacturing projects in all segments of the batteries value chain. More than EUR 20 billion is in the pipeline.

Innovators in the batteries chain have managed to attract considerable levels of early stage and late stage investments (with EU companies attracting about 40%) as new technology developments emerged[337]. France and Sweden stand out in terms of total size of investments in early stage companies, while Sweden and Germany are the EU's leading investors in late stage companies. Early and late stage investment peaked across the board in recent years as new technology developments emerged, with the EU holding a considerable share of these investments.

Public R&I funding

[333] Graphene enabled silicon-based Li-ion battery boosts capacity by 30% - Graphene Flagship

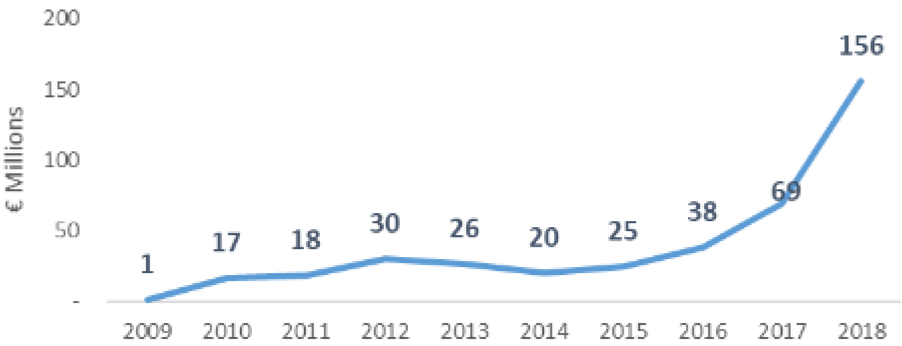
[334] ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020)

[335] Lebedeva, N., Di Persio, F., Boon-Brett, L., Lithium ion battery value chain and related opportunities for Europe, EUR 28534 EN, Publications Office of the European Union, Luxembourg, 2017, ISBN 978-92-79-66948-4, doi:10.2760/6060, JRC105010

[336] ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020)

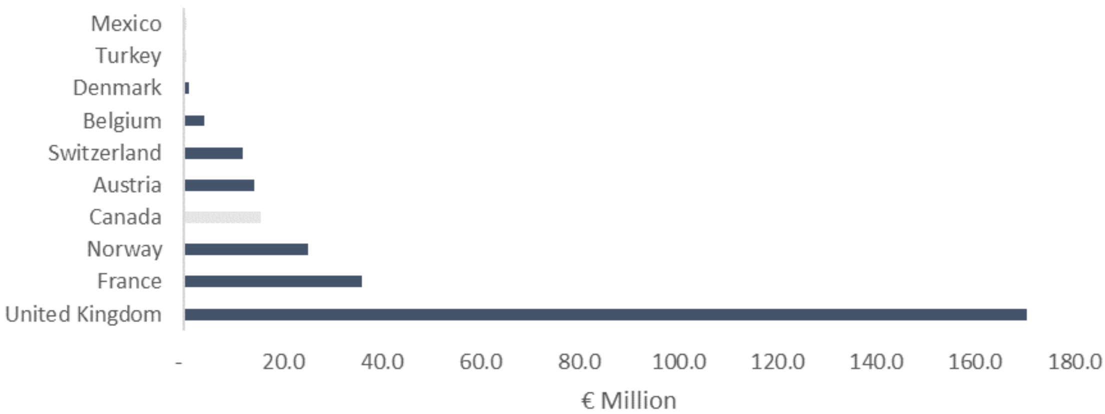
[337] ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020)

Figure 96 EU28 Public RD&D Investments in the Value Chain of grid-connected electrochemical batteries used for energy storage and digital control systems



Source 98 ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020)

Figure 97 Top 10 Countries - Public RD&D Investments (Total 2016-2018) in grid-connected electrochemical batteries used for energy storage and digital control systems



Source 99 ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020) (IEA data, does not include China)

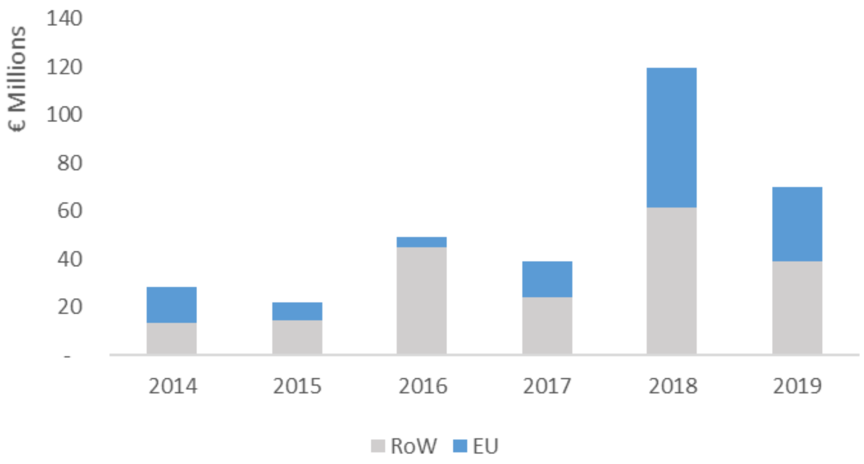
A number of Member States are strengthening their R&I capacity. One prominent example includes the Frauenhofer (Germany) with its own "battery alliance"[338], the biggest research production facility consisting of a number of institutes. Other important R&I players include CEA (France), ENEA (Italy), CIC energiGUNE (Spain), etc.

In the UK, the Faraday battery challenge (part of the Industrial Strategy Challenge Fund of the UK) has an investment of EUR 280 million, which addresses the growing automotive battery technology market. There are opportunities for EU-UK cooperation in this sector worth an estimated EUR 57 billion across Europe by 2025.

Private R&I funding

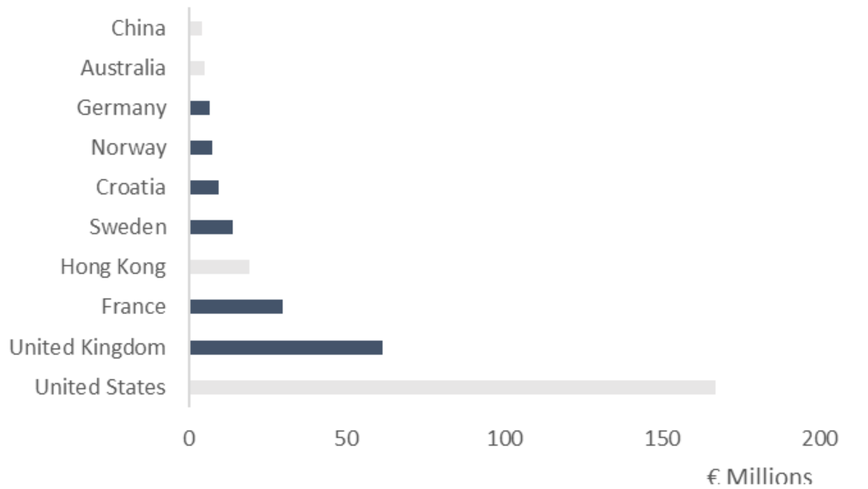
[338] https://www.fraunhofer.de/en/research/key-strategic-initiatives/battery-cell-production.html

Figure 98 Early Stage Private Investment in grid-connected electrochemical batteries used for energy storage and digital control systems



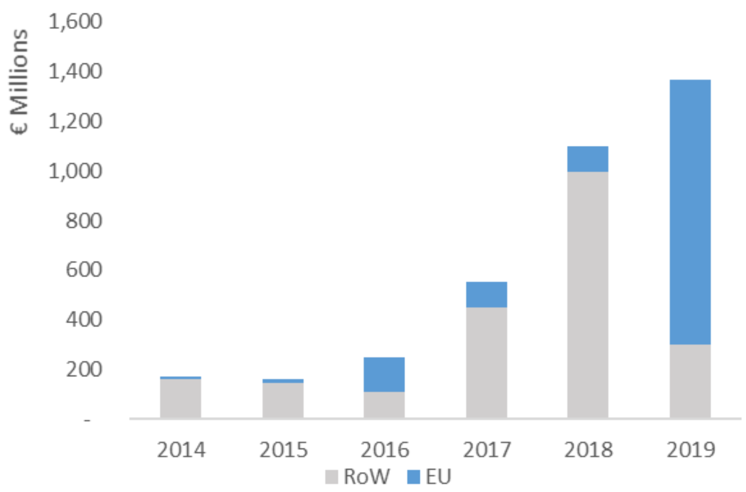
Source 100 ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020)

Figure 99 Total Early Stage Private Investment between 2014 and 2019 (top 10 countries) in grid-connected electrochemical batteries used for energy storage and digital control systems



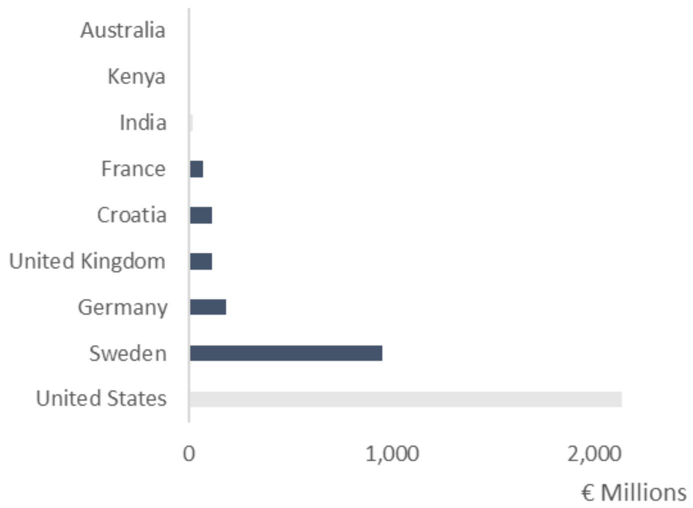
Source 101 ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020)

Figure 100 Late Stage Private Investment in grid-connected electrochemical batteries used for energy storage and digital control systems



Source 102 ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020)

Figure 101 Total Late Stage Private Investment between 2014 and 2019 (top 9 countries) in grid-connected electrochemical batteries used for energy storage and digital control systems

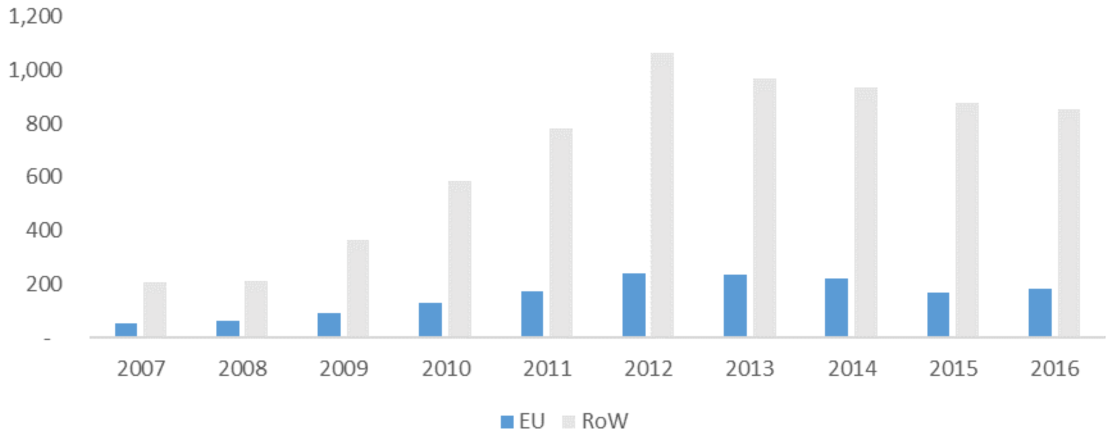


Source 103 ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020)

<u>Patenting trends</u>

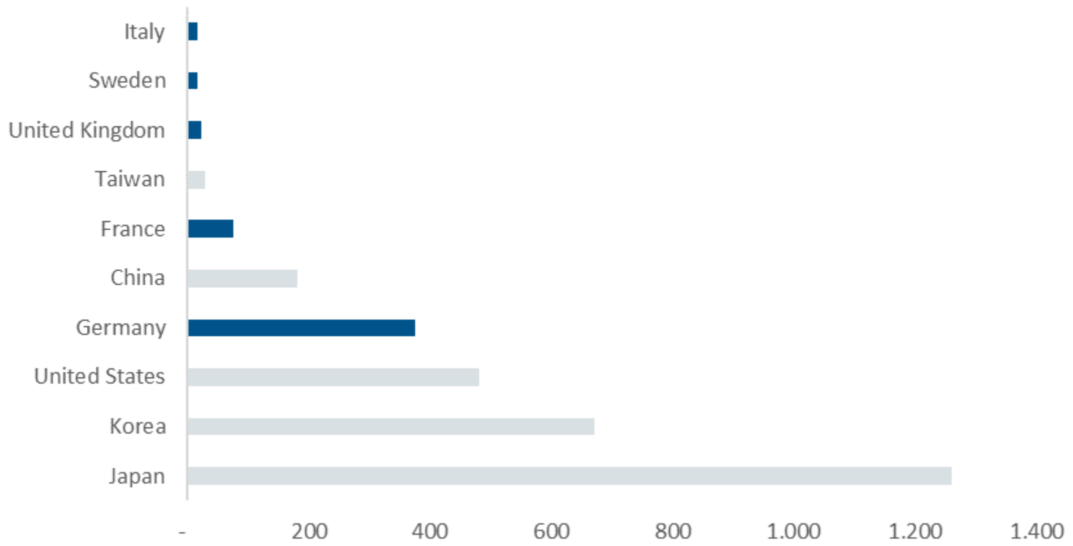
Historically, more patent applications have been filed in the RoW than in the EU[339] (EU share of high value patents is of about 18% between 2014 and 2016).

Figure 102 Patent Applications (2007-2016) – EU28 vs RoW in of grid-connected electrochemical batteries used for energy storage and digital control systems



Source 104 ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020)

Figure 103 Patent Applications - Top 10 Countries (Total 2014-2016) in of grid-connected electrochemical batteries used for energy storage and digital control systems



Source 105 ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020)

Five of the top ten countries where these patents originated were in the EU. More specifically, Germany and France stand out in terms of the number of high-value patent

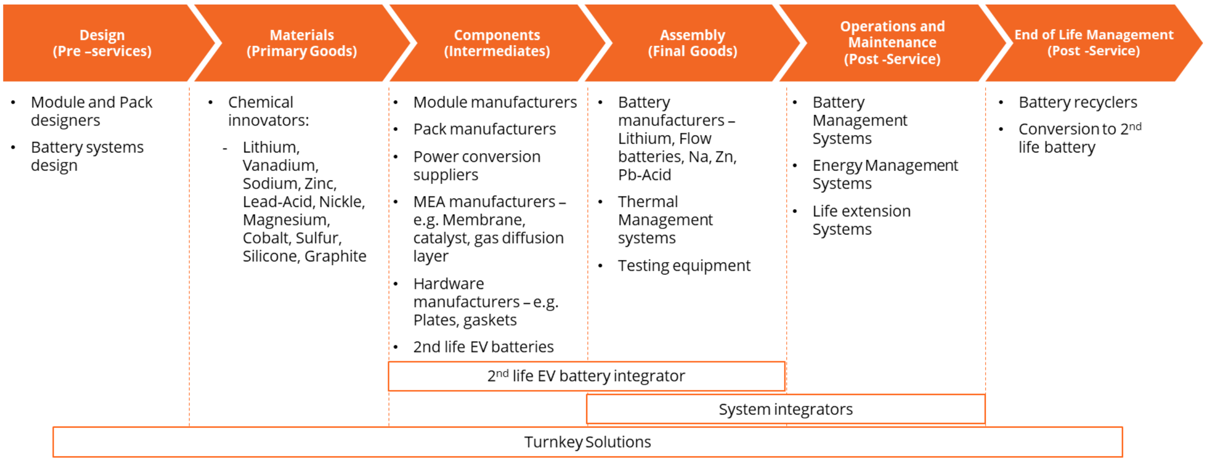
[339] ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020)

applications over the same period. Both patenting activity and public spending in R&I have increased over the last decade. However, when comparing with the rest of the world, the EU is still catching up.

3.6.2. *Value chain analysis*

Li-ion technology currently dominates the landscape as far as e-mobility and energy transition-related storage are concerned. Historically, the European battery segment has a large chemical industry cluster and a large ecosystem around batteries. However, when it comes to modern applications it could be considered a relatively new and growing economic sector.

Figure 104 Batteries value chain

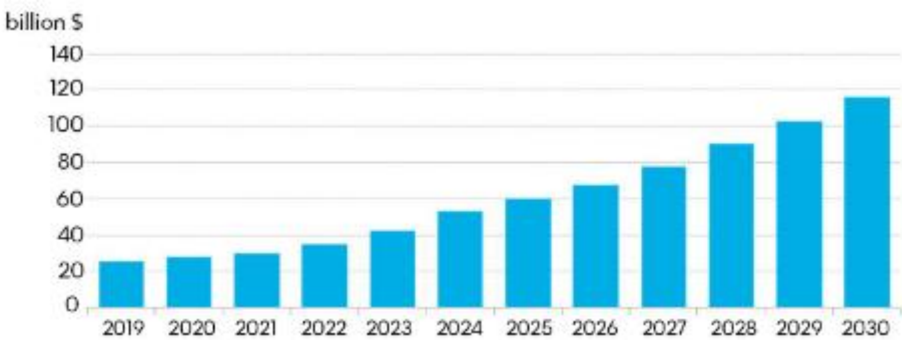


Source 106 ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020)

<u>Turnover</u>

The overall market size of Li-ion batteries is projected to increase.

Figure 105 Annual Li-ion battery market size



Source 107 BNEF[340]

340 https://about.bnef.com/blog/battery-pack-prices-fall-as-market-ramps-up-with-market-average-at-156-kwh-in-

Figure 106 SWOT analysis for the EU on the central segments of the batteries value chain

Value Chain Step	Strengths	Weaknesses	Opportunities	Threats
Advanced Materials	• Established EU industrial leaders with strong know-how in certain key advanced materials • Excellent knowledge and competences in research, and well-organized R&D structures • Strong knowledge and infrastructure in recycling technologies	• No full coverage of the whole spectrum of advanced materials by EU companies • EU R&I initiatives up to now have not generated enough IP (which results in Europe lagging behind in emerging technologies)	• Gain competitive advantage on next generation (Gen 3-5 battery materials) • Become the dominant player in battery sustainability issues (incl. sourcing, recycling, carbon footprint) • Significant part of the value of the battery market lies in advanced materials • Battery 2030+ Flagship Initiative	• Manufacturing infrastructure of key players could be outside Europe • No competitive access to primary raw materials for European players • Development cycles for key battery market applications (e.g. EV) are very long
Battery Cell Making	• Modelling & simulation expertise • Strong educational and university network with more than 30 pilot plants • Europe – expertise and players – is strong in Industry 4.0 (making operations more efficient) • Strong Renewable energy implementation allowing to make "green batteries"	• Still no large-scale manufacturing capacity in Europe by European players although many initiatives ongoing • Delay in Solid State piloting and manufacturing • Non-homogeneous legislative work frame	• Momentum for implementation of manufacturing capacity for the upcoming technologies (e.g. solid state, Na-ion) before Asia and US dominates • Development of a strong equipment manufacturing industry • Development of battery design easy to dismantle and recycle	• Dependence on companies outside of Europe • High CAPEX needed to build cell manufacturing capacity could decelerate capacity building
Integration into Applications	• Strong Integrator and Automotive industry in Europe	• Limited partnerships inside European e-mobility value chain	• Technology and legal base to create a "closed loop" battery industry (using second life applications for batteries and recycling)	• Import applications (buses, ESS...) from China & Asia • Significant investment needs in infrastructure (charging stations,
	• Legislative framework that favours clean mobility and green energy production	• Market confidence e-mobility still to be strengthened (model case Norway)	• Significant market anticipated in EU • Mobility industry in Europe under competitive stress to innovate	grid) could slow down market for batteries

Source 108 EMIRI technology roadmap 2019

Number of companies in the supply chain, incl. EU market leaders

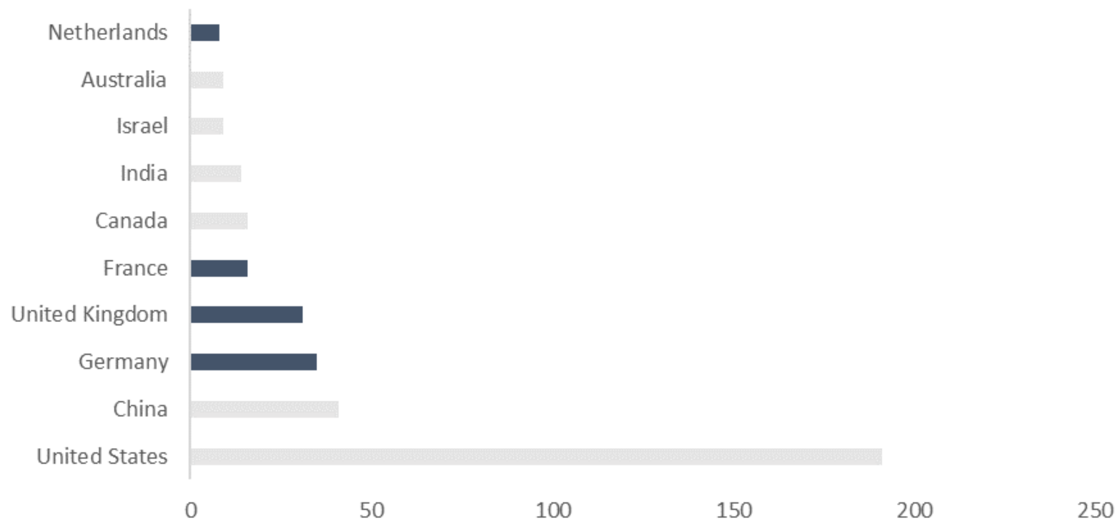
Around the world, a number of new companies/production installations are established along the whole battery value chain. For safety reasons it makes sense to produce battery cells close to consumer markets. This has led to numerous Li-ion cell and pack production facilities being started in the EU by European (NorthVolt, SAFT, VARTA[341]), Asian (LG, Samsung CATL) and American producers (Tesla). 21% of active companies in the batteries sector are headquartered in the EU, with Germany and France standing out[342].

2019/#:~:text=Shanghai%20and%20London%2C%20December%203,research%20company%20BloombergNEF%20(BNEF).

[341] Northvolt plans to have 32 GWh total facilities in Sweden in the coming years and 16 GWH in Germany (cooperation with VW is close). SAFT/TOTAL and Varta are part of first IPCEI on battery R&I. Northvolt will be involved in 2nd IPCEI on battery R&I.

