

Industrial Fuel Switching – Project ASPIRE

Vale Clydach Nickel Refinery



VALE



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Executive Summary

Vale Clydach Nickel Refinery (CNR) in South Wales has produced high-purity nickel products for over 100 years. CNR is a high energy user of electricity and natural gas for heating and the production of hydrogen and CO, with annual emissions of >65,000 tCO₂e. CNR seeks ways to decarbonise, whilst ensuring long-term competitiveness. During the latter part of 2018, the concept of replacing thermal energy on site was beginning to take shape leading to the development of a low carbon concept termed ASPIRE (Alternative, Smart Platform for Integrated Refinery Energy) by Christmas 2018.

During 2019, the Industrial Fuel Switching (IFS) scheme has supported a detailed feasibility study into establishing how to convert the process plant to fuel switching capability and how to utilise multiple energy vectors in incremental steps towards a carbon reduction goal of 66% and ultimate net zero carbon with the addition of CCUS. The IFS-funded feasibility work has enabled three significant risks to be explored and mitigations identified:

- **Large corporate industrial challenges and aversion to change.** The near-term pressures to replace decades-old, existing, fossil fuel-based process heating plant; requirement for such plant to be guaranteed, reliable and maintainable; and a high degree of inertia and financial and capital planning rigidity could all contribute to the end result being 'like-for-like' plant replacement. The IFS-funded work has thus far resulted in reducing these first-hurdle challenges.
- **Fuel switch of end energy users.** It is imperative that any new, alternative, process heating equipment must work, especially for 24/7 processes. ASPIRE minimises this risk through implementing early phase fuel 'switches' that allow plant to operate on existing fuels (natural gas) initially but be supplied by alternative net zero carbon fuels in the futures.
- **Achieving near-term plant replacement with fuel-switch capability whilst maintaining sufficient flexibility to incorporate emerging technologies and developing low carbon economies.** The feasibility study explored how energy vectors can be used within the process plant to provide the required heat transfers in potentially novel ways including direct combustion of alternative gases; use of waste heat at high and low grades; and the creation of industrial gases, such as hydrogen and CO in the case of CNR. This facilitated early feasibility and design work to determine whether proposed alternative thermal conversion technology can provide the required optimised energy outcomes, and what the impact is from a cost and greenhouse gas perspective. This also helped determine what plant changes can be implemented to be 'fuel-switch ready' should alternative, grid-based gases injected into natural gas, namely hydrogen, become available in the future and helps to inform the specific requirement for alternative gaseous fuels in terms of purity and volume.

Fuel Switching Focus

Establishing the process heating, electrical production and chemical process gas requirements allowed the concept to be built into a light feasibility proposal that could be challenged through a robust and broad ranging Risk & Opportunity (R&O) process.

This process identified the key processes that required low risk solutions:

Pellet Units – There are 19 pellet units on site that use recirculating hot gases at circa 500°C to transfer heat to recirculating nickel pellets to allow decomposition of a layer of nickel on to the pellets. Historical laboratory-based work had indicated that conversion to heat transfer fluid thermal heating could increase heat transfer leading to a more efficient process with tighter quality controls. One of the gasifier heat output vectors is heat transfer fluid and the feasibility investigated the options of utilising this vector leading to Project C in the potential next phase. Many practical measurements that correlate with both theoretical and previous laboratory trials have led to outline designs that could provide a 20th unit as production pressures and recent plant downtime has precluded the length of downtime available to convert a pellet unit.

Hydrogen Heaters – The site has two hydrogen heaters that heat the hydrogen reduction circuit gas to between 520°C and 560°C. These heaters are on the top of a roof that is circa 30 m high with limited space available, combined with lengthy shutdowns programmed every two years that enables major works. Utilising the existing designs with multifuel burners creates high varying heat transfer conditions in the radiant heat transfer section of the hydrogen heater. In addition, this section of a converted hydrogen heater may be exposed to greater hydrogen embrittlement risk potentially causing significant plant failure. The solution proposed in Phase 3 (Project A) is to separate out the thermal energy creation from the heat exchange. When this idea was explored the idea of using a thermal oxidiser a standard piece of technology that specialises in multifuel combustion and homogenising a hot gas stream to circa 800-850°C. A sectioned tubular heat exchanger can then be used to transfer heat to the heat exchanger. This aspect has undergone very robust R&O as if this process fails half of the plant output will cease. An output of the R&O has revealed a position that would allow the old heater to remain in situ for a year or two to gain confidence in the new heater. The proposed oxidiser will have the capability of combusting, natural gas, hydrogen (98% purity) and Syngas (CO & H₂ mix, plus other gases such as nitrogen).