[342] ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020)

Figure 107 Top 10 Countries - # of companies in grid-connected electrochemical batteries used for energy storage and digital control systems

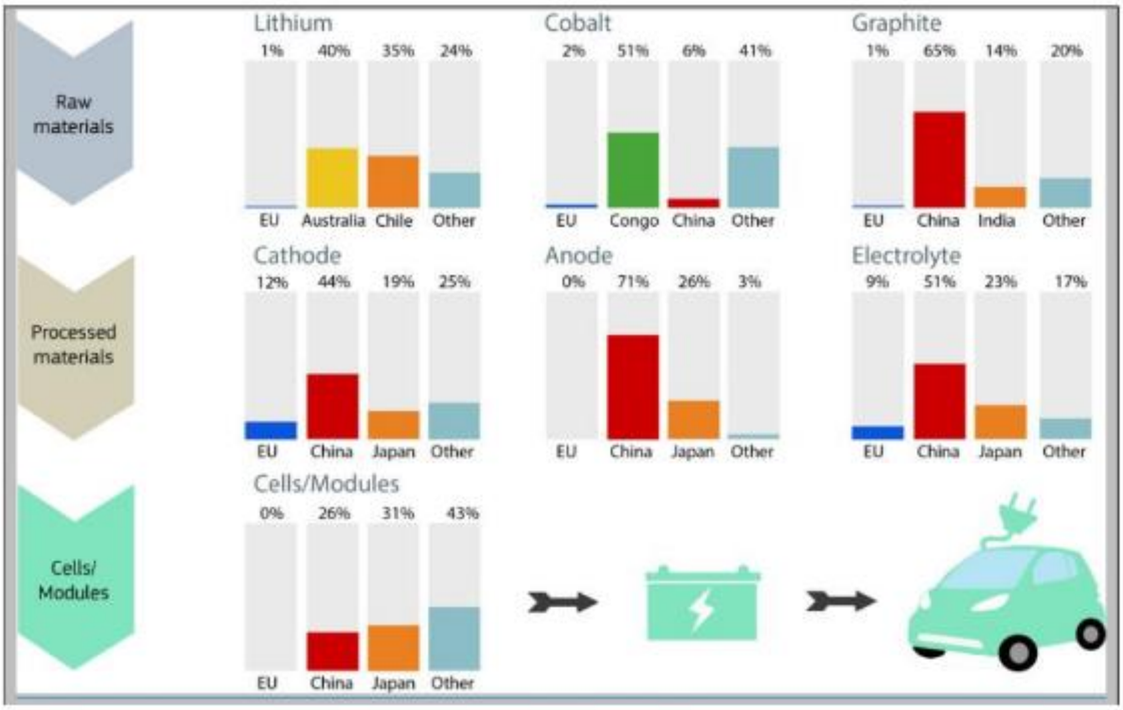


Source 109 ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020)

The EU industry has some production base in all segments of the battery value chain, but it is far from being self-sufficient. In the raw and processed materials, cell component and cell manufacturing value chain segments Europe holds a minor share of the market (3% in 2018), whereas in the pack and vehicle manufacturing and recycling segments Europe is among the market leaders[343]. It is characterised by many actors, which represent a mix of corporates and innovators. There is a high potential for non-energy storage focused participants to enter the space.

[343] Lebedeva, N., Di Persio, F., Boon-Brett, L., Lithium ion battery value chain and related opportunities for Europe, EUR 28534 EN, Publications Office of the European Union, Luxembourg, 2017, ISBN 978-92-79-66948-4, doi:10.2760/6060, JRC105010

Figure 108 EU's position in the batteries value chain in 2016



Source 110 JRC 2016[344]

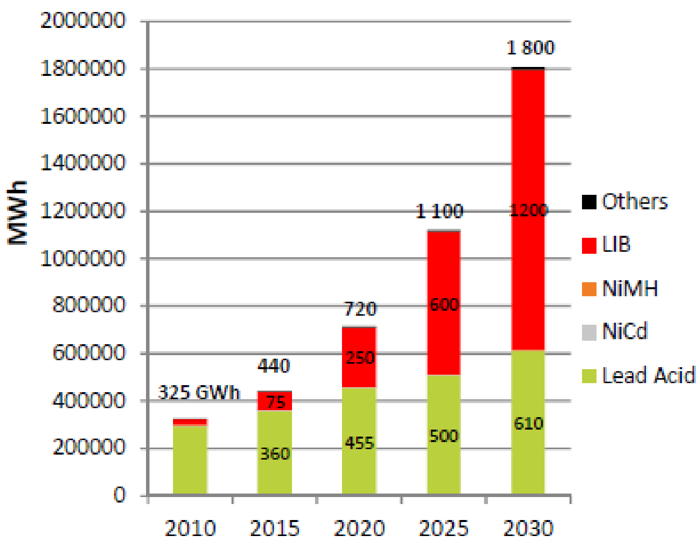
On the basis of the above, the EU recognised the needs and urgency to recover competitiveness in the battery value chain, and the Commission launched the European Battery Alliance in 2017 and in 2019 adopted a Strategic Action Plan for Batteries[345]. It represents a comprehensive policy framework with regulatory and financial instruments to support the complete battery value chain eco-system. A range of actions have already been put in place, including:

a) strengthening of the Horizon 2020 programme through additional battery research funding (more than EUR 250 million, for 2019-2020)
b) creating a specific technology platform, the ETIP "Batteries Europe" tasked with coordination of R&D&I efforts at regional, national and European levels and following up on the work in the Key Action 7 on batteries of the SET-Plan,
c) preparing of specific instruments for the next Research Framework Programme Horizon Europe,
d) preparing of new specific regulation on sustainability and
e) stimulation of investments, both national of the Member States and private, in creation of a modern and competitive EU battery value chain through Important Project of Common European Interest (IPCEI)[346].

[344] https://ec.europa.eu/jrc/sites/jrcsh/files/jrc105010_161214_li-ion_battery_value_chain_jrc105010.pdf
[345] COM 2019 176 Report on the Implementation of the Strategic Action Plan on Batteries: Building a Strategic Battery Value Chain in Europe
[346] Press release IP/19/6705, "State aid: Commission approves EUR 3.2 billion public support by seven Member States for a pan-European research and innovation project in all segments of the battery value chain", December 9, 2019. https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6705.

It is still to be seen how economies of scale in Li-ion battery sector will influence viability of other battery technologies and storage technologies in general. In principle, lead-acid battery producers, a well-established industry in the EU, should be able to keep certain role in automotive sector (12V batteries), in motive applications' sector and re-orient e.g. to stationary storage sector. In stationary storage sector, weight and volume - main disadvantage of lead-acid batteries - do not matter as much as in e-mobility sector. However, it also has to be seen how lead-acid technology will be able to keep its competitiveness vis-à-vis emerging sector of flow batteries and other types of stationary technologies.

Figure 109 Battery production in MWh



Source 111 (CBI) /Avicenne: Consortium for Battery Innovation "Advanced lead batteries the future of energy storage"

There are numerous European start-ups also in the field of flow-batteries focussed on stationary storage sector[347] prompted by their long discharge (> 4 hours) possibilities. However, no big company seems to be entering this segment in the EU yet. Concerning sodium-ion: one FR start-up in this field (+1 in UK), however development may take some years before becoming a significant industrial actor. The EU was involved in the sodium-based (NaNiCl2) technology with FIAMM (Italy) in the past but it seems that there are no more activities. Concerning Lithium Sulphur: despite some start-up announcing it, the technology seems not to be ready for the market, except some niche application. Some

[347] Here are some EU flow battery companies:
VisBlue (DK 2014) commercialises a new battery technology using a vanadium redox flow battery system.
BETTERY, an Italian Innovative Startup founded in January 2018 (flow batteries),
NETTERGY, a start-up related to E.ON (2016) - developer of a scalable distributed flow battery system that economically serves multiple stationary energy storage applications
Kemiwatt (FR) has made several world premieres since its creation in 2014, with the first organic Redox battery prototype in 2016 and the first industrial demonstrator in 2017.
Jena batteries GmbH (2013 DE) innovative company in the field of stationary energy storage systems rated at 100 kW and up. It offers metal-free flow battery systems.
Elestor (2014, NL) HBr flow batteries

development with alkaline rechargeable Zinc batteries is also observed, with at least two start-up in EU proposing this product for stationary applications[348].

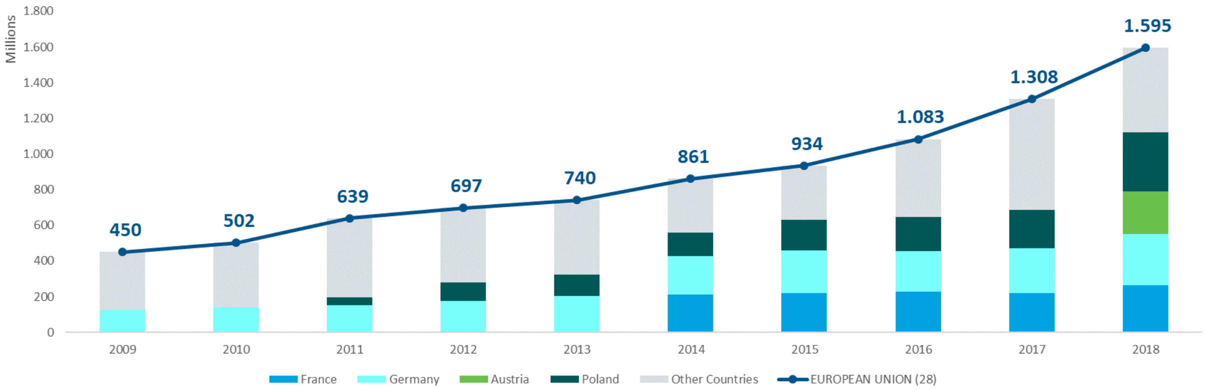
Moreover, in the nascent stationary integration segment, the EU has companies, which advance convincingly: Sonnen (owned by Shell, and rolling out domestic battery storage systems), Fluence (joint venture between Siemens and American AEG is world's number one as regards stationary storage systems), etc.

The market for Battery Management System currently growing faster than batteries themselves (from a lower baseline)[349], this technology utilise analytical models and machine learning to predict, simulate and optimise battery operation.

ProdCom statistics

Between 2009 and 2018, the annual production value of batteries in the EU has grown steady at annual rate of 39% a year (2009 to 2018 period). Poland accounts for 21% of the EU production, followed by Germany (18%), France (16%) and Austria (15%)[350].

Figure 110 Total Production Value in the EU28 and Top Producer Countries in grid-connected electrochemical batteries used for energy storage and digital control systems



Source 112 ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020)

3.6.3. *Global market analysis*

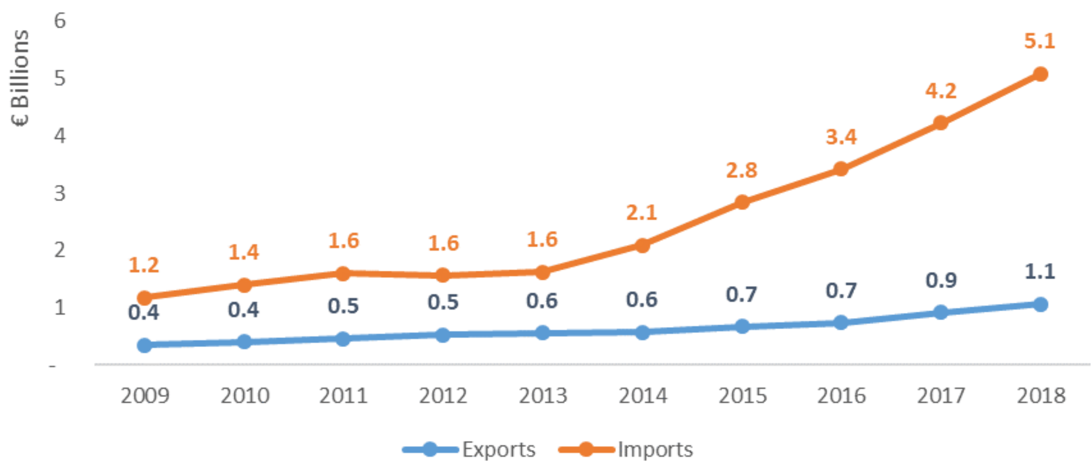
Trade (imports, exports)

In Li-ion batteries sector, the EU's share of global trade is currently limited, even if increasing with new battery factories being set up. Between 2009 and 2018, the EU28 trade

[348] Information received from RECHARGE
[349] ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020)
[350] ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020)

balance is negative, even if trade in lead-acid batteries is added. The countries with the highest negative trends are Germany, France and the Netherlands[351].

Figure 111 Total EU28 Imports & Exports of grid-connected electrochemical batteries used for energy storage and digital control systems



Source 113 ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020)

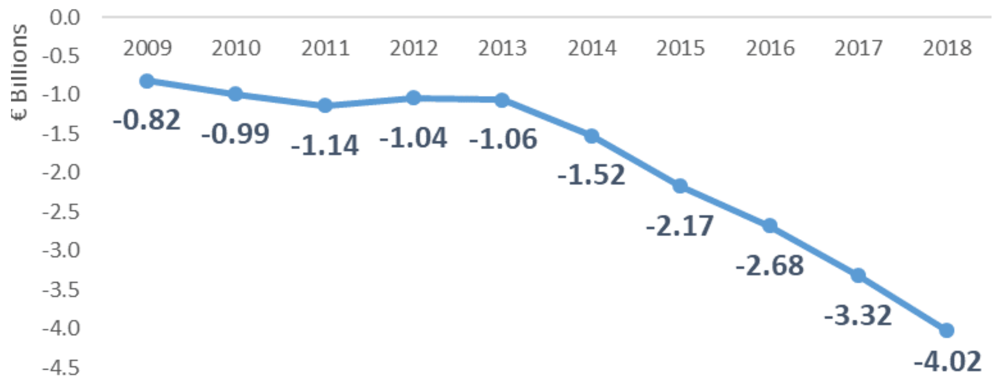
Most of the global manufacturing capacity for Li-ion batteries is located in Asia. Key RoW competitors are China, Korea, Japan, US and Hong Kong. Between 2016 and 2018, 3 out of the top 10 global exporters were EU countries (Germany, Poland and Czech Republic). However, not only the industrial capacity but also expertise, processes, skills and supply chain is concentrated around the regions dominating the market[352].

The manufacturing of electronic appliances in Asia has represented a significant advantage for the Asian battery industry, facilitating the supply of locally manufactured Li batteries. In addition, development and support of the battery industry have been considered a strategic objective for years in Japan, China and Korea, leading to strong support for local investment. China has played a predominant role in recent years.

[351] ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020)

[352] C. Pillot, Nice batteries conference, Oct 23, 2019.

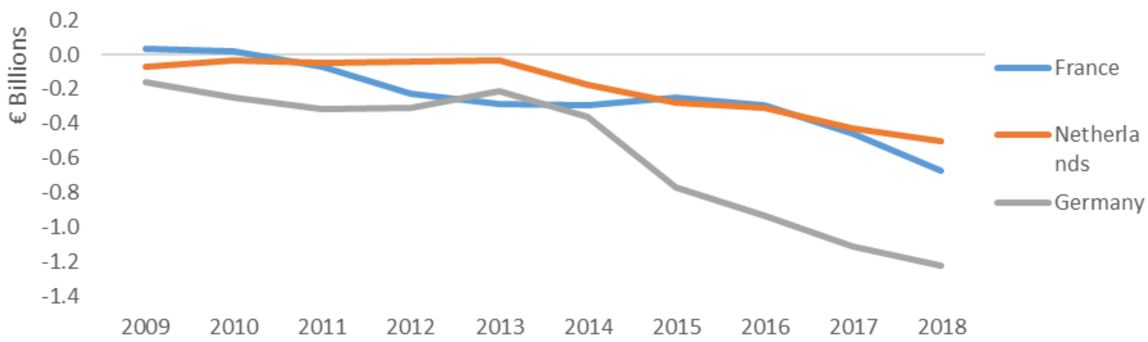
Figure 112 EU28 Trade Balance in grid-connected electrochemical batteries used for energy storage and digital control systems



Source 114 ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020)

Between 2009 and 2018, EU28 exports to the RoW have been steadily increasing from EUR 0.4 billion (2009) to EUR 1.1 billion (2018). On the other hand, imports more than tripled from EUR 1.6 in 2013 to EUR 5.1 billion in 2018[353]. This means that for the 2016-2018 period, the EU28 share of global exports was stable at roughly 2%. Top EU exporters were Germany, Netherlands, Hungary and Poland.

Figure 113 Top Countries - Negative Trade Balance in grid-connected electrochemical batteries used for energy storage and digital control systems



Source 115 ICF, commissioned by DG Grow – Climate neutral market opportunities and EU competitiveness study (2020)

However, the recent investments and investments in the pipeline should improve the trade balance. Increased investment in R&I, including through IPCEIs, H2020/HEU, etc. should improve technological leadership, including registered patents. Moreover, demand for new batteries has outpaced supply, creating an opportunity for new entrants as incumbents struggle to meet demand[354].

[353] ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020)

[354] ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020)

Global market leaders VS EU market leaders

Europe's position in the market is at risk, primarily from Asian competition. Although Asian participation in the market is largely around automotive electrochemical batteries for automotive use, their capacity ramp up will enable them to produce Li-ion batteries at lower cost than other participants, allowing them to enter the grid-scale energy markets. Key RoW competitors are China, Korea and Japan, with 70% of global planned manufacturing capacity is in China, but growth may stall when EV subsidies are reduced.

Critical raw material dependence

In the globalised economy, EU is mostly a price taker in this market segment dominated by the Asian producers. China is the major supplier of Critical Raw Materials (CRMs), with a share of ~40%, followed by South Africa, Russia, Democratic Republic of Congo (DRC) and Brazil. Li, nickel, manganese, cobalt and graphite mainly come from South America and Asia[355]. Growth in material demand, such as cobalt, Li and lead, creating dramatic cost increases, supply shortages and efforts to find alternatives. Battery manufacturers accounted for 54% of all cobalt usage (2017)[356].

Demand for materials to make batteries for electric vehicles will increase exponentially in the period to 2030; cobalt is the most uncertain reflecting various battery chemistries. Battery manufacturers accounted for 54% of all cobalt usage (2017)[357]. The demand for the materials used in electric vehicle batteries will depend on changing battery chemistries. Today, nickel cobalt aluminium oxide (NCA), nickel manganese cobalt oxide (NMC) and Li iron phosphate (LFP) cathodes for Li-ion batteries are the most widely used[358].

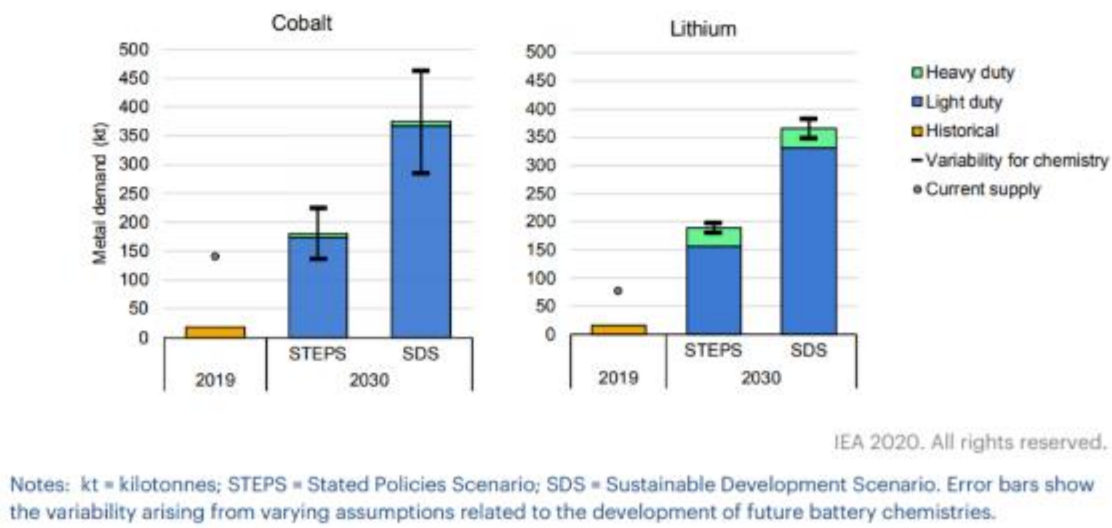
[355] ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020)

[356] ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020)

[357] ICF, commissioned by DG GROW - Climate neutral market opportunities and EU competitiveness study (Draft, 2020)

[358] IEA (2020), Global EV Outlook 2020, IEA, Paris https://www.iea.org/reports/global-ev-outlook-2020

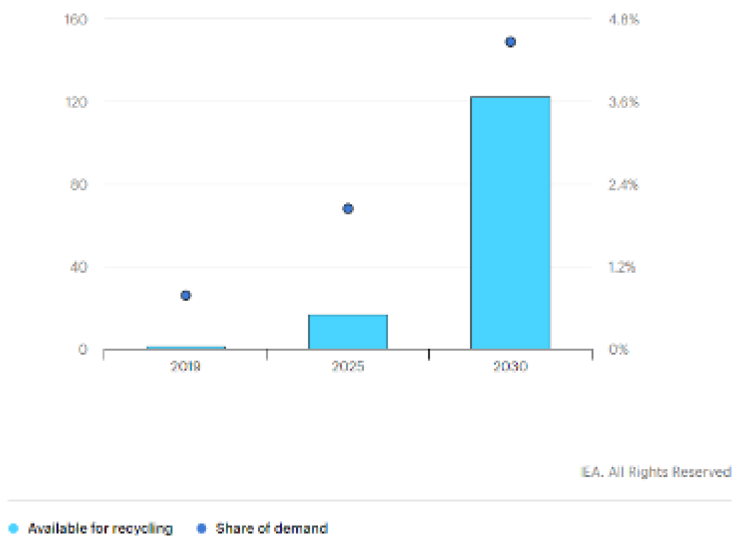
Figure 114 Global annual Li and cobalt demand for electric vehicle batteries, 2019-30



Source 116 IEA 2020[357]

A key challenge concerns the batteries end of life, which may represent a considerable environmental liability. The lifetime of batteries that are no longer suited for automotive applications can be extended via second use (e.g. for stationary storage applications for services to electricity network operators, electric utilities, and commercial or residential customers[359]) and/or recycling. Challenges for this new market include the continuously decreasing cost of new batteries, and a lengthy refurbishing process requiring information exchange along the value chain[360]. The current players in this market include OEMs, utilities and specialised start-ups.

Figure 115 Automotive battery capacity available for repurposing or recycling in the SDS, 2019-2030



Source 117 IEA 2020[357]

[360] IEA (2020), Global EV Outlook 2020, IEA, Paris https://www.iea.org/reports/global-ev-outlook-2020

The battery-recycling sector is currently struggling to prepare for increased volumes of battery waste expected from the automotive traction sector[361]. Issues associated with access and use 64 of critical materials for cell production can be addressed by (i) tapping new sources of critical materials, (ii) substituting critical materials with less critical ones and (iii) recycling/reuse of critical materials. R&I on alternative Li-ion chemistries, made of more accessible raw materials, could cover development of alternative chemistries to alleviate the need for the critical materials, cobalt and natural graphite[362]. R&I needs also to exist for improving the cost effectiveness of the recycling processes, development of more efficient processes, pre-normative research to develop standards and guidelines for collection and transportation of used batteries as well as standards and guidelines for battery second-use.

The EU Batteries Directive 2006/66/EC contributing to the protection, preservation and improvement of the quality of the environment by minimising the negative impact of batteries and accumulators and waste batteries and accumulators is currently under revision. The objective would be to start with disclosing to customers information on emissions during mining and production phase (before proceeding with introduction of limits), to facilitate re-use and impose new strict norms on collection and recycling. Stakeholder consultations are ongoing.

3.6.4. *Future challenges to fill technology gaps*

According to most technology pathways, the range of battery applications will significantly expand in the near future. The electrification of certain industrial sectors (vehicles and equipment, from automated loaders to mining or airports equipment) will be one of the drivers. This could represent about 100 GWH in the coming 10 years[363]. The system-scale deployment of batteries faces various challenges: economic (price), technical (energy density, power density, long term quality, safety), as well as other challenges related to the availability of resources and raw material on the one hand and to sustainability, recycling and circular economy on the other hand.

The IT sector is expected to maintain a strong growth rate in EU. Despite a relative market saturation for cell phones and tablets, new consumer products (drones, domestic robots, etc.) are further growing the market (in the range of 5 to 10% per year) of small batteries during the next 10 years[364]. In addition, digitalization remains important, involving computer-aided design of new chemistries, batteries with sensing capabilities and self-healing properties. See for example the Battery 2030+ initiative[365], which has recently issued a 2040 Roadmap targeting new scientific approaches that make use of technologies such as artificial intelligence, big data, sensors, and computing in order to advance knowledge in electro-chemistry and to explore new battery chemistries targeting in particular the needs of the mobility and energy sectors. Battery management system innovators are leveraging analytics and Artificial Intelligence to improve battery performance.

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[361] Lebedeva, N., Di Persio, F., Boon-Brett, L., Lithium ion battery value chain and related opportunities for Europe, EUR 28534 EN, Publications Office of the European Union, Luxembourg, 2017, ISBN 978-92-79-66948-4, doi:10.2760/6060, JRC105010

[362] Lebedeva, N., Di Persio, F., Boon-Brett, L., Lithium ion battery value chain and related opportunities for Europe, EUR 28534 EN, Publications Office of the European Union, Luxembourg, 2017, ISBN 978-92-79-66948-4, doi:10.2760/6060, JRC105010

[363] Information provided by RECHARGE (2020)

[364] Information provided by RECHARGE (2020)

[365] https://battery2030.eu/

The global aircraft electrification market is projected to grow from USD 3.4 billion in 2022 to USD 8.6 billion by 2030, at a CAGR of 12.2%[366]. Presence of key manufacturers of electric aircraft in Europe including Rolls-Royce (UK), Safran Group (France), GKN Aerospace (UK), Airbus (Netherlands), Thales Group (France), and Turbomeca (France), among others are driving the growth of the aircraft electrification.

On the waterborne side, greater widespread of pure battery powered solutions in the ferry and short-sea segment is the likely first step, with following greater use of hybrid applications in the deep-sea shipping market in Europe.

While improving the position on Li-ion technology may likely be a core interest stream for the next decades, at the longer term, other major progresses will come from new technologies (e.g. solid state) where the EU has a strong competitive position. It is therefore important to look into other new promising battery technologies (as e.g. all-solid state, post Li-ion and redox flow technology), which can potentially provide electricity storage for sectors whose needs cannot be met by the Li-ion technology. These technologies may surpass the performance of Li-ion batteries at the 2030 horizon in terms of cost, density, cycle life, and critical raw material needs (e.g. lithium-metal solid state battery, lithium-sulphur, sodium-ion or even lithium-air).

Table 6 Status of various Energy Storage Technologies

Status	Energy Storage Technology
Mature	Lead-acid, Ni-Cd[367] (nickel cadmium), NiMH (Nickel–metal hydride)
Commercial	Li-ion, Lead-acid, NaS (sodium-sulphur) and NaNiCl2 (Zebra), Li-ion capacitors, ZnBr (zinc bromine), Va (vanadium) flow batteries, Zinc-air, Li-polymer, LiS
Demonstration	Advanced lead-acid, Li-ion, Na-ion, HBr (hydrogen bromine) flow batteries, LiS
Prototype	FeCr (iron chromium), Li-ion capacitors, Solid-state batteries
Laboratory	Advanced Li-ion, new electrochemical couples (other Li-based), liquid metal batteries, Mg-based batteries, Li-air and other Metal-air batteries, Al batteries, non-aqueous flow batteries, solid-state batteries, batteries with organic electrodes
Idea, concept	Solid electrolyte Li-ion batteries, rechargeable Metal-air batteries (Mg-air, Al-air and Li-air)

The scale-up of these new technologies will need time to compete with the well-established Li-ion technology (in terms of large-scale manufacture, investments already made and solid understanding of its long-term durability characteristics)[368]. Even though on the longer term other storage solutions such as renewable hydrogen may take a share of current battery applications, battery energy technology will maintain a large share in the next future due to its extremely high energy efficiency. The European economic competitiveness in this area will depend on the capability of Europe to react quickly to changing demand and to develop innovative technology solutions. EU programmes such as Horizon Europe and the Innovation Fund will strongly support these efforts.

[366] https://www.globenewswire.com/news-release/2020/02/07/1981726/0/en/Global-Aircraft-Electrification-Market-Forecast-to-2030-Low-Operational-Costs-Reduced-Emission-and-Aircraft-Noise.html
[367] Nickel-based batteries have failsafe characteristics.
[368] IEA (2020), Global EV Outlook 2020, IEA, Paris https://www.iea.org/reports/global-ev-outlook-2020

Lastly, other efforts are to be focused on: (i) reducing to the maximum possible extent critical raw materials dependency in batteries production through further material substitution, providing local resources in a circular economy approach and substantial recycling of battery materials, both imported and local improving primary and secondary raw material processing; (ii) very high sustainability levels (approaching 100%) at production, use and the recycling stage, including improved end-of-life management – recycling and reuse, design for recycling; (iii) improvements in anode, cathode, separator, and electrolyte will enable further cost reductions in the near future, as well as improvements on non-battery pack system components (e.g. battery controller, structure around it) and improvements in manufacturing processes; (iii) ensuring safety.

3.7. Buildings (incl. heating and cooling)

With 40% of energy consumption and 36% of CO_2 emissions in the EU originating from buildings, the building sector is a key element in the EU climate and environmental policies[369] and therefore technologies related to buildings and their energy consumption are key to achieve the Green Deal.

For example, the EU environmental obligations to reduce 80-95% greenhouse gas emissions, the Common European Sustainability Building Assessment (CESBA) initiative, the Roadmap to a Resource Efficient Europe[370] and the new Circular Economy Action Plan[371] all promote buildings sustainability, energy efficiency and aim to reduce waste, thus highlighting the efficiency gains of using prefabricated building components. The Renovation Wave initiative[372] also examines and promotes energy efficiency in buildings, and aims to address the related issue of energy poverty.

This section analyses four elements of the buildings market that aim to capture the different dimensions, realising that this assessment is incomplete and needs to be expanded to give a complete picture. With respect to construction this SWD focuses on pre-fabrication, and with respect to energy consumption in buildings this document focuses on lighting as an important source of energy consumption in buildings, next to heating that is by far consuming most energy in buildings, and is therefore addressed in 2 parts, namely district heating and cooling (DHC) and heat pumps. Digital technologies to manage energy consumptions in homes and buildings (Home Energy Management Systems and Building Energy Management Systems) are also addressed in this SWD within the Smart Grids - Digital infrastructure part of this SWD. Considering that buildings solutions are often dependent on local circumstances, some data are difficult to aggregate and therefore not available, such as the cost or the productivity.

[369] https://ec.europa.eu/info/news/focus-energy-efficiency-buildings-2020-feb-17_en

[370] COM(2011) 571, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Roadmap to a Resource Efficient Europe

[371] COM(2020) 98, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A new Circular Action Plan for a cleaner and more competitive Europe.

[372] COM(2020)662 accompanied by SWD(2020)550, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A Renovation Wave for Europe – greening our buildings, creating jobs, improving lives.

3.7.1. *Prefabricated building components*

3.7.1.1. State of play of the selected technology and outlook

The increasing demand for buildings due to increase in population and urbanisation opens markets for faster and efficient construction. Some of the trends in the building industry include an aging and dwindling construction workforce, increasing cost of labour and skills shortages, which in turn are causing low productivity. On the other hand, prefabrication is safer, often cheaper, and more productive and attracts different skilled workers. In addition, prefabricated buildings can be structurally stronger than traditional builds and so are resilient to natural disasters, especially earthquakes.

It is expected that property technology (the use of IT and data in real-estate, PropTech) and construction technologies are the markets that will drive innovation in modular or prefabricated construction, however, the two are very similar and often overlapping.

Innovation in component design is enabling faster and more efficient logistics and assembly. Recently foldable prefabricated homes have been developed for quick assembly and easy transportation. Design processes like building information modelling (BIM) and Digital Twins demonstrate that designs can be refined, monitored and improved by integrating on-site feedback. Technologies to improve circularity and re-use of materials are driving innovation in the buildings sector, including in pre-fab. This needs to be integrated from the design-phase. A landmark innovation was the creation of a building design utilising exclusively reusable materials and prefabricated methodology in showcasing how the built environment can implement the integration of circular economic thinking.[373]

Capacity installed

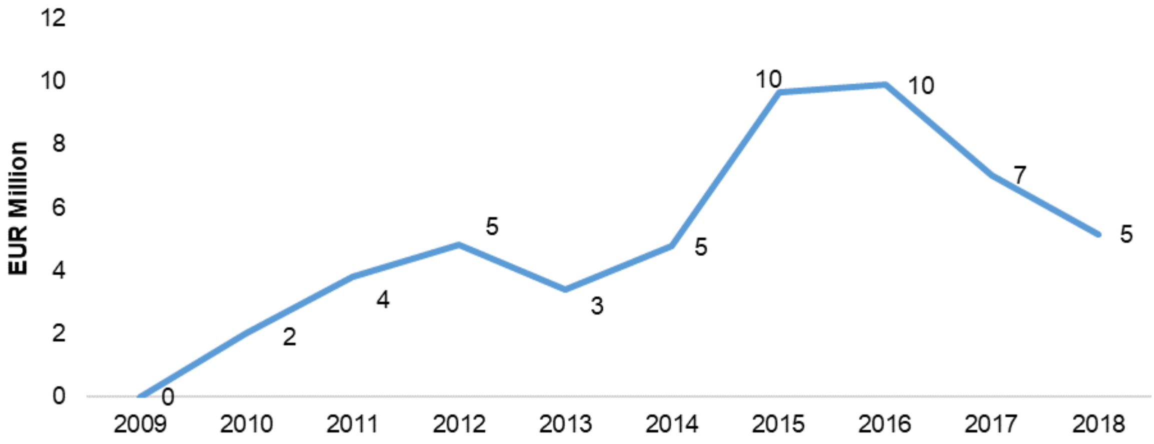
From 2020 to 2025, the European prefabricated building market was projected (prior to the COVID-19 crisis) to expand at a 5% compound annual growth rate (CAGR) as a result of the maturation of digital tools, changing consumer perception, increased design complexity, quality, and sustainability, and demand for small to midsize housing units. By 2022, it is estimated that 70100 prefabricated units will be built in Northern Europe. However, these numbers could be impacted with a short-term decline due to the crisis and the expected market contraction in the building sector.

Public R&I funding

The data on public investment in R&D is available for a limited group of countries covered by the IEA. Starting from 2009, EU public R&I investment has increased to EUR 5 million by 2012, with a peak of EUR 10 million in 2016 and 2017 and a following downward trend to EUR 5 million in 2018. Out of the countries for which the IEA has data, France was by far the largest investor, followed by Denmark and Austria, while Canada was also very active when it comes to public investments. In addition, nine out of the top ten countries where these investments happened are in the EU.

[373] Developed in 2016 by ARUP with BAM Construction, Freiner & Reifer, and the Built Environment Trust

Figure 116 EU28 Public R&D Investments in the Prefabricated Buildings Value Chain



Source 118 ICF, 2020

Private R&I funding

Over the 2015-2019 period, 40% of the total value of global private investments in early stage companies was in European companies. When assessing the number of investments, this percentage decreases to 32%, suggesting that the average size of investments was higher in Europe.[374] However, the availability of data for investments in European companies is limited.[375] Available data shows that investments in European early stage companies in 2019 was around EUR 108 million. The investment in the selected countries in the rest of the world has increased at a slower pace, from EUR 67 million in 2015 to EUR 75 million in 2019. According to the analysed data, UK, Belgium and Germany stand out in terms of total size of investments in early stage companies over the 2015-2019 period.

Over the same period, 1% of the total value of global private investments was in late stage European companies. When assessing the number of investments, this percentage grows to 6%, suggesting that the average size of investments was larger outside of Europe. In addition, one out of the top three countries where these investments happened is in Europe. The UK stands out in terms of total size of investments in late stage companies over the studied period.

Late stage investments, both in Europe and in the rest of the world remained volatile. In 2018, there was growth in late stage private investments, which was followed by a dip in 2019, especially in Europe.

Private R&I funding

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[374] According to the analysed data from the CleanTech Group's database. The Cleantech Group investment database is global. However, while there is confidence regarding the coverage of the investments in the US and the EU, data from emerging markets (notably China) can be underestimated due to this information not being made public.

[375] According to the analysed data from the CleanTech Group's database.

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Late stage investments, both in Europe and in the rest of the world remained volatile. In 2018, there was growth in late stage private investments, which was followed by a dip in 2019, especially in Europe.

3.7.1.2. Value chain analysis

The prefabricated value chain is represented amongst others by the European Federation of Premanufactured Buildings (EFV) and the European PropTech Association – PropTech House. They aim to create a legal framework in the EU that fosters innovation and adapts to new technologies across the European real estate industry. Other existing building associations also promote the use of prefabrication technologies.

Turnover

Between 2009 and 2018, the production value of prefabricated buildings in the EU increased steadily by 40% – from EUR 31.85 billion to EUR 44.38 billion. France and Italy accounted for around one third of the EU production value of prefabricated buildings.

Until 2018, the UK led the European PropTech market with USD 821 million raised between 771 companies. Germany, Austria and Switzerland, the three countries together, follows in second with 515 PropTech companies and USD 340 million raised so far. Among the top 15 most active investors, eight are based in Germany, with VitoOne (a part of Viessmann) being the most active investor in the region with 15 portfolio PropTech companies.

Some of the factors for growth in this sector included increasing acceptance of alternative methods and materials for prefabricated constructions, alongside environmental, efficiency and cost gains. Advanced assembly technologies like 3D printing reduce labour cost and increase replicability. In addition, 3D printing of concrete structures relies on prefabrication

[376] According to the analysed data from the CleanTech Group's database. The Cleantech Group investment database is global. However, while there is confidence regarding the coverage of the investments in the US and the EU, data from emerging markets (notably China) can be underestimated due to this information not being made public.

[377] According to the analysed data from the CleanTech Group's database.

due to the logistics of sending a large and comparatively delicate printer to a construction site.

Number of companies, incl. EU market leaders

There are some prefabricated material such as wood, which make building very well insulated and low in carbon content.

Sweden is the European market leader in this sector with 80% of the housing integrating prefabricated components, 45% of houses and 35% of new build multi-resident structures using prefabricated modules. Other leading countries include Austria, Switzerland as well as Denmark and Norway.

Currently, Europe is home to 44% of the active companies of the industry on prefabricated building components. Considering the top 10 countries in the sector, US has 34 companies active in the prefabricated buildings sector, UK 15, France 6, Switzerland and Germany 5, the Netherlands 4, Canada and Norway 3, Italy and Spain 2.[378]

Between 2009 and 2018, EU28 exports to the rest of the world increased from EUR 0.83 billion in 2009 to EUR 1.88 billion in 2018. On the other hand, imports have been relatively stable around EUR 0.18 billion in 2009 to EUR 0.26 billion in 2018 with a low of EUR 0.15 billion in 2012-13.

3.7.1.3. Global market analysis

The global modular construction market size is projected to grow from EUR 85.4 billion in 2020 to EUR 107.9 billion by 2025, at a CAGR of 5.7% from 2020 to 2025. Currently, the Asia-Pacific region has the largest share in the prefabricated building market. In 2018, it accounted for over 30%, which is due to a growing middle class and increasing urbanisation. North America is the second largest market, driven by factors such as consumer preference for green buildings and sustained investments in commercial real estate. Some of the countries around the world also implement policy measures to support this sector and to strengthen the active companies in this domain. For instance, China has a governmental target for 30% of new buildings to be prefabricated by 2026 and has implemented cash bonuses and tax exemptions for prefabricated buildings. The US International Code Council (ICC) building code was modernised to allow the increased height of mass timber building from 6 to 18 stories, enabling high-rise timber frame prefabricated buildings.

Trade (imports, exports) & Global market leaders vs. EU market leaders

The EU28 share of global exports has remained at 17.6% from 2016 to 2018. Top EU exporters are the Netherlands, Germany and the Czech Republic. For the same period, eight out of the top ten global exporters were European countries. For the studied period, key

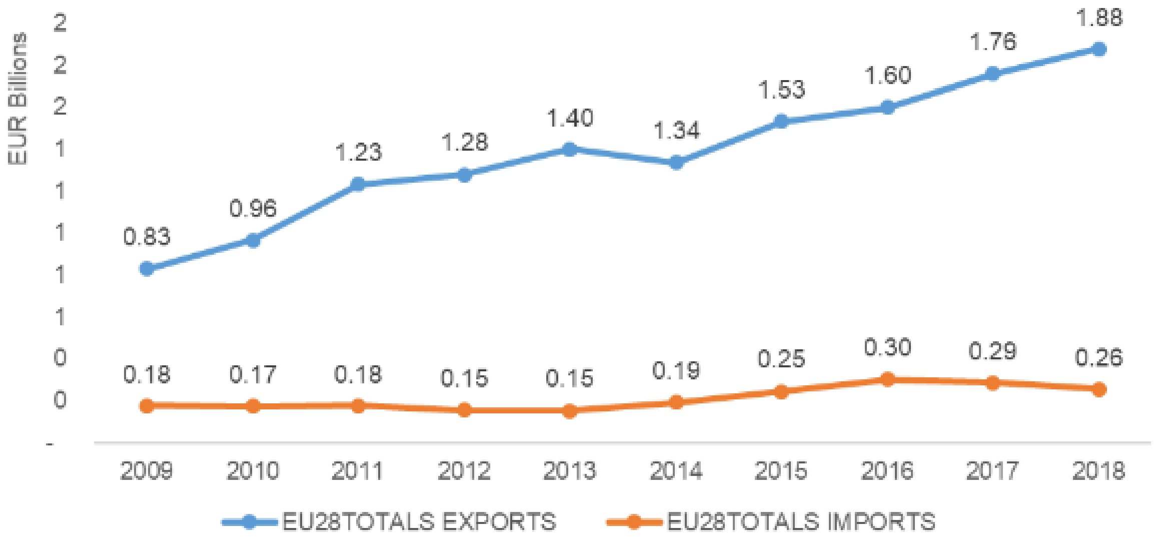
[378] According to the analysed data from the CleanTech Group's database. The Cleantech Group investment database is global. However, while there is confidence regarding the coverage of value chain investments in the US and the EU, data from emerging markets (notably China) can be underestimated due to this information not being made public.

competitors to the EU in this VC were China and the US. For the same period, six out of the top ten global importers were EU countries. Germany was the largest importer followed by Norway, France and the Netherlands. However, some EU countries were importing mainly from within the EU.

Between 2009 and 2018, the EU28 trade balance has remained positive with an increasing trend. The countries with the highest positive trends were the Czech Republic, Estonia and the Netherlands, and the ones with the lowest negative trends were the UK, France and Germany. Poland, Estonia and Latvia had a trade balance with an upwards trend.

The Czech Republic exported mostly to Germany amongst the EU countries and the UK mainly imported from the Netherlands. These trends could be influenced by the ongoing Brexit negotiations.

Figure 117 Total EU28 Imports & Exports



Source 119 ICF, 2020

<u>Critical raw material dependence</u>

Raw materials for buildings tend to be bulk materials sourced within limited distance. Critical raw materials come into play when the devices for the energy management systems for buildings and homes (HEMS and BEMS) are considered.

3.7.1.4. Future challenges to fill the technology gap

Competitiveness and sustainability. The prefabricated buildings technology addresses mostly the new buildings market, touching a limited fraction of the building stock. Moreover, traditional concrete prefabricated buildings recorded, in the past, poor energy performances. The challenge of this industry is the conjugate competitiveness and sustainability.

- **High fragmentation**. Both the market and its supply chains are fragmented with too many and small players which might represent a difficulty for manufacturing capacity and scalability. For instance, in Germany in 2018, the top five prefabricated housing developers (WeberHaus, SchwörerHaus, Danwood, Equistone, DFH) represented approximately 30% of the market, beyond these top five developers market shares are all below 3%. Mergers, acquisitions and corporate engagement with this market are expected to reduce fragmentation and improve efficiencies via economies of scale.