Steam Boilers & Hot Water Heating – The oxidiser solution was again chosen for supplying the thermal requirements of first the heat transfer fluid (heat to pellet units, then steam production) with residual heat to hot water that will pre-heat the boiler feed water and serve a space heating hot water demand. The exhaust from this oxidiser will be initially routed into the main stack again proving the concept towards moving to one emission point.

Gas Plant (SMR producing H₂ & CO Outputs) – A large proportion on the on-site consumption of natural gas is used as both a feedstock and thermal energy provider to the gas plant. Six emission points are present within this facility as it also contains

2 steam package boilers. In this case, hydrogen purity levels of 98% are required by the kiln plant (H₂ user), whilst CO is also required by the pellet & powder plant at a purity level of 99.8%. Developers of advanced thermal conversion (ATC) technology, introduced below, which converts a wide range of biomass and refuse derived fuel (RDF) into clean hydrogen-rich gas (Syngas), have worked on a preliminary design that could supply these CO & H₂ requirements. This substitution of an SMR plant with an ATC-based system demonstrates the advantages that the ASPIRE concept can deliver in optimising multi-vector energy/chemical use within the right industrial setting. This will produce cost savings to CNR and is a risk mitigator to the likelihood of changing the grid's natural gas composition.

Electrical Vector Replacement – The last remaining energy vector on site is electricity. ASPIRE will use the Syngas to produce electricity for the site and the ATC system's parasitic power. Waste heat will be used as the primary sources to service the heat transfer fluid and hot water requirements before reverting to using the oxidisers, fuelled by Syngas or hydrogen with natural gas being the ultimate backup.

Advanced Thermal Conversion

Kew Projects Ltd (Kew) have developed a high-efficiency advanced thermal conversion (ATC) process which converts a wide range of biomass and refuse derived fuel (RDF) into clean hydrogen-rich gas (Syngas). By positioning this type of technology on the right site, circa 70% of the energy in feedstocks can be utilised in a safe, clean, and efficient manner. This cutting-edge technology has been developed over 7 years alongside the Energy Technologies Institute (ETI) and is being demonstrated at the Sustainable Energy Centre in Wednesbury. Kew aided this fuel switch feasibility study, in particular by providing data for their ATC system utilising dynamic modelling and real-time data from their West Midlands demonstration plant. This assisted in the concept advancement for deployment of an optimal number of ATC modules at CNR and informed the applicability for further industrial roll-out.

Alternative Delivery of Process Heating

The heart of ASPIRE's innovation comes from using existing technology in a new way that leaves the door open in the future to achieve net zero carbon and beyond. One of these technologies that has been adapted is a robust, decades-old oxidiser technology. The fundamental idea is that it has the capability be fuelled using natural gas initially and can run using the Syngas created from the ATC modules or from hydrogen supplied from ATC modules or other potential sources. The innovation involves employing a multiheaded burner and separating the heat generation and heat transfer sections to allow for the different intensities of the flame profiles of the different fuels. The centralised heating platform reduces the amount of emission points on the site, thereby making future CCUS more viable than it would otherwise be.

This design in ASPIRE is relatively agnostic to the heat delivery system to avoid over-reliance on specific technology and open up the possibility to utilise any advancement in low-carbon systems such as hydrogen networks.

Greenhouse Gas Impact

The ASPIRE vision will totally switch the site away from dependence on grid supplies of electricity and natural gas to utilising in a more efficient manner the potential energy contained within RDF/biomass. The counterfactual position to ASPIRE is the site's energy vectors are supplied via the grid connections and the RDF that would be employed by ASPIRE would be used in a conventional energy from waste (EfW) facility to create predominantly electricity from generated steam. The difference in carbon positions by adopting ASPIRE represents ~43 ktCO₂ saving per year, which is equivalent to 66% of CNR's current carbon emissions (see Section 8).