- **Industry knowledge**. The lack of familiarity and certainty with the different materials and techniques, difficulties with the planning systems and complying with building regulations can lead the industry to decisions against its use. In addition, the construction industry is notoriously conservative and slow in adapting to changes.
- **Skill gap**. New skills and expertise will need to be built up and invested in, particularly digital and design skills. As the industry is historically tech adverse this may be a concern. High levels of investment in training and education will be required.
- **Lack of data and development of digital tools**. There is limited available data on performance and durability of buildings constructed via modern methods of construction. In addition, due to competition and the use of new technologies, companies may be reluctant to share or publish information. At the same time, BIM and Digital Twin software are improving the replicability and learning capacity of prefabricated building design and assembly monitoring. The use of these are being encouraged by the EU via the EU BIM task group, whilst in Germany BIM will become mandatory for public infrastructure projects by 2021. By using these digital tools performance can be tracked throughout the entire lifecycle of the building in a continuous cycle that will provide info back to design, but it is important to share data to develop these tools.
- **High capital costs**. Upfront factory costs are high, requiring assemblers to benefit from economies of scale to ensure competitive costs. The small size of most construction companies is a further barrier both to technological development and adoption of new techniques.
- **Access to finance and risk assurance**. Due to lack of data and high market fragmentation, insurers and lenders may deem insolvency risk to be high and so can overprice or refuse support, slowing progress. Difficulties securing mortgages might occur. As the market scales up, insolvency risks are expected to be reduced. In 2012, the European Commission co-launched a digital library for prefabricated building designs as part of its Green Prefab project[379]. This has helped to improve market confidence by aggregating data, and will also improve replicability, enabling economies of scale.
- **Logistics**. Restrictive transport regulation can increase project costs by 10%, paying for extras like road escorts for wide loads. Particularly difficult with big modules, wider 3D structures, a trade off exists between how much a structure is prefabricated and how easy it is to transport.
- **Consumer perception**. There are still some negative perceptions due to past failures rather than new technologies delivering quality and more cost-effective buildings from consumers, developers and wider industry. Difficulties related with durability, making adjustments and repairs to the properties also cause some apprehension from the consumers.

[379] http://www.greenprefab.com/ 3

3.7.2. *Energy efficient lighting*

3.7.2.1. State of play of the selected technology and outlook

<u>Technology development and capacity installed</u>

Lighting is the second largest electricity consumer in the EU eco-design programme (after electric motors), responsible for about 12% of the gross electricity generation in the EU28. The 2017 data of the MELISA model scenario projected the electricity consumption of lighting products in scope of eco-design (with effect of current regulations, without any new measure) to 320 TWh in 2020[380]. Technology for light sources keeps evolving, thereby improving energy efficiency. LED technology, has had a rapid uptake on the EU market. Almost absent in 2008, it reached 22% of the market in 2015. The average energy efficiency of LEDs quadrupled between 2009 and 2015, and prices dropped significantly. In 2017, a typical LED lamp for household was 75% cheaper and a typical LED lamp for offices 60% cheaper than in 2010[381].

During the last decade, Solid-State Lighting (SSL) based on components like OLEDs, LDs and particularly LEDs have challenged conventional technologies, displaying improved performance in most aspects. It is therefore anticipated that in the short-to-medium term, the new electric lighting installations will be based on SSL. However, this leaves the existing installations, which will be upgraded depending on use and maintenance. With equipment lifetime sometimes exceeding 15 or 20 years, inefficient systems are likely to remain in use unless change is triggered through incentives or requirements.

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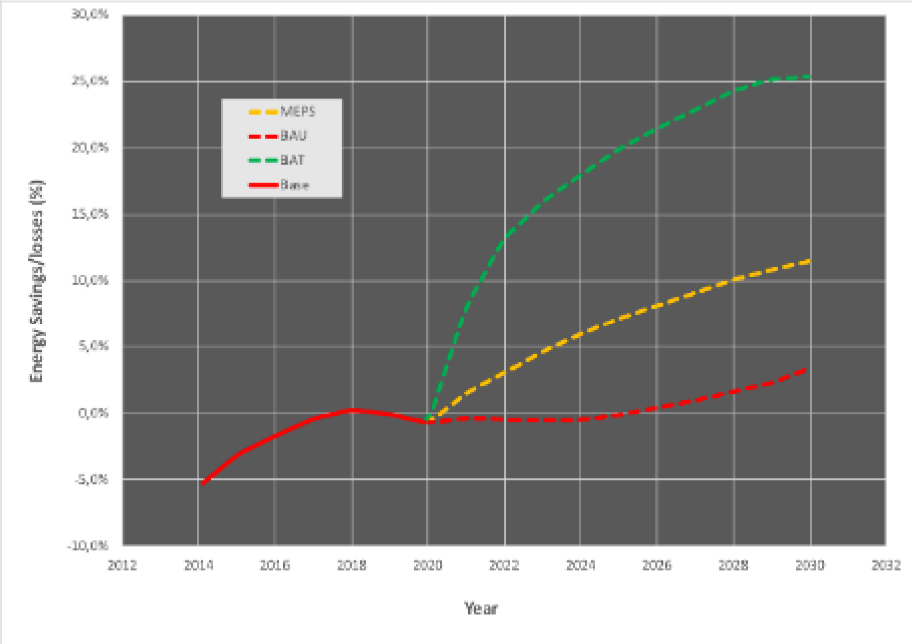
[380] European Commission Staff Working Document – Impact Assessment. SWD (2019) 357 final

[381] European Commission Staff Working Document – Impact Assessment. SWD (2019) 357 final

Figure 118 Variation of electricity savings/losses for lighting till 2030 following different scenarios[382]



Source 120 Data from [SCO-17] modified by G. Zissis

Technological advances in 2019 concern both components and lighting systems. All these advances serve at least one of the following objectives: 1. Increasing the efficiency and reliability in all levels from the component to the global system. 2. Reducing the cost of the components and single lamps and using more sustainable materials. 3. Enhancing the quality of light associated to the comfort and more focusing on lighting application efficiency (LAE). 4. Implementing new functionalities and services beyond basic illumination for vision and visibility.

Since mid-2010's a net increase of proposed technological advances at systems level can be observed, whereas innovations at component/device-level[383] are less common.

Patenting Trends

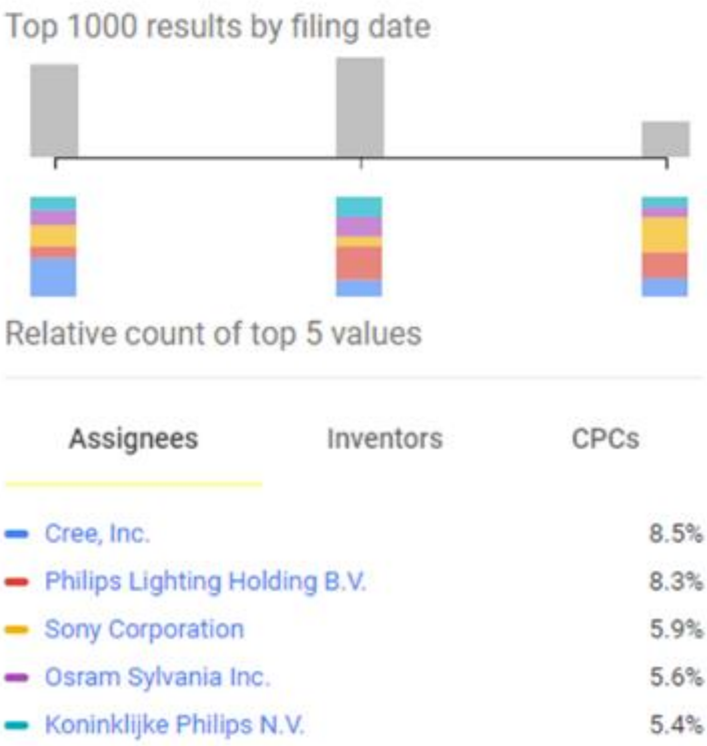
Regarding the patents on solid-state lighting, as per data from Google Patents[384] website, from 2010-01-01 to 2020-09-30, a number of 135,828 patents have been submitted at the European Patent Office, with Cree and Philips leading the pack in terms of patents filed in the period described.

[382] The "Base" line is calculated extrapolating observed consumption values, the reference year is set to 2017; BAU scenario admits massive replacement of legacy light sources by LEDs; MEPS scenario suppose the adoption of Minimum Energy Performance Standards worldwide; BAT scenario supposes the use of the Best Available Technology in the market.

[383] In this text a "component" means a single encapsulated small size electronic component whereas "device" corresponds to a larger encapsulated emitting element; both are drive-less but can include some reverse-current protection elements. "Component" applies better to LEDs and LDs when "device" is more appropriated for OLEDs and laser-systems.

[384] https://patents.google.com/?q=(solid+state+light)&country=WO&before=priority:20200930&after=priority:20100101&type=PATENT&num=100

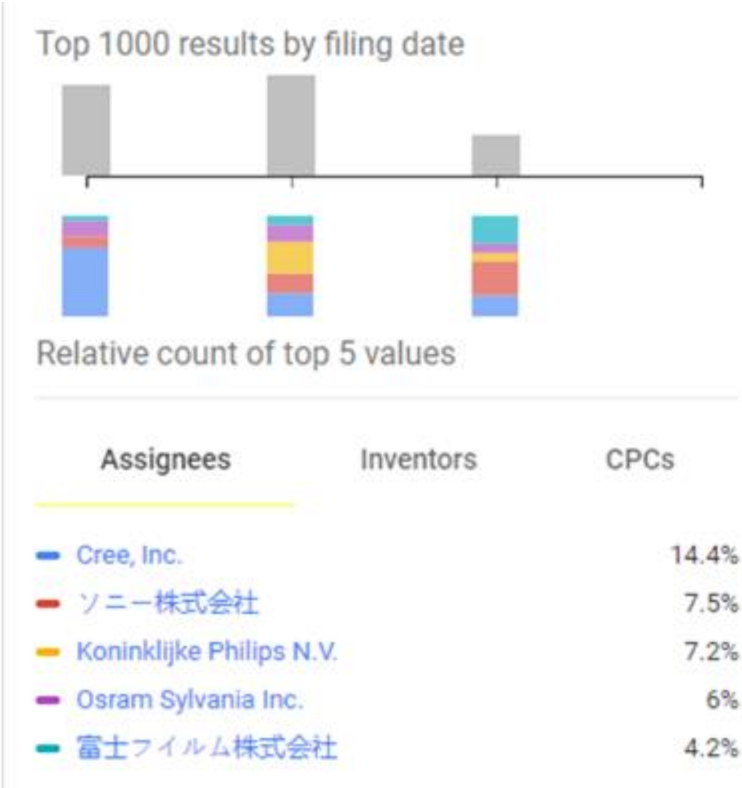
Figure 119 Patents filed in the EPO since 2010



Source 121 Google Patents

As for the Worldwide submission of patents regarding solid-state lighting, as the figure below shows, Cree is still the leading company submitting patent requests, followed by Sony Corporation and Koninklijke Philips N.V.

Figure 120 Worldwide patents on Solid State Lighting



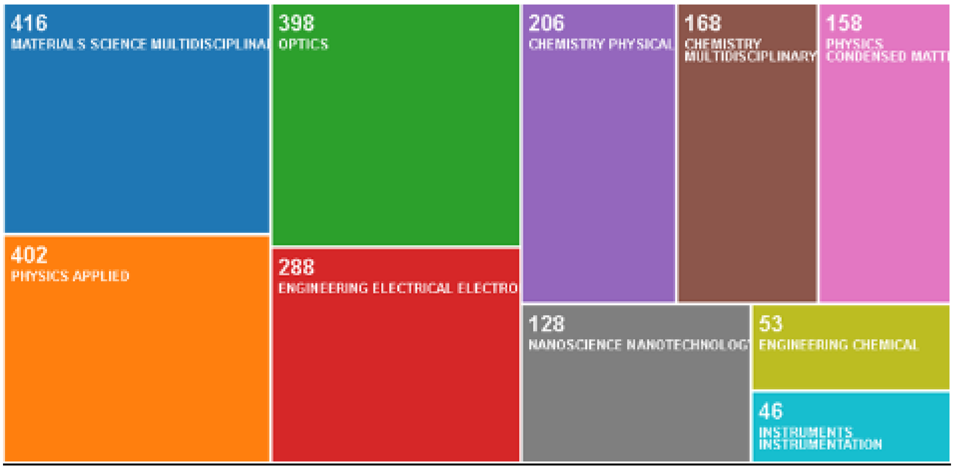
Source 122 Google Patents

Publications/Bibliometrics

In terms of scientific output, solid state lighting research has been steadily producing journal articles under Scopus[385] publications (2123 articles in 2020, 2991 in 2019, 2902 in 2018 and 2949 in 2017), with China, the United States, Germany and Japan leading as the countries with most publications. As for Web of Science database[386], the same trend can be seen, with 1978 journal articles published already in 2020 with solid state light as a topic, 2815 in 2019, 2781 in 2018 and 2790 in 2017, with China, the USA, India and Germany being the countries with most publications during this period.

[385] https://www.scopus.com/
[386] https://www.webofknowledge.com/

Figure 121Web of Science categories of solid state light publication



Source 123 Web of Science

3.7.2.2. Value chain analysis

<u>Turnover & Gross-value added growth</u>

The European lighting market is expected to grow from EUR 16.3 billion in 2012 to EUR 19.8 billion in 2020[387]. Following the Geography - Global Forecast to 2022[388], Europe is expected to be the second largest LED lighting market by 2022. LEDs lighting is increasing its market share from 15% in 2012 (or even 9% in 2011) to 72% in 2020.

However, more recent data shown that Europe overall LED penetration rates are estimated in 2016 to be 8% of lamps and 9% of luminaires[389] which lagging back previous predictions. This can be partially understood by the fact that Europe has a population that has a relatively high standard of living. The Ecodesign Law states that the maximum standby power of 0,5 W and a minimum efficacy requirement of 85 lm/W. In addition, the Energy Performance of Buildings' (EPBD) minimum energy performance requirements at building level provide pressure to use efficient lighting.

CSIL analysts estimated that in 2019, the lighting market for the EU30 would reach around 21 billion (+1.6% increase) distributed as follows:

- Lighting fixtures EUR 18,1 billion (+0.9%)
- LED lamps EUR 1,9 billion (14%)
- Legacy lamps EUR 450 million (-17%)
- Lighting controls EUR 550 million (+4.8%)

387 CBI Ministry of Foreign Affairs, Electronic Lighting in the Netherlands, 2014
388 Geography - Global Forecast to 2022, online teaser, Report SE4912 published January 2017
389 Navigant, Let's talk numbers – retail lighting: adoption rate of led lighting, presentation for US AATCC, October 2017

The slight increase of consumption of lighting fixtures comes from a +2% for professional luminaires and around -1% for consumer lighting.

Number of companies, incl. EU market leaders

The LED lighting ecosystem comprises hardware component manufacturers, prototype designers, and original equipment manufacturers (OEMs) in the EU such as Signify (previously called and still operating under the brand Phillips from the High-Tech Campus in Eindhoven in the Netherlands), OSRAM Licht AG (Germany), Cooper Industries Inc. (Ireland) and the Zumtobel Group AG (Austria). Internationally, the key companies are General Electric Company (US), Cree, Inc. (US), Virtual Extension (Israel), Dialight plc (UK), Samsung (South Korea), and the Sharp Corporation (Japan).

Among the companies that are expanding in the European market during 2019 were Zumtobel, IKEA, Fagerhult, Yankon, Glamox, SLV, Flos, Xal. European leaders include Signify (on all the market segments), Ledvance (mainly on lamps), Eglo (consumer lighting), Flos (design), Trilux (industrial lighting), Glamox (office), Fagerhult (retail), Molto Luce (hospitality), Schréder, AEC (street lighting).

3.7.2.3. Global market analysis

Trade (imports, exports)

In 2019, the volume of lighting fixtures exports reached EUR 13,4 billion, registering an increase of 0,6% compared to the previous year. Imports of lighting fixtures in Europe reached EUR 17.1 billion in 2019, with an increase of 2,6% compared to 2018[390]. In 2019, the European trade balance recorded a deficit of EUR 3.7 billion, (EUR 3.6 billion the previous year). As the internal EU market accounted for EUR 21 billion revenue in 2019, this means that the difference of EUR 4 billion is supplied by European production[391].

Global market leaders VS EU market leaders

Table 7 Ranking of the top 10 packaged LED manufacturers

Rank	2016	2017	Change
1	Nichia	MLS	↑
2	MLS	Nichia	↓
3	Lumileds	Lumileds	stable
4	Everlight	OSRAM OS	↑
5	OSRAM OS	Everlight	↓
6	Nationstar	Nationstar	stable
7	LiteOn	LiteOn	stable
8	Honglitronic	Seoul Semiconductors	↑
9	Cree	Honglitronic	↓
10	Seoul Semiconductors	Jufei	New

Source 124 Amerlux Innovation Center, LED Energy Market Observer, Energy Observer, August 2018

[390] Center of Industrial Studies, The European market for lighting fixtures, press release, published online May 2020

[391] Georges Zissis G., Bertoldi P., Update on the Status of LED-Lighting world market since 2018, JRC Technical Report (under publication)

According to the Amerlux Innovation Center[392], the Chinese LED package market scale had a size of US$ 10 billion in 2017, representing an increase of 12% year-on-year. Among the top ten manufacturers, four are international firms, two are Taiwanese companies and four are Chinese enterprises. Amongst the top 10 manufacturers, Lumileds and OSRAM are European companies, while 4 are Chinese enterprises and another 2 are Taiwanese companies. The top ten manufacturers took up market share of 48%.

Critical raw material dependence

Metals such as arsenic, gallium, indium, and the rare-earth elements (REEs) cerium, europium, gadolinium, lanthanum, terbium, and yttrium are used in LED semiconductor devices. Most of the world's supply of these materials is produced as by-products of the production of aluminium, copper, lead, and zinc. Most of the rare-earth elements required for LED production in 2011 came from China, and most LED production facilities were located in Asia.

3.7.2.4. Future challenges to fill the technology gap

The lighting sector is evolving rapidly and changing quite fundamentally. Firstly, the market is moving towards solid state devices that consume a fraction of the energy of the older technology. These devise also create many more possibilities (colour, shape, size) to integrate lighting in the living and working environment that may change the way in which lighting markets are organised and where the added value in the lighting market may be (e.g. lighting as a service).

The high innovative capacity in manufacturing and design in the EU are based on a long tradition in designing and supplying innovative highly efficient lighting systems. But the drive towards large-scale mass production of solid-state lighting, and the fact that most LED manufacturing takes place in Asia, seems to favour Asian suppliers.

3.7.3. *District heating and cooling industry*

3.7.3.1. State of play of the selected technology and outlook

Technology development and capacity installed

District heating stands out as one of the most effective and economically viable options to reduce the heating and cooling sector's dependence on fossil fuels and reduce CO_2 emissions[393]. A smart energy system, comprising at least 50% district heating and relying on sector integration, is more efficient than a decentralised/conventional system and allows for higher shares of renewable energy at a lower cost.[394] The most important characteristic is the use of an energy source that provides a significant cost differential in generating heat/cool compared with conventional heating/cooling systems (like boilers or direct electric heating).

[392] Amerlux Innovation Center, LED Energy Market Observer, Energy Observer, August 2018

[393] EHP Country by Country Study - https://www.euroheat.org/publications/country-by-country.

[394] Towards a decarbonised heating and cooling sector in the EU – unlocking the potention of energy efficiency and district energy, Mathiesen, Brian Vad; Bertelsen, Nis; Schneider, Noémi Cécile Adèle; García, Luis Sánchez; Paardekooper, Susana; Thellufsen, Jakob Zinck; Djørup, Søren Roth, Aalborg University, 2019: https://heatroadmap.eu/decarbonised-hc-report/

It is this cost differential that finances the high capital investment in the heating/cooling network. For citywide schemes, such sources typically include combined heat and power production from major power stations or energy from waste incineration plants. For smaller communities, the heat source may be a small-scale Combined Heat-Power (CHP) plant, a biomass-fired boiler or waste heat from a local industry. Also city-wide schemes can be made up of multiple interconnected small-scale heat networks, running on locally available renewables. In both cases, thermal storage may be used to provide additional benefits. The heat is distributed using pre-insulated pipes buried directly into the ground and at each building, there will be a set of control valves and a heat meter to measure the heat supplied. A heat exchanger is typically used to separate the district heating system from the building heating system, although this is not always necessary.

In 2018, just under 6% of global heat consumption was supplied through District Heating and Cooling (DHC) networks, of which Russia and China each accounted for more than one-third[395]. DHC currently meets about 8% of the total EU heating and cooling demand via 6000 DHC networks. The share of DHC varies significantly from one region to another. District heating is by far the most common heating solution in the Nordic and Baltic regions whereas it has historically played a minor role in Southern Europe and other Central and Western European countries (e.g. Netherlands, UK).

In urban areas, the heating and cooling demand assumes the highest density. At the same time, a high amount of low-grade waste heat is available within the urban landscape[396] and could be captured as used a source for DHC systems. The industrial waste heat alone could meet the heat demand of the EU's building stock.[397]

Currently, approximately 60 million EU citizens are served by district heating, with an additional 140 million living in cities with at least one district heating system. If appropriate investments are made, almost half of Europe's renewable heat demand could be met by district heating by 2050[398]. The DHC sector has a significant green growth potential. Denmark is one of the front runners with a district heating share of about 50% and substantial exports of technology.[399]

[395] www.iea.org/articles/how-can-district-heating-help-decarbonise-the-heat-sector-by-2024

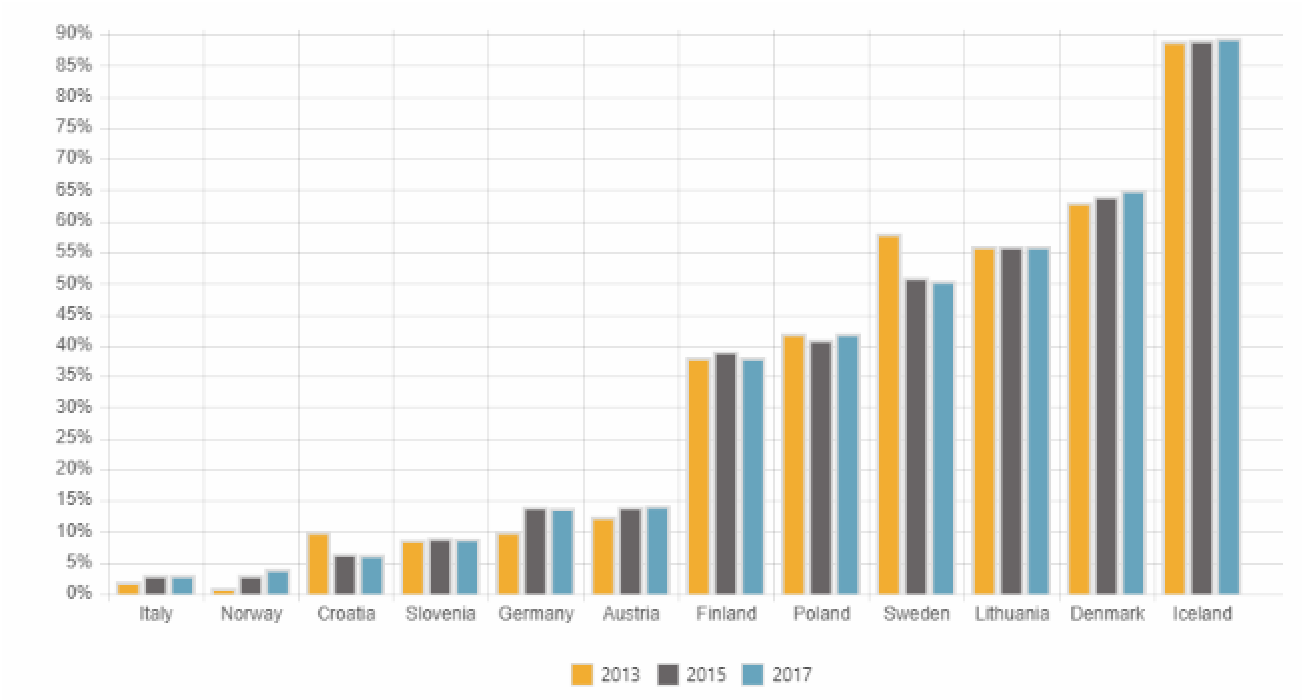
[396] Such as shopping malls, supermarkets, hospitals, metros, see www.reuseheat.eu/facts-figures/

[397] Pan-European Thermal Atlas (PETA) prepared as part of the Heat Roadmap Europe project, 2019, https://heatroadmap.eu/peta4/

[398] Towards a decarbonised heating and cooling sector in the EU – unlocking the potention of energy efficiency and district energy, Mathiesen, Brian Vad; Bertelsen, Nis; Schneider, Noémi Cécile Adèle; García, Luis Sánchez; Paardekooper, Susana; Thellufsen, Jakob Zinck; Djørup, Søren Roth, Aalborg University, 2019: https://heatroadmap.eu/decarbonised-hc-report/

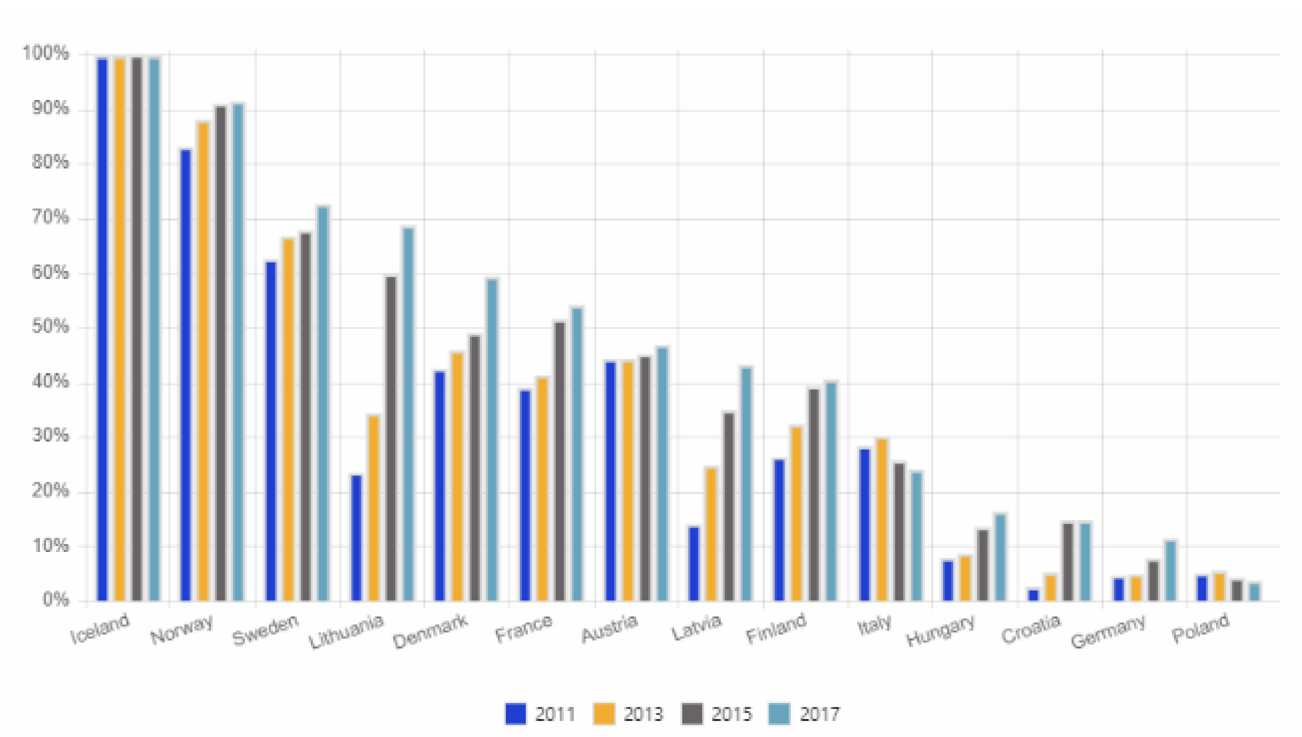
[399] It has a record 2019 year for new solar district heating installations, bringing online 10 new solar district heating plants and expanding 5 existing plants, for a total of 134 thermal MW added (compared to only 6 new plants and 4 expanded plants totalling 47 thermal MW added in 2018).

Figure 122 DH share in energy sources used to satisfy heat demand (2013-2017)



Source 125 Euroheat & Power Country by Country

Figure 123 The share of renewable energy in DH (2011-2017)



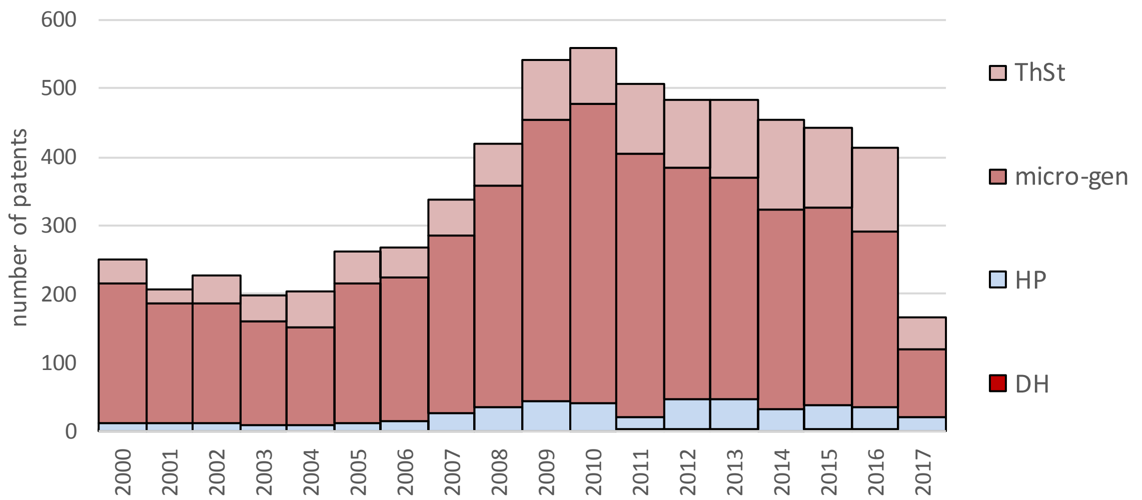
Source 126 Euroheat & Power Country by Country

Patenting trends[400]

[This section also addresses the patenting trends for thermal storage, micro-generation and heat pumps – for further information on heat pumps see the next section.]

This chapter focuses on heat pumps and district heating but most buildings patents are in micro-generation and thermal energy storage.

Figure 124 Patents in the EU by heating and cooling technology category. ThSt = Thermal storage; micro-gen = Micro-generation; HP = Heat pumps; DH = District heating.

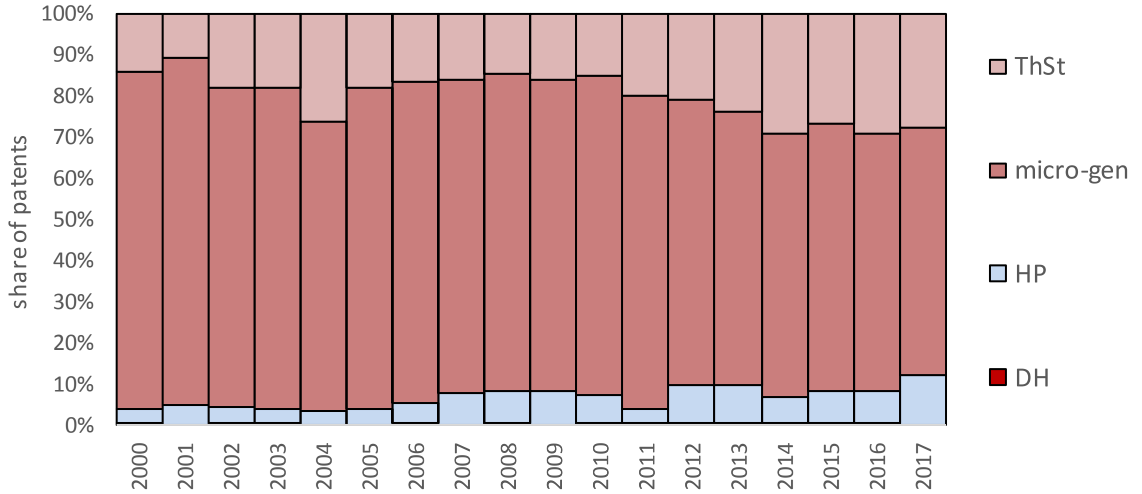


Source 127 Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

The relative trends by technology are easier to discern and more robust. Patenting activity in district heating is extremely low, due to the maturity of core technologies and the small number of companies involved. The share of heat pump patents has been steadily rising however.

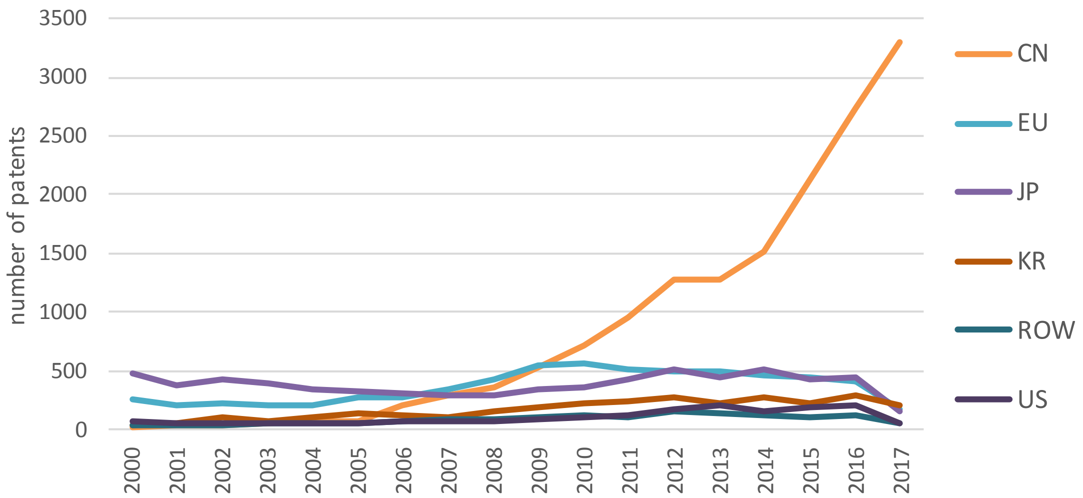
[400] This section is based on the autumn 2019 version of the PATSTAT database (JRC update: December 2019). The methodology is provided by Fiorini, A., Georgakaki, A., Pasimeni, F. and E. Tzimas (2017) *Monitoring R&I in Low-Carbon Energy Technologies*, EUR 28446 EN, Publications Office of the European Union, Luxembourg. ISBN 978-92-79-65591-3, https://doi.org/10.2760/434051; Pasimeni, F., Fiorini, A. and A. Georgakaki (2019) *Assessing private R&D spending in Europe for climate change mitigation technologies via patent data*, World Patent Information, 59, 101927. https://doi.org/10.1016/j.wpi.2019.101927; Pasimeni, F. (2019) “SQL query to increase data accuracy and completeness in PATSTAT” in *World Patent Information,* 57, 1-7, https://doi.org/10.1016/j.wpi.2019.02.001.

Figure 125 Share of patents in the EU by heating and cooling technology category. ThSt = Thermal storage; micro-gen = Micro-generation; HP = Heat pumps; DH = District heating



Source 128 Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

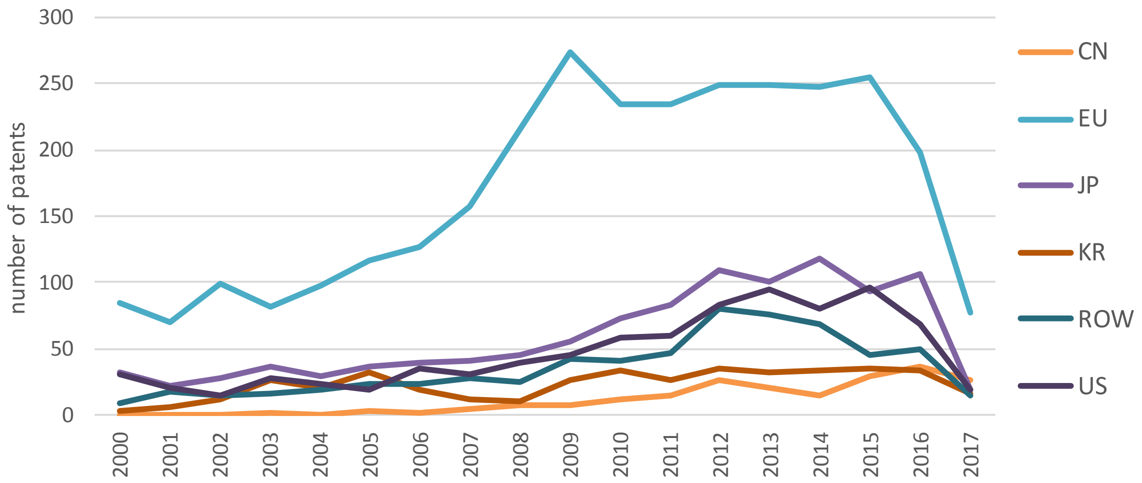
Figure 126 Number of heating and cooling patents, by region. CN = China; JP = Japan; KR = Korea; ROW = Rest of the world; US = United States



Source 129 Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

High-value inventions (or high-value patent families) refer to patent families that include patent applications filed in more than one patent office.

Figure 127 Number of high-value heating and cooling patents, by region. CN = China; JP = Japan; KR = Korea; ROW = Rest of the world; US = United States



Source 130 Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

3.7.3.2. Global market analysis

<u>Trade (imports, exports)</u>

Today Europe has the highest standards in the world in terms of energy efficiency, strengthened recently by the introduction of Ecodesign criteria for the sale of heating products. The EU commitment to ambitious energy and climate goals has paved the way for the large presence of energy efficient technologies developed in Europe.

The European heating industry is world leader in highly efficient heating systems. Today the European heating industry covers 90% of the European market and is an important exporter of heating technologies. This includes countries such as Russia, where the European heating industry is market leader, Turkey where it represents half of the market, and even in China where it plays an important role in the development and deployment of efficient heating.

Danish and other European district heating technology is exported globally, especially to China, US and South Korea. Exports to the US have risen by 91% in the period between 2010-2018. Denmark exports of district heating technology and service amounted to DKK 6.77 billion in 2018, with the biggest exports to Germany (close to EUR 140 million), followed by Sweden (close to EUR 80 million) and China (EUR 65 million)[401]. In 2025, it is expected that the sector will achieve annual exports of DKK 11 billion[402]. But Europe's solar district heating industry suffered losses in 2019, leading to some bankruptcies and

[401] Branchestatistik 2019 "Fjernvarmesektorens samfundsbidrag', https://danskfjernvarme.dk/viden/statistik-subsection/branche-og-eksportstatistik/2019

[402] Equal to 0.91 billion EUR and equal to 1.48 billion EUR at an exchange rate of 0.13 EUR/DKK, respectively: www.danskfjernvarme.dk/sitetools/english/eu-and-globally.

restructuring, among others because of high fluctuations in turnover and low margins in contracted projects[403].

Global market leaders VS EU market leaders

European companies are world leaders in the manufacture of DHC pipes, valves and related IT solutions. Danfoss is the leading pioneer in district heating and cooling equipment. In 2019, Danfoss' sales amounted to EUR 6.3 billion.

Europe is home to world-leading DHC pipe manufacturers: Logstor is the leading manufacturer of pre-insulated pipe systems in the world, being active in 12 different countries and10 factories in Europe and China. German-based Aquatherm GmbH is the leading global manufacturer of polypropylene pipe systems for industrial applications and building services. Austrian company Austroflex is recognised within the industry as an expert supplier of flexible pre-insulated Pipe Systems, thermal Solar Pipe Systems and Technical Insulation solutions. Swedish company Cetetherm is a leading manufacturer of DHC substations and has manufacturing plants in 6 countries including China and US. Devcco (based in Sweden) offers consulting services across the district energy sector and has completed projects in countries in North and South America, the Middle East and South Asia.

The systems in operation in Europe, particularly in the Nordic countries, are at the forefront of the industry in terms of innovation, efficiency, reliability and environmental benefits, in the form of renewables integration, and a reduction in both local air pollution and primary energy demand, and developing the next generations of DHC systems that require smart components and IT solutions, such as demand-side controllers, sensors, AI platforms and automated systems for heat networks. There are a number of small-scale innovative players from Europe on the market leading the development, such as NODA Intelligent Systems, OPTIT, Gradyent and Leanheat.

Critical raw material dependence

Dependency on raw materials is not an issue for district heating. Pumps may use permanent magnets but alternative technologies exist hence this use should not lead to dependence on materials. Pipes are usually from non-critical raw materials like steel or plastic.

3.7.3.1. Future challenges to fill the technology gap

The key challenge for the DHC sector is to integrate low-grade waste heat into existing high temperature DH systems. New smart networks operate at lower temperatures and are capable of integrating locally available renewable and waste heat sources.

District heating projects, including expansion of existing systems, require a large initial infrastructure investment with long payback times that make the sector vulnerable to changes in the legislative framework and mean that new DHC technologies are slow to be taken up. Replacing existing systems by more climate-neutral DHC technologies can benefit from the minimum standard for a new heating installation that is represented by the very efficient boiler condensing technology, and further measures to support the renovation of the installed

[403] REN21 Global Status Report: https://www.ren21.net/wp-content/uploads/2019/05/gsr_2020_full_report_en.pdf

stock of heaters would accelerate the positive trend. Ensuring coordinated investments between suppliers of (waste) heat and demand require a strong coordination that is often considered a public responsibility. EU policies aim to overcome these barriers through support for local (holistic) planning and decision-making and to provide incentives to consider environmental and societal advantages.[404]

Because of its large indoor appliances or installations and the need for house retrofitting consumer acceptance is key for market uptake of new DHC technologies.

Developing novel business models and capacity building may enable earlier and stronger market uptake. The challenge is to develop markets for services, rather than single technologies, as this can engage those end-users who cannot or will not interest themselves in using/maintaining technologies/measures most efficiently.[405] This can prove to be a business opportunity for companies related to energy-savings measures, H&C supply units and district energy by overcoming a main economic barrier, namely the large up-front investment costs[406].

3.7.4. *Heat pumps*

3.7.4.1. State of play of the selected technology and outlook

Introduction

Heat pumps, mostly electricity-driven, are an increasingly important technology to meet heating and cooling demand in a sustainable way[407]. They efficiently extract heat from a source at lower temperature and provide it at higher temperature. If coupled with a heat storage tank, heat pumps can store heat or cold when there is an abundance of renewable electricity in the grid and/or the electricity price is lower and provide it when needed. Heat pumps achieve higher performances[408] than conventional boilers and electric heaters and can drastically reduce emissions of the delivered energy services.[409] Heat pump (HP) technology is mature and reliable and can be integrated with other systems (e.g. photovoltaic electricity or other heat generators, such as gas boilers) and use a diverse set of (renewable) sources

[404] See also the final chapter on Smart Cities and Communities in this SWD

[405] See also chapter 3.17 on smart grids & digital infrastructure for a further analysis of the energy services market based on digital technologies.

[406] Business Cases and Business Strategies to Encourage Market Uptake - Addressing Barriers for the Market Uptake of Recommended Heating and Cooling Solutions, Heat Roadmap Europe 4, Trier, Daniel; Kowalska, Magdalena; Paardekooper, Susana; Volt, Jonathan; De Groote, Maarten ; Krasatsenka, Aksana ; Popp, Dana ; Beletti, Vincenzo; Nowak, Thomas; Rothballer, Carsten ; Stiff, George ; Terenzi, Alberto ; Mathiesen, Brian Vad, 2018: HRE4: http://vbn.aau.dk/files/290997081/HRE4_D7.16_vbn.pdf

[407] This sections focuses on heat pumps for buildings and domestic use. Heat pumps for industrial use are discussed in the section on Industrial Heat Recovery (chapter 3.12). Heat pumps driven by gas will not be discussed here as their efficiency is still low.

[408] In comparison, the minimum seasonal space heating energy efficiency for an air-to-water and water to water heat pump is 110 % in comparison to 86 % for a gas and oil boiler and 30 % for an electric boiler (source: Regulation (EU) 813/2013).

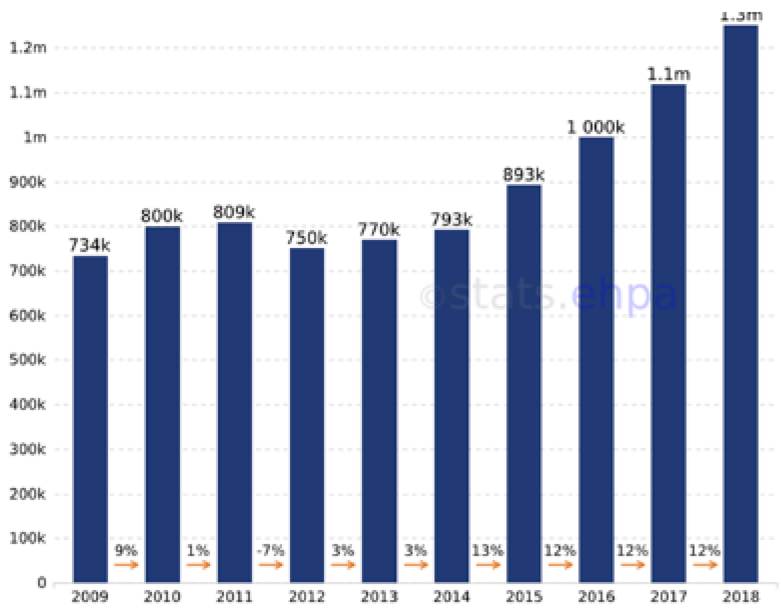
[409] Transferring the heat demand (via HP) to the power system could increase peaks during winter season (for heating), and summer (for cooling), making the electricity demand profiles (load curves) steeper and more dependent on the weather conditions.