CapEx and OpEx

The total CapEx cost of the fully deployed ASPIRE vision is estimated at just over £100M. The main costs of ASPIRE include 6 ATC modules, an RDF processing unit, thermal oxidisers for reduction gas heating and the wider thermal oil heating platform, pellet unit preheaters, a hot-oil steam boiler, along with other auxiliary plant equipment. The alternative to this is by going down the 'like-for-like' carbon route at an estimated cost of £77M based on the previous cost of plant equipment, which will be replaced at some stage in the next 12 months.

The operational cost of the proposed solution results in a saving of ~£10.5M per year based on current operational cost. Although this is a lengthy financial payback the alternatives have no framework to create financial paybacks and thus global companies will be unlikely to invest. In fact, if the decarbonisation burden is unfairly placed particularly on the foundation industries, global companies are likely to move operations to other countries.

Conclusion

This solution helps extract highly efficient, valuable energy and chemical vectors from waste sources that would otherwise be routed through comparatively low-efficiency, traditional EfW plants. This, combined with the smart application of existing technologies on-site, will enable appropriate industrial sites to move towards net zero carbon and be in a better operational position whilst creating jobs.

Alternative fuel switching technologies such as electrification and the hydrogen economy have yet to develop a business case suitable for private investors. As such, although the national impact may not be as wide-ranging as the alternatives, the ASPIRE type of project can offer industry a feasible route to a lower carbon future that encompasses infrastructure and outcomes that can help achieve net zero carbon or beyond and allows for action to be taken in the near-term.

1 Highlights

1. A Low Carbon future in a globally competitive business market.
2. Transforming particularly foundation industries towards "Clean Growth".
3. Reluctancy of foundation industries to change due to a lack of capital investment & expertise.
4. Continuous replacement of end of life plant. Low risk is to replace "like for like" basis = CARBON ROUTE.



Example hydrogen heater that will either be replaced by conventional plant or resilient fuel switching plant.

The Challenges



The gasifier plant that could provide the hydrogen-rich Syngas and 98% purity hydrogen.

- Multi-fuel vector approach used to mitigate risk - if failure occurs then the plant could close.
- Allows hydrogen-rich Syngas from a gasifier to be used as well as 98% pure H₂.
- Commissioning will prove capability of the fuel switch plants on blends of gas.
- ASPIRE - remainder of the work designed to de-risk and progress the site to being "Order Ready" at the end of stage 3. i.e. de-risked.
- Provides one of the few economic pathways towards a net zero carbon site.

Fuel Switch Approach



- ASPIRE – a flexible, practical and sustainable programme.
- Transforming the carbon platform of a site to create a platform for "Clean Growth", reduced carbon, improved quality, increased throughput, improved well-being and a more reliable plant.
- Switching the high-carbon vectors to low-carbon vectors – to leave the door open to achieve net zero carbon and beyond.
- Smart Flexible Use of existing technologies to achieve initially 66% Carbon Reduction.



Note the Clydach site already has large storage tanks on site that store gas created from its own Steam Methane Reformer (SMR). Thus, capabilities exist on site to manufacture and utilise the appropriate fuel switch gases.

The Overall Vision



The Circular Economy works best when the aspects of People, Planet & Profit combine to create the right balance of drivers. The ASPIRE Vision provides a payback in an environment where it is difficult to find "investable Projects".

For the refinery:

- ✓ Avoided carbon from short term plant replacement pressure.
- ✓ Easily leads on to further CO₂ reduction by maximising low carbon vectors.
- ✓ Benefits - ASPIRE ~43 ktCO₂e/y lower than the counterfactual.

For Government and the UK:

- ✓ Provides examples to multiple replication sites.
- ✓ Short-term replication potential with industry.
- ✓ £Bn's potential SMR CCS subsidies avoided.