(e.g. as an air source, water source, ground source or waste source). It comes with capacities from a few kW to several MW, to be used in applications ranging from households to industrial applications and district heating systems. Furthermore, heat pumps work in a wide range of climatic conditions and can be used in energy storage and grid management.

<u>Capacity installed, generation</u>

The yearly market demand and the related growth in unit sales in Europe is growing rapidly, as shown in Figure 128. Industry experts expect this trend to continue and potentially accelerate. At the end of 2018, total installed heat pumps in Europe was 11.8 million. Air-to-air heat pumps are most commonly used, followed by air-to-water heat pumps.

Figure 129 Heat pump market development in Europe (annual sales, 2009–2018)



Source 131 European Heat Pump Association, 2020

The largest markets in terms of units sold are the Southern European countries where heat pumps are primarily used to deliver cooling. France, Italy, and Spain together account for almost 48% of sales[410]. The largest growth in number of units in 2017 was in France, Spain and Denmark. The European Heat Pump Association foresees a doubling of the number of units sold in the period 2018 to 2025.[411] According to the National Energy and Climate Plans (NECPs), significant contributions are foreseen from heat pumps in most Member States in order to increase the share of renewables in the heating and cooling sector. The total added annual final energy consumption from heat pumps is 7.7 Mtoe from 2020 to 2030[412] according to the NECPs. When compared to the rest of the world, the EU market has lagged

[410] European Heat Pump Association, 2020, Sales, www.stats.ehpa.org/hp_sales/story_sales/
[411] European Heat Pump Association, 2020, Forecast, www.stats.ehpa.org/hp_sales/forecast/
[412] JRC Technical report, 2020, Assessment of heating and cooling related chapters of the National Energy and Climate Plans (NECPs), to be published.

behind China, Japan and the US but is now growing rapidly. The US demand is driven by installation incentives, while the development in the Asia-Pacific region is driven by construction sector growth.

The housing construction market is the largest market for heat pumps. New buildings are well insulated and thus suitable for heat pumps. However, there are increasing prospects in the housing renovation market, which accounts for high share of the building stock. Today's heat pumps can supply higher temperatures thus better meeting the energy needs of the older housing stock.

Cost

The operating costs of heat pumps are among the lowest in the heating and cooling sector. However, upfront investment cost is high, resulting in pay-back times of up to 20 years. According to recent studies[413,414] the average life time for air-to-air heat pumps would be 10 to 15 years (depending on the size) and for air-to-water heat pumps 15 to 20 years (depending on the size), meaning that capital cost reduction is a key issue for the sector.

Patenting trends

According to the Top 10 Innovators Report, the highest number of inventions originates from the Asia Pacific region (86%), with China at 58% of total inventions, followed by Europe at 9% and North America at 4%. The average IP strength score for inventions from Europe is more than that of Asia-Pacific (including China), but less than North America[415].

Stiebel Eltron and Robert Bosch are the most prominent innovators from the EU with the highest number of inventions. Siemens, Électricité de France, Robert Bosch, Vaillant, ATLANTIC Climatisation & Ventilation SAS and Viessmann Group remain active since 2010, and have high quality patent portfolios. Grundfos Management has been less active in Europe since 2010, despite having high-quality inventions. Worth noting, none of the prominent European innovators appear in the global top ten list.[416]

[further details on patents for heat pumps are included in the section above on DHC]

3.7.4.2. Value chain analysis

Turnover

The turnover generated in Europe in 2017 was EUR 7.1 billion[417]. The turnover is largest in France (EUR 1 474 million), followed by Germany (EUR 1 383 million), Italy (EUR 1 117 million) and Sweden (EUR 550 million).

[413] Review study ecodesign and energy labelling for space heaters and combination heaters, task 5, final report, VHK, July 2019

[414] Review of Regulation 206/2012 and 626/2011 air conditioners and comfort fans, task 3, final report, Armines and Viegand Maagøe, May 2018.

[415] Top 10 Innovators Report - Heat pumps, Innoenergy, December 2018

[416] Top 10 Innovators Report - Heat pumps, Innoenergy, December 2018

[417] ENER/C2/2016-501, Study on the competitiveness of the renewable energy sector, 28 June 2019

Number of companies, incl. EU market leaders

In Europe there are about 180 heat pump manufacturers accounting for 70% of the global number of manufacturers. During the last few years, major European heat pump manufacturers have been consolidating. For instance, in 2016 and 2017, the Nibe Group (based at Markaryd) acquired many assets of the UK-based Enertech Group, including the highest value brand CTC, based at Ljungby in Sweden. The CTC product range includes ground source and air/water heat pumps. In 2017, Stiebel Eltron announced the acquisition of Thermia Heat Pumps, a brand that was previously owned by the Danfoss Group. Thermia was the third biggest heat pump supplier of the Scandinavian market, with annual sales close to EUR 70 million. With this acquisition, Stiebel Eltron becomes a major global electrical heating player.

Table 8 Non-exhaustive list of European heat pump manufacturers

Company	Brand	Country
BDR Thermea	De Dietrich	France
	Sofath	France
	Chappée	France
	Remeha	Pays-Bas
	Oertli Thermique	France
	Brotje	Allemagne
Bosch Thermotechnology	Bosch	Allemagne
	Buderus	Allemagne
Daikin Industries	Daikin Europe	Belgique
	Rotex	Allemagne
Atlantic	Atlantic	France
Nibe	Nibe Energy System	Suède
	CTC	Suède
	Technibel	France
	KNV	Autriche
Vaillant Group	Vaillant	Allemagne
	Saunier Duval	France
Viessmann Group	Viessmann	Allemagne
Stiebel Eltron	Thermia	Allemagne
	Stiebel Eltron	Allemagne
Waterkotte	Waterkotte	Allemagne

Source 132 Eurobserv'er Heat Pumps Barometer (2018)

Employment figures

In 2018 the sector employed more than 224 500 people, directly or indirectly, an increase from 191 000 in 2017. However, employment in the sector has declined by 20% between

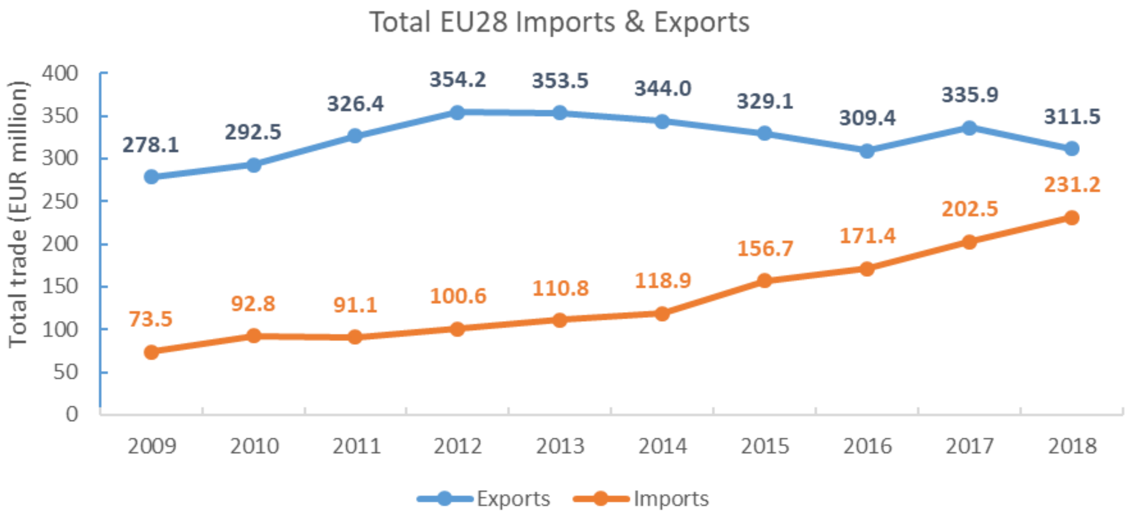
2015 and 2017. The Member States that employ by far the most are Spain (68 700), France (41 200) and Italy (37 600).[418]

3.7.4.3. *Global market analysis*

<u>Trade (imports, exports)</u>

Between 2009 and 2018, EU-28 exports to the rest of the world were relatively stable at about EUR 0.3 billion, with a peak in 2012/13 of EUR 0.4 billion. For the 2016-2018 period, the EU28 share of global exports was stable - roughly 1%. Top EU exporters were France, Germany and Italy. For the same period, four out of the top ten global exporters were EU countries. Key competitors were China, Mexico and the US. In addition, for the 2016-2018 period, three out of the top five global importers were European countries. The US was the largest importer followed by Germany, France and the UK.[419]

Figure 130 EU28 Trade in the heat pump value chain (EUR million)



Source 133 ICF, 2020

<u>Global market leaders VS EU market leaders</u>

The European heating industry is a well-established economic sector and a world leader in highly efficient heating systems. The European heat pump sector is characterised by a few, mostly large corporations and a relatively small ecosystem with some innovative SMEs. The heat pump value chain is well represented through a number of industry associations – most notably the European Heat Pump Association (EHPA).

Globally, Japanese (Daikin, Mitsubishi, Toshiba, Fujitsu, Panasonic) and South-Korean (LG, Samsung) manufacturers mainly produce residential and commercial air-to-air and air-to-

[418] Eurobserv'er Heat Pumps Barometer (2018): https://www.eurobserv-er.org/online-database/#
[419] ICF study for DG GROW, to be published

water heat pumps, while US manufacturers (Trane, Carrier/UTC, Johnson Controls, Honeywell, Lennox) produce mainly chillers for large commercial buildings.[420]

Critical raw material dependence

Critical raw materials used are mainly copper in the heat exchanger and the gold in the printed circuit boards (PCBs).[421]

3.7.4.4. Future challenges to fill the technology gap

The IEA has recently identified three gaps to fill: Enhance heat pump flexibility; raise heat pump attractiveness; and reduce costs of heat pump technologies.[422] A stakeholder consultation in the framework of the Horizon Europe work programme[423] highlighted as issues to address the high upfront prices and a lack of adaptability to multiple building contexts (e.g. multi-family residential buildings with limited outdoor space for exterior heat pump units) that needs to be addressed in particular by lowering device dimensions.

Reaching higher real life energy performances through the development of new texting methods that reflect real life usage behaviour better are important too.

Considering the growth potential of heat pumps in the EU, and the fact that it is a key technology for the decarbonisation of heating and cooling, it is important to keep on promoting innovative technological solutions in Europe, so manufacturers can distinguish themselves based on quality and innovation rather than on price. Improving existing (ecodesign and energy labelling) regulations and updating the requirements can contribute to innovation in the EU.

3.8. Carbon Capture and Storage

3.8.1. *State of play of the selected technology and outlook*

Reaching climate neutrality by 2050 requires strategic investment decisions. The pathway towards climate neutrality will bring about a major transformation of energy-intensive industries, such as cement, lime, steel and chemicals that are at the core of the European economy by producing basic industrial materials and products. For these sectors, carbon capture and storage (CCS) could represent the lowest-cost route to decarbonisation while maintaining industrial activity[424] in Europe. CO2 capture in natural gas-based hydrogen plants

[420] Review study ecodesign and energy labelling for space heaters and combination heaters, task 2, final report, VHK, July 2019

[421] Review of Regulation 206/2012 and 626/2011 air conditioners and comfort fans, task 5, final report, Armines and Viegand Maagøe, May 2018.

[422] IEA Innovation Gaps, Key long-term technology challenges for research, development and demonstration, Technology report — May 2019

[423] Input Paper for the SRIA for the CET, Stakeholder Cluster: Heating & cooling, to be published

[424] Zero Emissions Platform, "Climate Solutions for EU industry", 2017

could also enable the delivery of early, large-scale quantities of low-carbon hydrogen[425], which is a versatile energy vector that can be used across a number of sectors: energy intensive industries, transport, electricity production, and buildings, and it can also play an important role for zero-carbon domestic heating.

The Commission's 2018 analysis of different CO2 reduction pathways[426] showed a correlation between increasing climate ambition (i.e. pathways compatible with the 1,5ºC temperature target) and the need for deploying Carbon, Capture and Storage technologies. The Communication states that 'CCS deployment is still necessary, especially in energy intensive industries and – in the transitional phase - for the production of carbon-free hydrogen. CCS will also be required if CO2 emissions from biomass-based energy and industrial plants are to be captured and stored to create negative emissions'.

The in-depth analysis further elaborates on the modelling: 'For the 1.5°C scenarios, the higher carbon prices allow the appearance of CCS from 2040, with 54 / 58 MtCO2 captured (for 1.5LIFE / 1.5TECH respectively), increasing to 71 /80 MtCO2 in 2050 and further to 112 / 128 MtCO2 post-2050'.

Table 9 Carbon capture and stored underground (MtCO2) in different CO2 reduction scenarios

CCS	Baseline	ELEC	H2	P2X	EE	CIRC	COMBO	1.5TECH	1.5LIFE	1.5LIFE-LB
Power	5	6	7	16	4	7	7	218	9	20
Industry	0	59	57	61	60	44	60	81	71	71
Total	5	65	63	77	65	52	67	298	80	92
*from Biomass**	0	5	6	6	4	5	6	178	6	14

Source 134 PRIMES model; In-depth analysis in support to the "A Clean Planet for all" Communication, 2018

The Commission's proposal for a European Green Deal[427] confirmed that achieving climate neutrality by 2050 will be the European Union's overarching climate goal, which will orient policies and investments. This development put the LTS 1,5 TECH and LIFE scenarios at the centre, and implied that the deployment of CCS at scale will be necessary. Correspondingly, the Green Deal Communication highlights CCS in two policy contexts:

- it recognizes that the regulatory framework for energy infrastructure, including the TEN-E Regulation, will need to be reviewed to ensure consistency with the climate neutrality objective. This framework should foster the deployment of innovative technologies and infrastructure, such as smart grids, hydrogen networks or carbon capture, storage and utilisation, energy storage (CCUS), also enabling sector integration;
- it calls for 'climate and resource frontrunners' in the European industrial sectors to develop the first commercial applications of breakthrough technologies in key

[425] For renewable hydrogen through electrolysis, see chapter 2.2.1.6.
[426] European Commission (2018). IN-DEPTH ANALYSIS IN SUPPORT OF THE COMMISSION COMMUNICATION COM(2018) 773 A Clean Planet for all A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy.
[427] Communication (COM(2019) 640)

industrial sectors by 2030. Priority areas include clean hydrogen, fuel cells and other alternative fuels, energy storage, and carbon capture, storage and utilisation.

Other European Commission Communications that followed the European Green Deal mentioned CCUS, including: the Industrial Strategy, the Circular Economy Action Plan, the Strategy for Energy System Integration, the Hydrogen strategy and, finally, the European Taxonomy on Sustainable Finance.

Capacity installed, generation

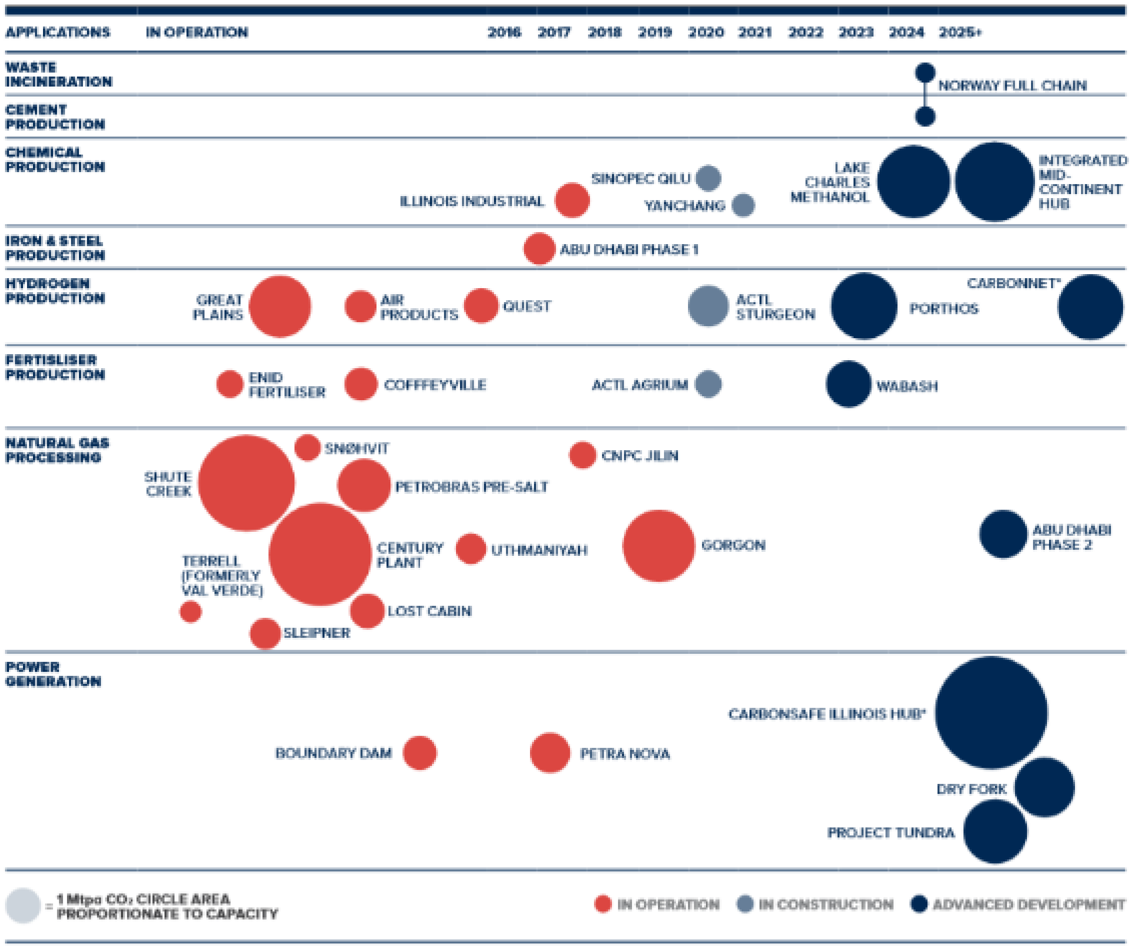
The 2019 report of the Global CCS Institute identified 51 large-scale CCS facilities worldwide.[428] Of these: 19 are operating, 4 are under construction, 10 are in advanced development using a dedicated front-end engineering design (FEED) approach, and 18 are in early development. Right now, those in operation and construction have the capacity to capture and permanently store around 40 million tons of CO2 every year. This is expected to increase by about one million tons in the next 12-18 months. In addition, there are 39 pilot and demonstration scale CCS facilities (operating or about to be commissioned) and nine CCS technology test centres (including the Technology Centre Mongstad in Norway).

2 of the 19 operating CCS projects are in Norway and they store a combined 1,7 MtCO2 per year. In addition, Norway's government-backed full-chain CCS project (Longship) is in Final Investment Decision phase, awaiting the Parliament's approval.

In the EU, there are no large-scale CCS facilities in operation. However, the Netherlands' flagship PORTHOS project in the Port of Rotterdam area is in advanced planning phase, closely followed by Amsterdam's ATHOS project. In Ireland, Ervia is planning an off-shore CO2 storage project South of Cork. The total storage capacity of these sites, if implemented, together with six CCS projects in the UK, could add up to as much as 20,8 Mt of CO2 stored per annum, according to the Global CCS Institute.

428 Global Status of CCS, 2019 by the Global CCS Institute. https://www.globalccsinstitute.com/resources/global-status-report/

Figure 131 Large scale CCS facilities in operation, under construction and in advanced development, by sector (status in 2019)



Source 135 Global status of CCS 2019, Report of the Global CCS Institute

In a global perspective, the IEA estimates that some 1030 MtCO2[429] will need to be captured and stored from industry by 2040, and an additional 1 320 MtCO2[430] from power to keep on track with the IEA's Sustainable Development Scenario (compatible with the Paris Agreement).

A significant share of that may be deployed to produce "negative emissions" via biomass or biogenic waste combustion coupled with CCS (BECCS). The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) suggests a potential range of negative emissions from BECCS of 0 to 22 gigatonnes per year.

Considering the capacities of today (33 MtCO2/year captured globally, out of which 1,7 MtCO2/year in Norway), the CCS sector needs a huge global step change in all relevant

[429] IEA (2020), CCUS in Industry and Transformation, IEA, Paris https://www.iea.org/reports/ccus-in-industry-and-transformation

[430] IEA (2020), Large-scale CO2 capture projects in power generation in the Sustainable Development Scenario, 2000-2040, IEA, Paris https://www.iea.org/data-and-statistics/charts/large-scale-co2-capture-projects-in-power-generation-in-the-sustainable-development-scenario-2000-2040

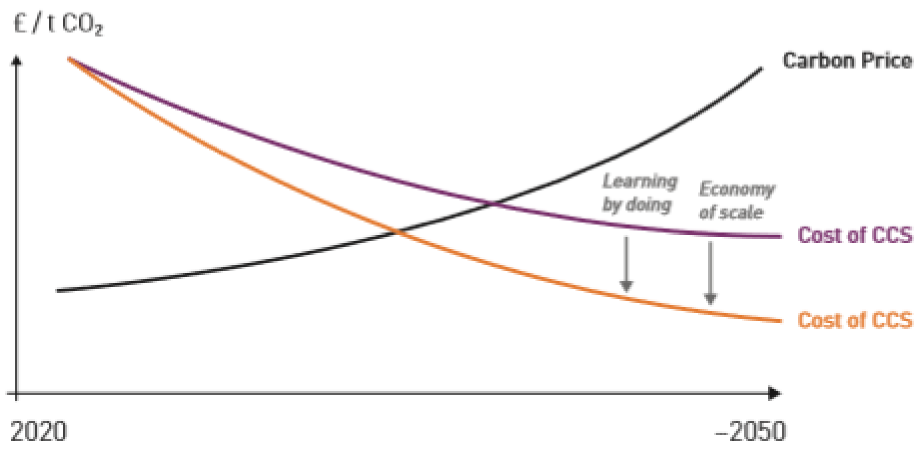
sectors (power, industry, hydrogen) in order to fill in the significant role envisaged in some decarbonisation pathways.

Cost, LCOE

The upfront investment costs of CO2 transport and storage are considerable, however, not all needs to be built at once, the infrastructure can be progressively expanded. In some instances, investments to retrofit existing natural gas pipeline networks into CO2 pipeline networks can be advantageous and cut initial costs of infrastructure. Over time, the initial infrastructure will be progressively expanded to accommodate increasingly volumes of CO2.