Towards net zero carbon

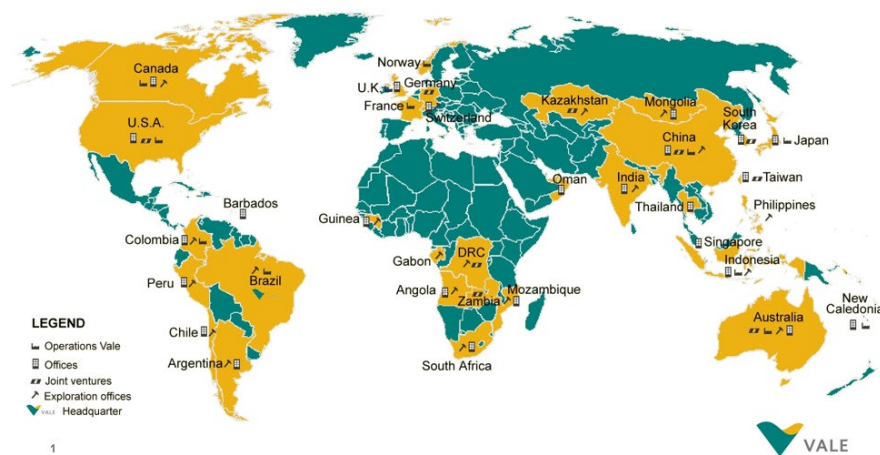


2 Introduction

2.1 Introducing Fuel Switching at Vale Clydach Nickel Refinery

2.1.1 Vale

Vale is a large mining company that has headquarters in Rio de Janeiro and Brazil with operations in 5 continents and employs a global workforce of around 115,000 people.



Vale's main output is iron ore, but they also produce nickel, copper, cobalt and coal. Clydach Nickel Refinery (CNR) is part of the Vale Base Metals division this division has headquarters in Toronto and Canada. The division produces 20% of the worlds nickel supply with

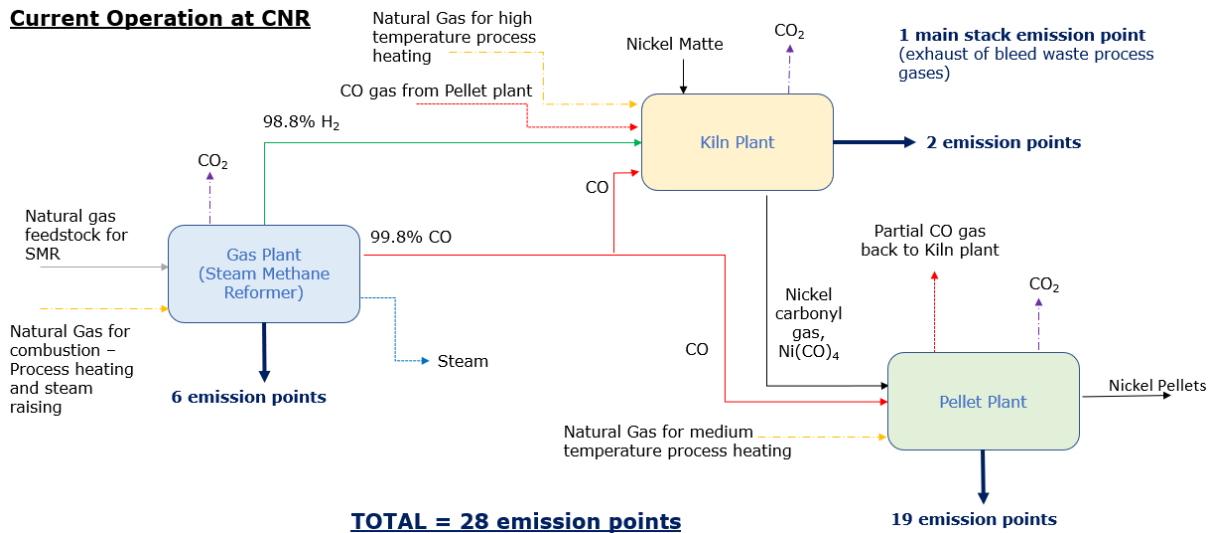
mines in Brazil, Canada and Indonesia. Clydach Refinery (pictured below) has been in operation for over 117 years and uses the Mond nickel carbonyl process to produce high quality (>99.9%) refined nickel. The refinery employs 193 direct Vale employees and a further 56 permanent contractors on site. Site operations run 24 hours a day, 365 days a year and produces around 40,000 tonnes of nickel per annum. The nickel pellet and powder products produced are sold to over 280 customers in over 30 countries worldwide with the main customers in Europe and Asia.

Strategically, the plant output is important to the UK as almost all forms of electrical battery storage utilise nickel within the system. Thus, the site at Clydach strategically is part of the Low Carbon future.

The production process is complex and has many features that are unique to the UK Site. For an overview of the process see figure overleaf.

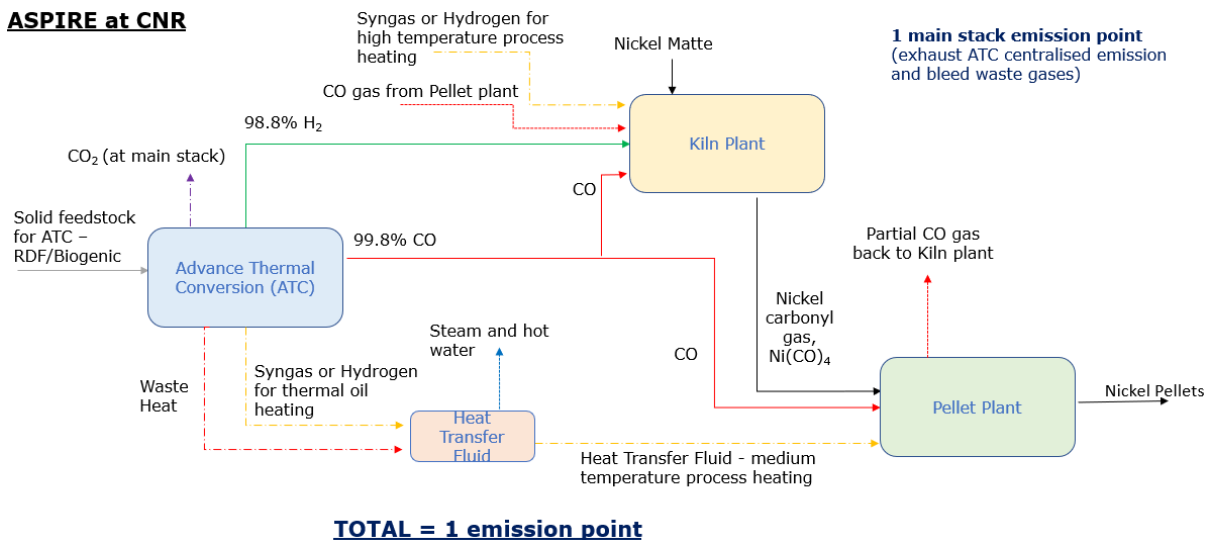


Current Operation at CNR



The above figure shows a simplified overview of the industrial process at Clydach with the delivery gases shown. Carbon dioxide is depicted as being emitted from the gas plant, kiln plant and the pellet plant. Currently there are 28 emission points ranging from the steam package boilers, process gas heaters, vaporisers and 19 separate emission points for each of the 19 pellet units on site. This can be compared to the below diagram that describes the ultimate vision scenario where the single emission point is shown coming off the ATC plant. In the scenario the 19 pellet unit emission points no longer exist as heat transfer fluid is now the heating medium as opposed to exhaust gases. The remaining exhaust gases are to be piped back to the existing stack as the single emission point to improve efficiency of carbon capture, usage, and storage.

ASPIRE at CNR



The above ASPIRE vision is to have zero reliance on natural gas and instead harness the energy available in refuse derived fuel and/or biomass. The above diagram shows the gas plant being replaced by the advanced thermal conversion plant that produces the hydrogen-rich Syngas for fuel at the kiln and pellet plants and the purified hydrogen and carbon monoxide that are used in the nickel purification process. It can also be seen from the above figure that the steam raising, and heating of the Pellet Plant is now carried out by heat transfer fluid. The proposed fuel switch at CNR to a low-carbon future will provide an exemplar to other sites for similar transformational change, both in the South Wales

Industrial Cluster (SWIC) and beyond. A real-world reference, meeting all regulatory and commercial requirements, is invaluable in incentivising private sector investment in decarbonisation.

2.2 Background to Industrial Fuel Switch (IFS)

2.2.1 Phase 1 Report

During 2018 Clydach explored several options that looked at how the refinery could move towards carbon neutrality. Following a SWIC meeting on the 14th Jan 2019, with a variety of attendees from different industries across South Wales, CNR concluded that their Clydach refinery fit perfectly into the category of thermal fuel switching. CNR's decentralised natural gas combustion plant (many emission points) can be switched to hydrogen or a hydrogen rich gas that is centralised, meaning that the number of emission points are reduced allowing for the possibility of future carbon capture. This vision fits perfectly with the potential for alternative hydrogen supply given CNR's core process includes a natural gas SMR creating hydrogen and CO.