At the same time CO2 emitters (power plants, industrial sites) can install CO2 capture solutions to trap their emissions and load them into the transport and storage infrastructure. This often comes not only with a higher CAPEX but also higher OPEX due to energy penalties and maintenance, which on their turn bear on the competitiveness of these clean products relative to unabated, high carbon products. In the same way as for every other low-carbon investment, in the absence of a "functional" (global) carbon price (min. EUR 50-60/tCO2), investment in CCS will have no business case today and will largely depend on public funding and policy and/or regulatory incentives (e.g. to purchasing zero-carbon products, such as clean steel or cement). It is thus crucial to fund R&I activities to develop an infrastructure backbone and reduce costs.

Figure 132 The Carbon price and CCS cost curves



Source 136 Scaling up CCS in Europe, IOGP Fact sheet, September 2019

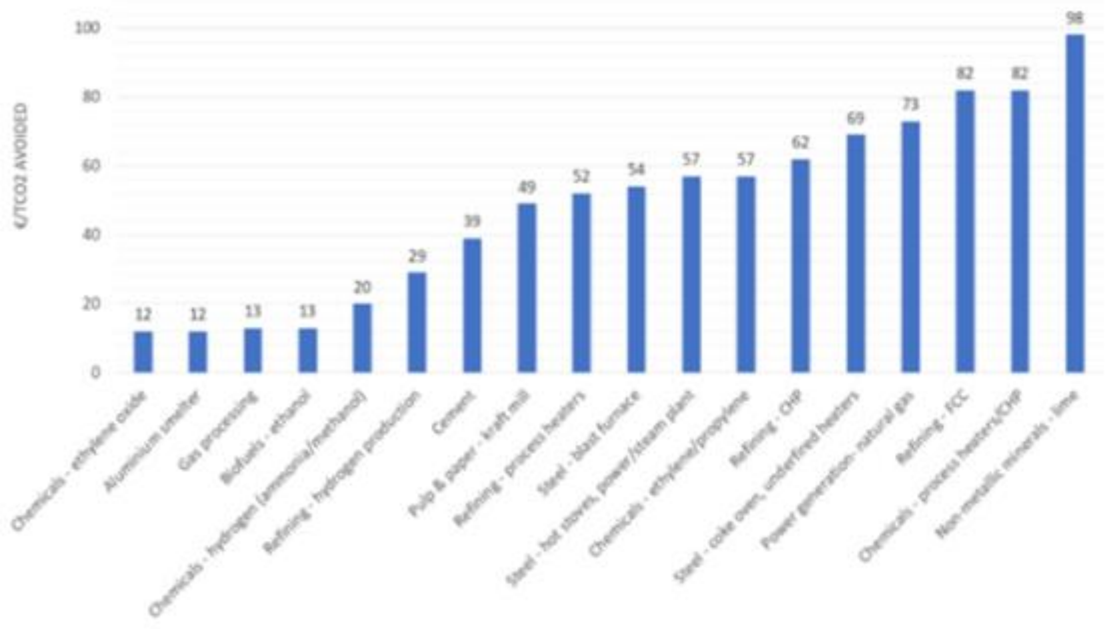
Costs of CO2 capture[431]

CO2 capture is typically the largest cost component in the CCS and CCU (carbon capture and use) value chain, as a result of the technology costs and energy requirements. Costs of capture equipment are determined by the percentage volume of CO2 in the flue gas from which it is captured. As the Figure below shows, the higher the CO2 purity, the lower the cost in terms of CO2 avoided. In addition, the figure highlights that indicative carbon capture for

[431] The potential for CCS and CCU in Europe. Report to the thirty second meeting of the European Gas Regulatory Forum 5-6 June 2019, coordinated by IOGP. https://ec.europa.eu/info/sites/info/files/iogp_-_report_-_ccs_ccu.pdf

many processes is currently more expensive than the EU ETS price and will need support in the near-term. Higher purity sources of CO2 include hydrogen production from reforming natural gas, and ethanol and ammonia production. Many current and emerging capture technologies are engineered to remove 80% - 90% of the CO2 from flue gas. Higher capture rates are possible, with the H21 North of England project having modelled 95% capture rates. Recent work by the IEAGHG suggest that 99% capture rates on combined cycle gas turbines (CCGT) are achievable with an increased cost below 10% compared to 90% capture rates.[432]

Figure 133 Overview of median carbon capture costs in various industrial processes



Source 137 (adapted by IOGP): Navigant (2019). Gas for Climate. The optimal role for gas in a net-zero emissions energy system, Appendix E

<u>Costs of CO2 transport[433]</u>

On the basis of existing and planned CCS and CCU projects in Europe, the key options for CO2 transportation are pipeline transport using new or repurposed infrastructure, and shipping. CO2 transportation by ship will benefit from future standardization of the key ship components, including connection valves and flanges between ship and storage facilities, as well as optimization of the size and number of CO2 transport vessels to efficiently match the CO2 volumes. Equipment standardization will also increase the potential for cost reduction and will facilitate the construction and deployment of new CO2 transport ships relatively quickly using a "design one, build many" strategy.

[432] IEA Greenhouse Gas Programme: 2019-03 Review of Fuel Cell Technologies with CO2 Capture for the Power Sector. https://www.ieaghg.org/publications/technical-reports/reports-list/9-technical-reports/950-2019-03-review-of-fuel-cell-technologies-with-co2-capture-for-the-power-sector

[433] The potential for CCS and CCU in Europe. Report to the thirty second meeting of the European Gas Regulatory Forum 5-6 June 2019, coordinated by IOGP. https://ec.europa.eu/info/sites/info/files/iogp_-_report_-_ccs_ccu.pdf

Repurposing offshore oil and gas pipelines to transport CO2 to depleted oil and gas fields or saline aquifers suitable for CO2 storage can help to avoid installing new offshore infrastructure. The costs savings of reusing existing infrastructure, which would otherwise be decommissioned, depends on the condition of the existing pipelines, as well as any necessary technical interventions, e.g. installing additional concrete mattresses or repairing corrosion.

Reusing offshore oil and gas pipelines to transport CO2 may represent 1 – 10% of the cost of building a new CO2 pipeline. Offshore CO2 pipelines costs can vary between EUR 2–EUR 29/tCO2. Costs for ship transport range between EUR 10 – EUR 20/tCO2 and this option is usually preferable when smaller volumes need to be transported over longer distances. For onshore transportation of CO2 from industrial and power facilities to the storage location or port, gas infrastructure companies are exploring both the repurposing of existing gas pipelines, and also new-build CO2 pipelines.

Costs of CO2 storage[434]

The cost of CO2 storage depends from location to location. The storage capacity in deep saline aquifers is much greater compared to onshore basins or offshore depleted oil and gas fields; these deep saline formations therefore have a better scaling-up and cost reduction potential. The upfront storage costs are lower in depleted oil and gas fields due to the presence of infrastructure that can be (re)used for CO2 injection. However, risks associated with securing legacy wells for storage operations may add additional risks and costs. Storage costs, while much lower than capture costs, are site dependent and require some upfront investment in mapping and understanding storage complexes (including, e.g. formation pressures, reservoir characteristics, cap rock efficiency, faults, trapping structures, mineralogy, salinity); estimating storage capacity; and designing infrastructure. Well costs are usually the highest component.

CO_2 geological storage is a safe and mature technology ready for broad implementation, as evidenced by over twenty years of successful storage offshore in Norway, combined with more recent onshore storage in Canada and the US. In the EU, CCS benefits from a clear set of regulations and requirements under the 2009 EU CO_2 Storage Directive that ensure the identification of appropriate storage sites and the safety of subsequent operation[435]. In the U.S. the recent 45Q tax bill, which provided a 55 USD support for every tons of CO2[436] stored underground, and 35 USD/ton[437] for enhanced oil recovery, proved to be a sufficient incentive for some industries. In Norway, two large-scale CCS projects are in operation: Sleipner (1996) and Snøhvit (2008). Both projects capture CO2 from natural gas processing. The business case is found in the otherwise payable CO2 tax (EUR ~40/t).

According to a paper of the the Zero Emissions Platform European Technology and Innovation Partnership (ZEP), in a mature CCS industry, the technical cost of storing CO2 in

[434] The potential for CCS and CCU in Europe. Report to the thirty second meeting of the European Gas Regulatory Forum 5-6 June 2019, coordinated by IOGP. https://ec.europa.eu/info/sites/info/files/iogp_-_report_-_ccs_ccu.pdf

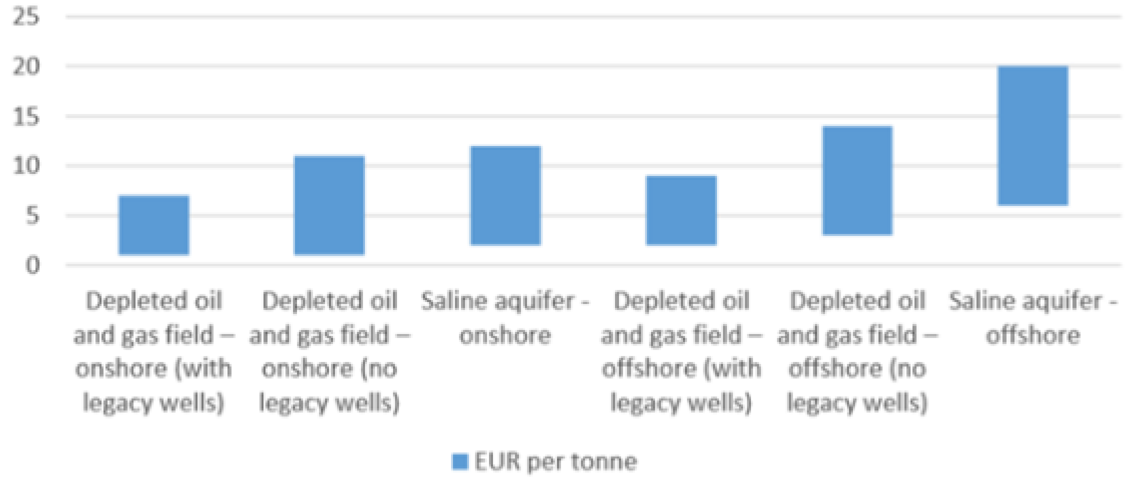
[435] ZEP paper from November 2019: CO2 Storage Safety in the North Sea: Implications of the CO2 Storage Directive (https://zeroemissionsplatform.eu/co2-storage-safety-in-the-north-sea-implications-of-the-co2-storage-directive/)

[436] EUR 46,8 (1 USD = 0,85 Euro)

[437] EUR 29,79 (1 USD = 0,85 Euro)

offshore storage reservoirs is expected to lie in the range EUR 2 – 20/tonne; adding transport and compression cost will bring this in the range of EUR 12 – 30/tonne[438].

Figure 134 Storage costs in the EU28 per formation type



Source 138 IOGP from: ZEP (2011). The Costs of CO2 Capture, Transport and Storage

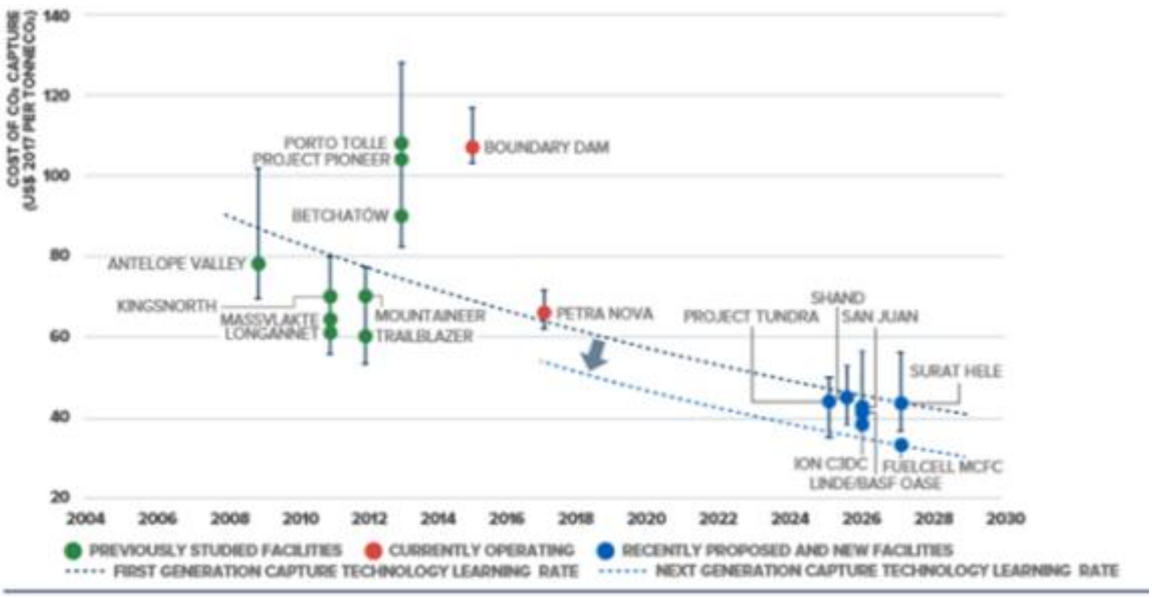
Learning curves[439]

The cost reductions for CCS value chain are strongly connected to local and regional developments and to the introduction and adoption of EU policies and funding mechanisms. Shared CO2 transport and storage infrastructure - connecting industrial clusters and allowing numerous emitters to benefit from CCS applications – can deliver economies of scale and decrease the transport unit cost.

There is strong evidence that capture costs have already reduced in the U.S. The Figure below shows estimated costs from a range of feasibility and front end engineering and design (FEED) studies for coal combustion CCS facilities using mature amine-based capture systems. Two of the projects, Boundary Dam and Petra Nova are operating today. The cost of capture reduced from over USD100[440] per tonne CO2 at the Boundary Dam facility to below USD65[441] per tonne CO2 for the Petra Nova facility, some three years later. The most recent studies show capture costs (also using mature amine-based capture systems) for facilities that plan to commence operation in 2024-28, cluster around USD 43[442] per tonne of CO2. New technologies at pilot plant scale promise capture costs around USD 33[443] per tonne of CO2.

[438] ZEP paper from January 2020 on cost of CO2 storage (https://zeroemissionsplatform.eu/wp-content/uploads/Cost-of-storage.pdf).
[439] Global Status of CCS, 2019 by the Global CCS Institute. https://www.globalccsinstitute.com/resources/global-status-report/
[440] EUR 85.1 (1 USD = 0.84 EUR)
[441] EUR 55.3 (1 USD = 0.84 EUR)
[442] EUR 36.6 (1 USD = 0.84 EUR)
[443] EUR 28.1 (1 USD = 0.84 EUR)

Figure 135 Levelised cost of CO2 capture for large-scale post-combustion facilities at coal-fired power plants, including previously studied facilities



Source 139 Global status of CCS 2019, Report of the Global CCS Institute

In the EU, new industrial-scale CCS projects may become operational in this decade with sufficient support and coordination. Most importantly, the five Projects of Common Interest funded by the EU's Connecting Europe Facility, all aiming to build cross-border CO2 pipelines as part of larger CCS infrastructures: Northern Lights (Norway), PORTHOS/CO2 TransPorts and ATHOS (both in the Netherlands), ERVIA CCUS (Ireland), Acorn/Sapling (UK).[444]

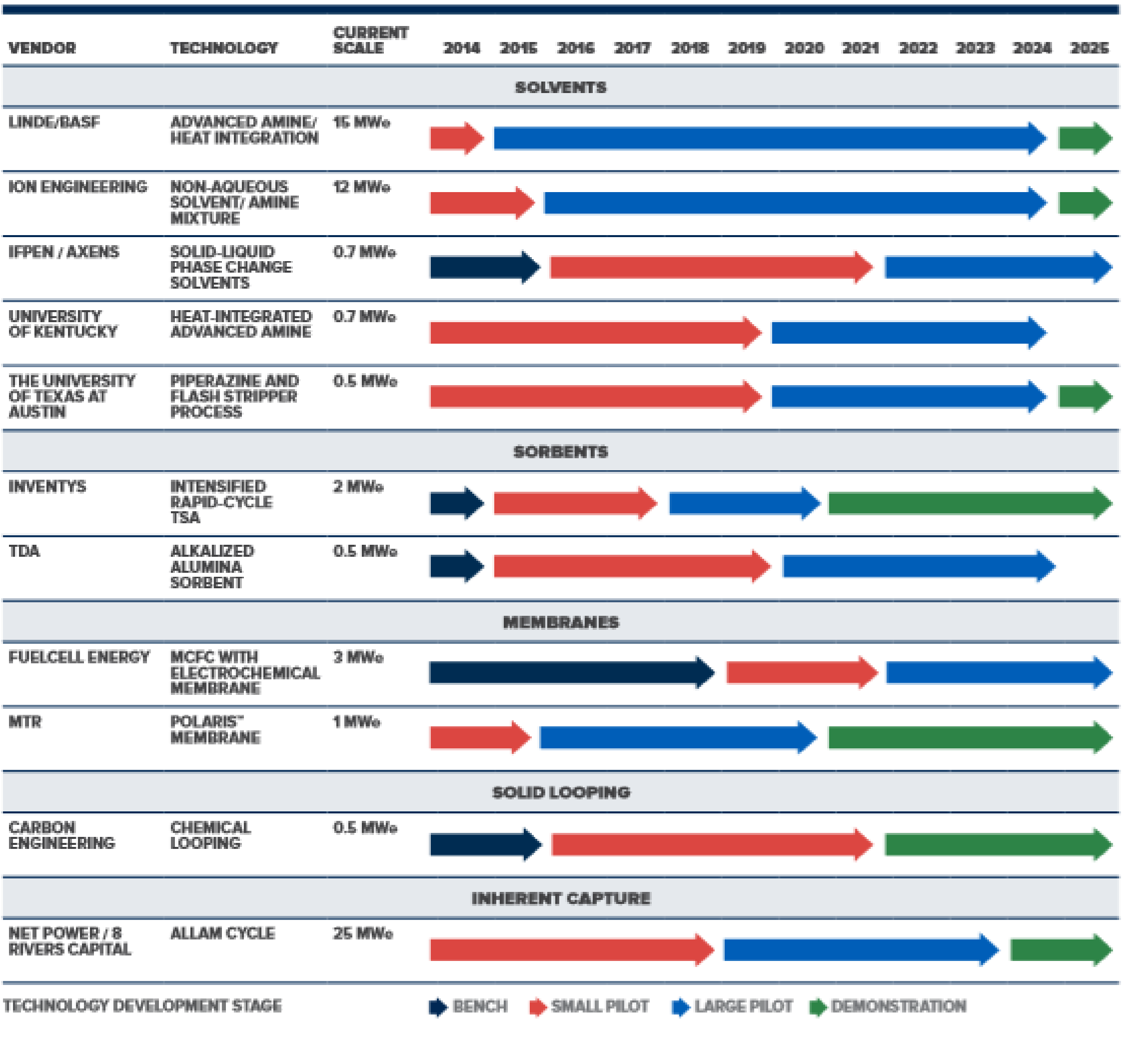
Energy intensive sectors have also started putting up projects, which, once scaled up, can make these players part of the climate solution. Recent hydrogen projects include H2M (clean hydrogen), H2morrow (clean hydrogen for clean steel production), HyDemo (clean hydrogen for maritime sector) and H-Vision. Industrial CO2 capture projects include ViennaGreenCO_2 (solid sorbent capture technology pilot), Technology Centre Mongstad (post-combustion capture technologies), Norcem (capture from cement plant), LEILAC project (Pilot installation for breakthrough technology in cement production)[445].

Knowledge sharing across these and other projects should help with improving CCS technologies while bringing down their costs. The Global CCS Report 2019 estimates that next-generation capture technologies have unique features – either through material innovation, process innovation and/or equipment innovation – which reduce capital and operating costs and improve capture performance.

[444] See: Annex to the Delegated Regulation establishing the EU's 4th PCI list. https://ec.europa.eu/energy/sites/ener/files/c_2019_7772_1_annex.pdf

[445] ZEP (2020): A CCS industry to support a low-carbon European economic recovery and deliver sustainable growth, https://zeroemissionsplatform.eu/a-ccs-industry-to-support-a-low-carbon-european-economic-recovery-and-deliver-sustainable-growth/

Figure 136 Selected next-generation capture technologies being tested at 0,5MWe (10 T/D) scale or larger with actual flue gas



Source 140 Global status of CCS 2019, Report of the Global CCS Institute

The learning opportunities go beyond individual sectors. In fact, the development of the CCS infrastructure requires close cross-sectoral (and sometimes cross-border) cooperation among point sources of CO2 emissions (cement, steel, chemical, hydrogen, etc.) and the transport and storage providers. Integrated CCS infrastructure planning and development will hence be one of the major challenges of the decade.

R&I[446]

The EU has been long-time supporting research and innovation in CO2 capture and storage through its successive R&I framework programmes (e.g. FP7: 2007-2013; Horizon 2020:

[446] For more details see the joint paper of ZEP and the European Energy Research Alliance (EERA): Priorities on CCUS R&I activities (https://zeroemissionsplatform.eu/wp-content/uploads/ZEP-input-CCUS-RI-priorities-1.pdf)

2014-2020). CO2 capture in industrial plants has become particular area under Horizon 2020, with focus on the cement sector (e.g. the CEMCAP, LEILAC and CLEANKER projects) and steel making (e.g. STEPWISE and C4U). CO2 storage research has also continued receiving support (e.g. STEMM-CCS, ENOS, SECURe and CarbFix2).

For joint R&I priority setting and funding, the Commission established stakeholder-driven platforms under the Strategic Energy Technology (SET) Plan[447], which typically include Member States, as well as industrial and R&I stakeholders. These platforms include the CCS Implementing Working Group of the SET Plan (which is Member State driven), the Zero Emissions Platform European Technology and Innovation Partnership (which is stakeholder driven)[448] and the CCUS Project Network[449] (which is project-driven).

In the 2020 decade, industrial scale CCS and CCU projects will generate many new challenges that can best be solved by undertaking R&I in parallel with large-scale activities. Therefore, under Horizon Europe, the EU's now starting R&I programme, will have to focus on industrial clusters. An iterative process is needed where R&I projects address specific industrial challenges, including those related to negative emissions, with the results then implemented and published by large-scale projects. For example, pilot projects still have an important role to study the potential long-term impacts of varying flow rate and composition on CO2 pipeline, wellbore and reservoir integrity. Further knowledge will help large-scale projects establish the safe limits within which pipelines and wells can be operated.[450]

Priority research topics (from laboratory to pilot scales) may include the following areas:

- CO2 capture in industrial clusters;
- CO2 capture in power applications;
- technological elements for capture and application;
- CCS and CCU transport systems;
- CO2 Storage;
- standardisation and legislation issues, and non-technological elements.

In view of longer-term CCS infrastructure development, a mapping of European CO2 storage assets and the implementation of a European storage development/appraisal programme is considered necessary. This is to optimise development and investment decisions against regional characteristics, resources and CO2 reduction pathways.

The revision of the CCS Implementation Plan of the SET Plan will reflect these needs.

<u>Public R&I funding[451]</u>

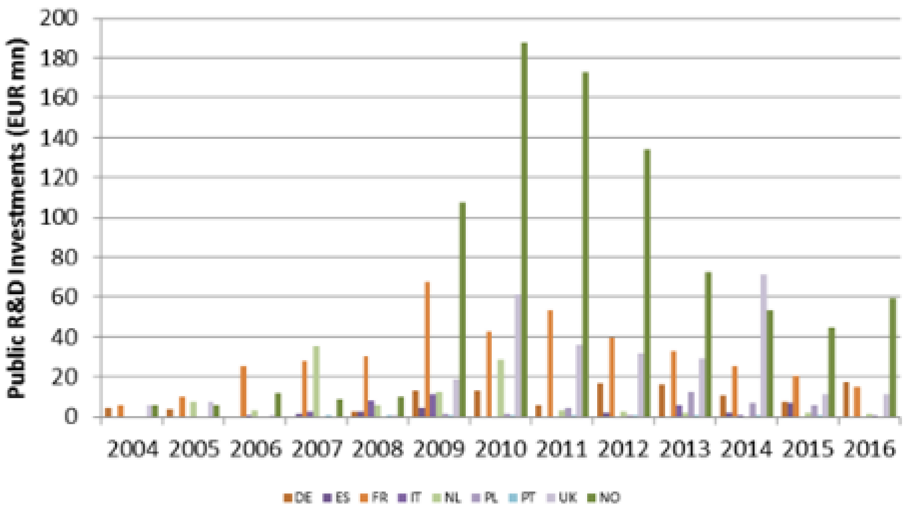
National and EU public funding for CCS R&I continues being very important. The EU's Horizon 2020 programme has provided close to EUR 240 million for carbon capture, use and

[447] https://ec.europa.eu/energy/topics/technology-and-innovation/strategic-energy-technology-plan_en#key-action-areas
[448] https://zeroemissionsplatform.eu/about-zep/zep-structure/
[449] https://www.ccusnetwork.eu/
[450] Briefing on Operational Flexibility for CO2 Transport and Storage, EU CCUS Project Network (2020) www.ccusnetwork.eu/
[451] Kapetaki Z., Miranda Barbosa E., Carbon Capture Utilisation and Storage Market Development Report 2018, JRC118310

storage projects during the 2014-2020 period. In the future, the Innovation Fund, which among other renewable and low-carbon energy technologies will also support CCS, will be instrumental for realising a new wave of CCS demonstrators and first-of-a-kind facilities in Europe. Horizon Europe, the EU's new research and innovation framework programme will support not only the development of a new generation of CCS technologies, but also the necessary stakeholder engagement and knowledge sharing activities needed for the rollout of complex industrial CCS projects and infrastructure.

Government or public R&D investment can have a significant positive effect on the development and deployment of the CCS technology. It creates a positive environment for private initiatives, and affects among others the number of relevant publications and patent applications.[452] Public R&D investment from 2004 to 2016 in the European Economic Area (EEA), is shown in the following figure. Since 2009, Norway is the largest investor in CCUS R&D in terms of public funds, except from 2014 when it was overtaken by the UK.

Figure 137 Public R&D investments in CCUS for the EEA (top countries)



Source 141 JRC 2018 'Data collection and analysis on R&I investments and patenting trends in support of the State of the Energy Union Report' based on 2018 IEA RD&D Statistics. Available at: https://www.iea.org/statistics/RDDonlinedataservice/

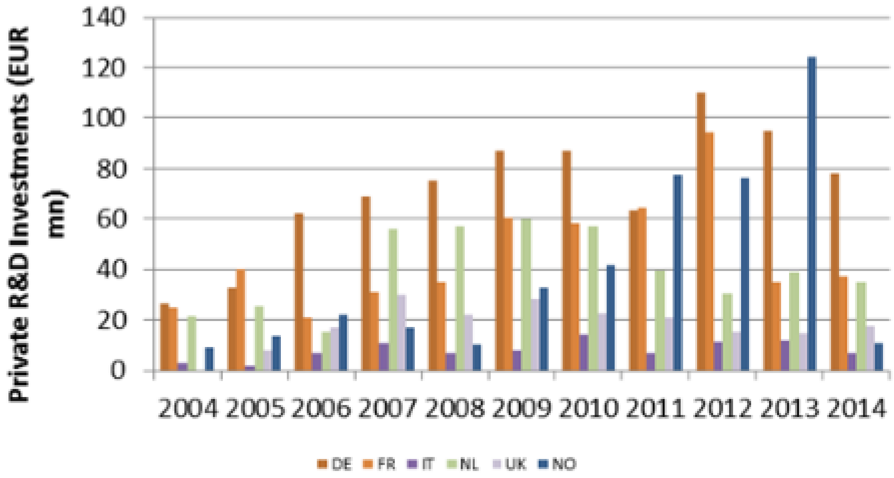
<u>Private R&I funding</u>

On private R&I funding, JRC analysis[453] showed that amongst the countries most highly investing in CCUS, public to private R&D investments were mostly leveraged in Germany, followed by the Netherlands and France. This means that these countries noted significantly higher private investments compared to the public ones.

[452] In-house JRC methodology (Fiorini et al., 2017; Pasimeni, Fiorini and Georgakaki, 2018), monitored Research Innovation and Competitiveness in the Energy Union R&I priorities.

[453] Kapetaki Z., Miranda Barbosa E., Carbon Capture Utilisation and Storage Market Development Report 2018, JRC118310

Figure 138 Private R&D investments in CCUS for the EEA (top countries, based on available data)



Source 142 JRC 2018 'Data collection and analysis on R&I investments and patenting trends in support of the State of the Energy Union Report'

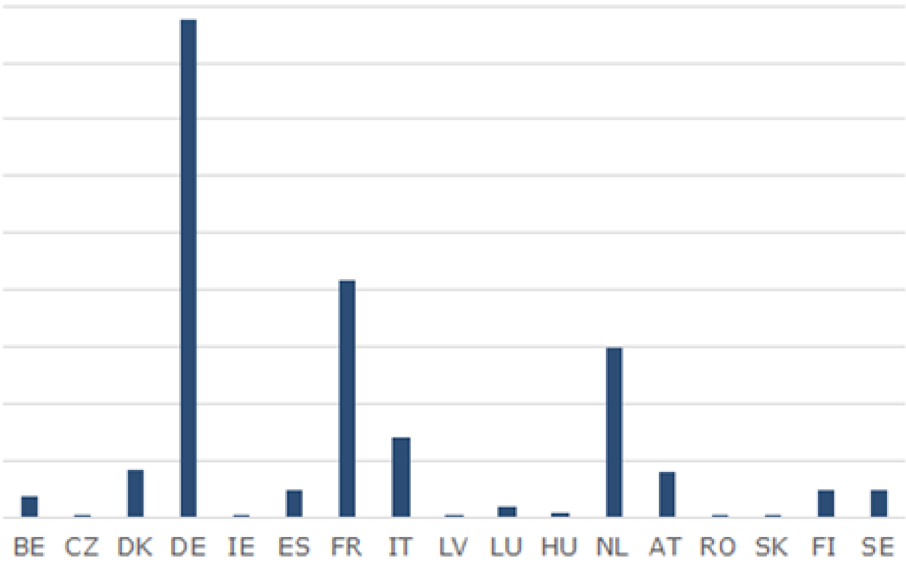
<u>Patenting trends[454]</u>

To identify trends, the JRC analysed the "inventive activity" of EU companies in certain technologies, i.e. the family of patents relevant to the technologies. The inventive activity from 2006 to 2016 showed that capture by absorption peaked in 2009 surpassing all the other technologies considered. In 2011 it was surpassed by capture with chemical separation and capture by adsorption has been the major trend ever since. According to the data, patent families related to CO_2 storage peaked in 2009 and 2015 but have been generally stable.

The following graphs indicate trends of inventive activity per year in different technologies as well as most active countries (hence no y-axis presented). The following figures show activity of companies of European Member States in each component of CCUS. Germany dominated activity in CO_2 capture technologies, followed by France and the Netherlands. These countries were also among the four countries with interest in CO_2 storage, together with Austria.

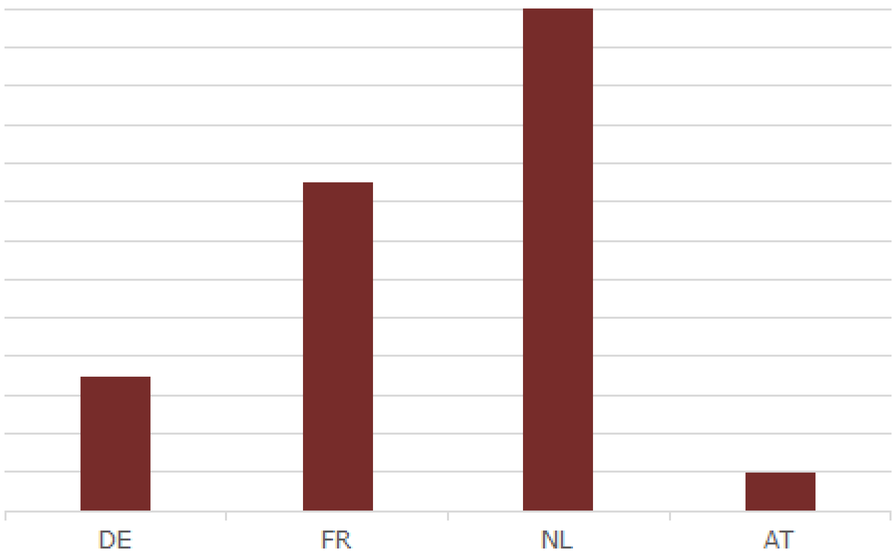
454 Kapetaki, Z. Low Carbon Energy Observatory Carbon Capture Utilisation and Storage Technology Development Report, 2020, JRC120801

Figure 139 Activity by EU MS companies in CO2 capture.



Source 143 JRC, 2018 based on data from the European Patent Office, "European Patent Office PATSTAT database, 2019 autumn version." 2019

Figure 140 Activity by EU MS companies in CO2 storage



Source 144 JRC, 2018 based on data from the European Patent Office, "European Patent Office PATSTAT database, 2019 autumn version." 2019

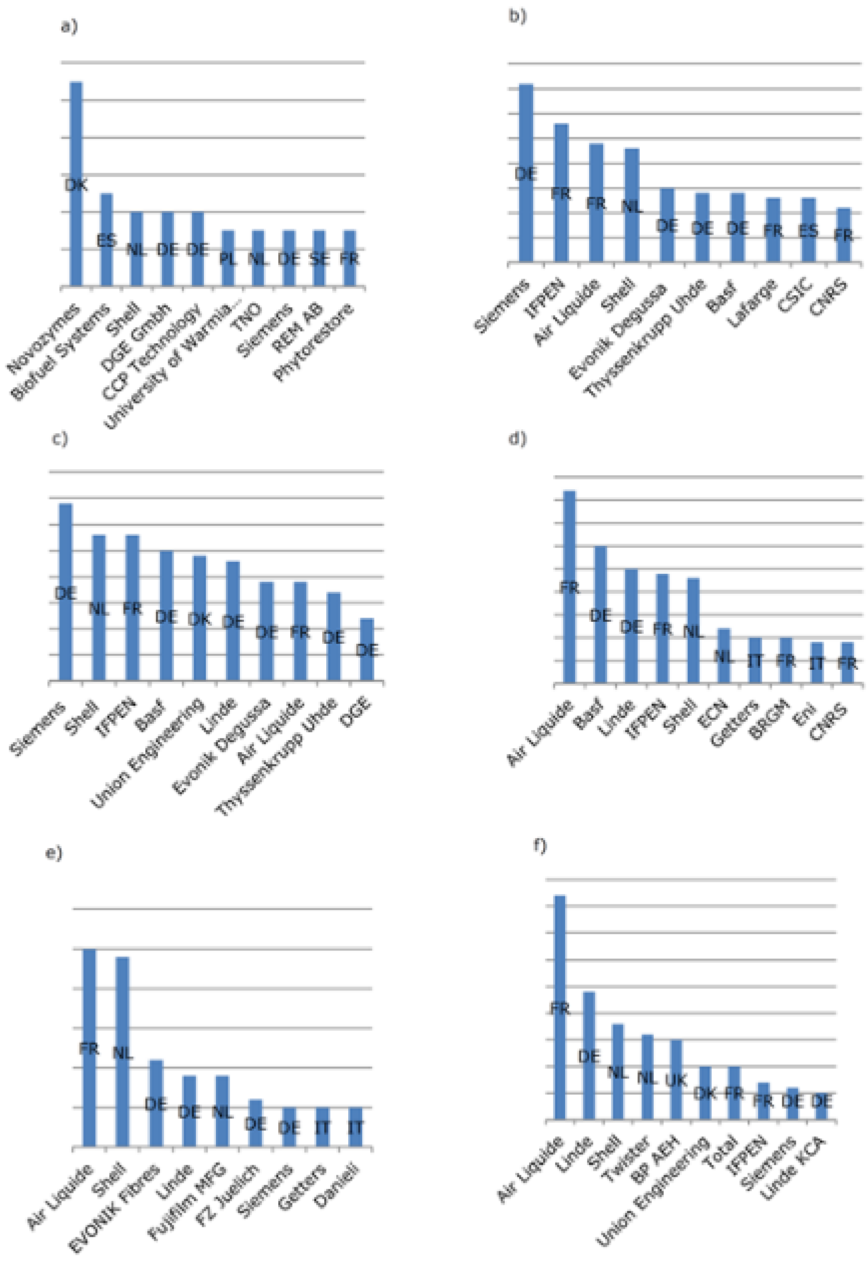
3.8.2. *Value chain analysis*

Number of companies in the supply chain, incl. EU market leaders [455]

Analysing the patenting activity per priority year, from 2004 to 2014, the larger number of cumulative patents is found in the categories of capture by adsorption and capture by rectification and condensation. The third sub-class with more patenting is capture by chemical separation. Despite the current interest on membranes, patenting is still far from the three leading technologies. Big multinational companies such as Shell, Air Liquide, Siemens, BASF and Linde are amongst the companies with the highest activity in patenting. Regarding CO2 storage, since important investments on CCUS have been dependent on the oil and gas industry, the number of patents varies as a function of their interests for innovation or technology improvements. According to the data, patent families related to CO2 storage peaked in 2007 and have decreased ever since. The following graphs provide the relative patenting activity of company by country for CO2 capture and storage technologies.

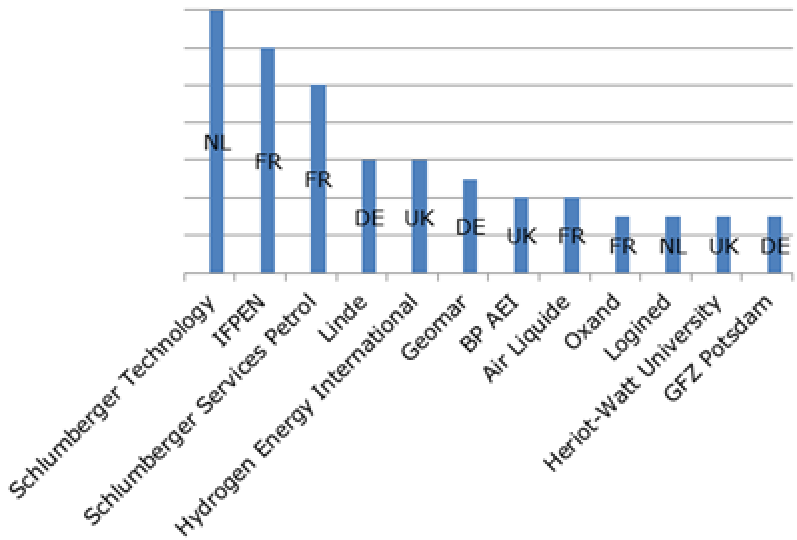
[455] Kapetaki Z., Miranda Barbosa E., Carbon Capture Utilisation and Storage Market Development Report 2018, JRC118310

Figure 141 Top companies and organisations patenting in CO2 capture technologies from 2004 to 2014 in Europe. a) capture by biological separation, b) capture by chemical separation, c) capture by absorption, d) capture by adsorption, e) capture by membranes, f) capture by rectification and condensation



Source 145 JRC, 2018 based on the 'European Patent Office PATSTAT database, 2018 spring version'

Figure 142 Top companies and institutions patenting in subterranean or submarine CO2 storage technologies in Europe from 2004 to 2014



Source 146 JRC, 2018 based on the 'European Patent Office PATSTAT database, 2018 spring version'

Large-scale CO2 transport and storage projects are typically driven by global gas and oil corporations, e.g. Shell, Total, Equinor, BP, which are often active in CCS projects outside of Europe, hence dispose of competitive knowledge and experience in the field. However, the development of a complex infrastructure like CCS requires the contribution of a large number of other stakeholders, including the users of the transport and storage infrastructure, public and licensing authorities, modellers, or those involved in site monitoring.
The picture is even more divers when it comes to CO2 capture, which potentially includes many different industrial sectors, processes and technology providers. The market of capture technologies may be relatively small today, but one can expect its rapid growth with higher price for carbon emissions, the development of CCS, as well as CCU solutions. Research and innovation policy has a very important role to support the development of a European CO2 capture industry that can compete on global markets. Recently, Gassnova, Equinor, Shell, and Total have renewed their commitment to research and testing of innovative capture technologies at the Technology Centre in Mongstad (Norway) until 2023[456], highlighting the momentum around CCS.

3.8.3. *Global market analysis*

Global market leaders vs EU market leaders

With no viable business model for CCS today, there is a limit to which terms of market economics (demand/supply, market leaders, competitive advantage, economy of scale, etc.)

[456] https://tcmda.com/three-more-years-of-testing-at-technology-centre-mongstad/

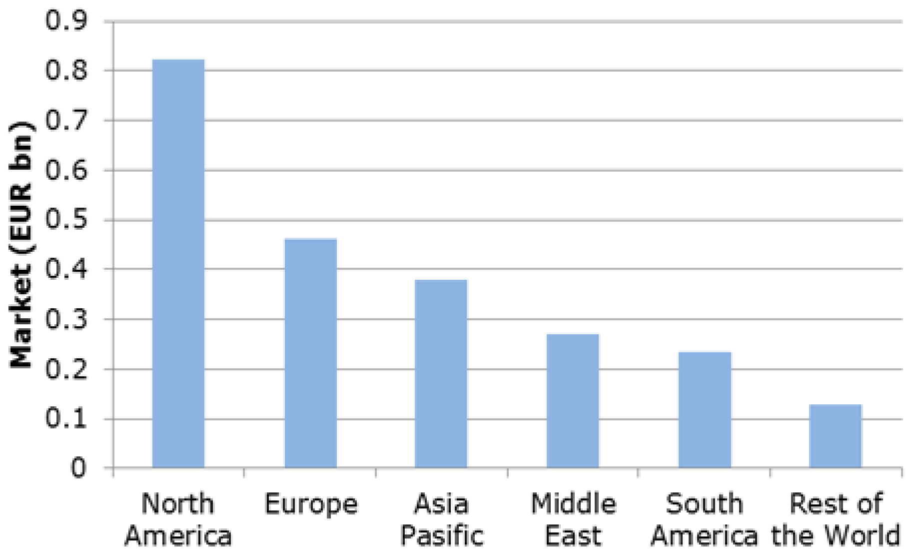
can be applied for CCS. Nevertheless, technology leaders (countries and companies) can be clearly distinguished.

Out of the 51 large-scale CCS facilities worldwide (in operation or development), most can be found in the U.S., which makes it a global CCS leader. Norway, thanks to its two CCS major facilities operated by Equinor (Sleipner since 1996 and Snøhvit since 2008), as well as to the Technology Centre Mongstad, is also a global technology leader and CCS promoter.

The adoption of the Paris Agreement, the growing scientific consensus on human-induced climate change, and government policies, which require CO2 reductions in all sectors (incl. cement, steel, chemicals, hydrogen production), are making a momentum for CCS. Today, ambitious CCS projects are planned and implemented in Europe (The Netherlands, UK, Ireland), Australia, Canada, China and the Middle East.

Analysis of the full CCUS value chain i.e. capture, transportation with pipelines and storage, presented in the following figure, indicates that Europe holds the second highest market share in all CCUS elements following North America. Asia Pacific, Middle East and South America are following. Asia Pacific and Middle East can be seen as emerging since it is these regions, which count the most projects in planning according to the Global CCS Institute projects database[457].

Figure 143 CCUS technologies market by region (2017)



Source 147 Source: JRC, 2018 with data from Accuray Research (2018) Global Carbon Capture Utilization Storage Technologies Market Analysis Trends

[457] https://co2re.co/

3.8.4. *Future challenges to fill technology gap*

Many stakeholders and analysts, including the IEA, see CCS as a mature and readily available technology that will need to be deployed at scale for reaching climate neutrality by 2050. In Europe, this is particularly true for energy intensive industries (cement, steel, chemicals), for which no alternative routes exist to zero-emissions, or for which the alternative routes may be significantly more expensive. CCS may also be needed for stepping up clean hydrogen production, as well as for producing negative emissions via direct air capture or BECCS. Cross-border CO2 transport and storage infrastructure that connects industrial clusters with storage sites needs to be the backbone to which industrial emitters could plug in to get their CO2 emissions transported to permanent CO2 storage sites. This shared CO2 transport and storage infrastructure can help with safeguarding industrial jobs and activity in Europe while moving towards a climate-neutral economy.

However, the complexity of full-chain (i.e. CO2 capture-transport-storage) CCS infrastructure projects, their relatively high investment and operating costs, as well as regulatory and public acceptance issues have been hindering the rollout of CCS.

Credible energy and climate policies (e.g. strong CO2 price signal), as well as governments' support to CCS projects (e.g. by including them in the National Energy and Climate Plans) are therefore deemed necessary. The European Green Deal legislative framework, including the TEN-E regulation and EU ETS directive, is expected to provide the necessary push for long-term public and private investments, helping to prepare for the rollout of CO_2 and clean hydrogen infrastructure. Public funding for CCS infrastructure, including the EU's Innovation Fund and the Horizon Europe R&I programme, is highly important, also in view of mobilising and de-risking private investment.
The recent EC Communication on Stepping up Europe's 2030 climate ambition defines clearly the task ahead: "hydrogen and carbon capture, utilisation and storage, will need to be developed and tested at scale in this decade"[458].

[458] COM(2020) 562 final, page 10