2.2.2 Phase 2

CNR's Alternative Smart Platform for Integrated Refinery Energy (ASPIRE) vision is to decarbonise and secure its long-term competitiveness by meeting future energy needs through converting biomass/residual waste into multiple energy vectors using advanced thermal conversion (ATC) modules.

Fundamental to the ambitious ASPIRE vision is that heat, currently provided by natural gas (i.e. prime heat) can be substituted for alternatives such as hydrogen rich Syngas generated from the Kew ATC modules, or potentially hydrogen in the future when suitable supply's became available.

The Syngas produced from the ATC modules is defined as grade A, B & C depending on the amount of processing and polishing it has undergone.

Grade C Syngas – is the raw Syngas that comes from the gasifier that contains approximately 30% hydrogen and carbon monoxide combined, 30% carbon dioxide, hydrocarbons and nitrogen.

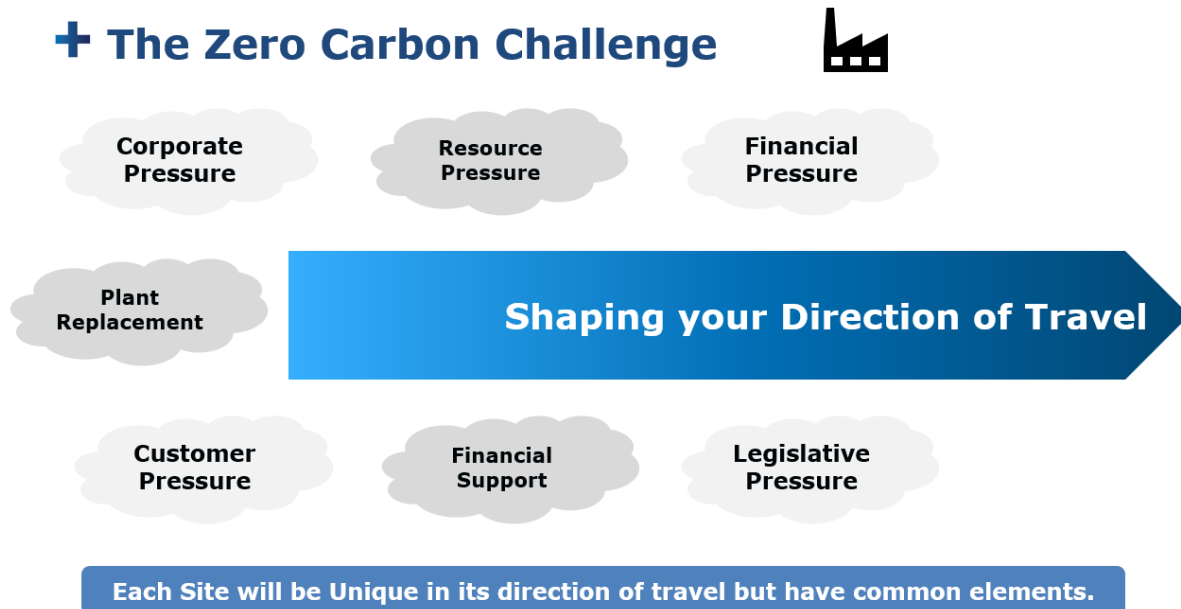
Grade B Syngas – is the Syngas that has undergone some polishing to remove hydrocarbons and has been reformed increasing the combined amount of carbon monoxide and hydrogen to around 70% with carbon dioxide and nitrogen making up the rest.

Grade A Syngas – is further processing of the Grade B gas to increase the purity of the hydrogen to >98.0%

The Phase 2 feasibility study concluded it is possible to create a bold project that will serve the needs of the site and yet be resilient to possible future energy/carbon vectors that may become more economic in the future.

3 The Challenges

Industrial sites have many challenges to overcome within their business environment. The diagram below represents a few of the challenges most industrial sites face on a day to day basis.



Financial pressure represents a serious break in the foundation industry’s progress towards net zero carbon. Despite usually being large corporations, their pockets are not “deep” as many would believe. Government support measures are often aimed at the SME-sized industrial sectors where decisions can be made quickly, with less administrative burden and the capability to apply resources rapidly. Large foundation industries are characterised in a totally opposite way. They are slow decision makers with high administrative burdens often having difficulty in applying resources dynamically. Siloed thinking in larger organisations can be commonplace.

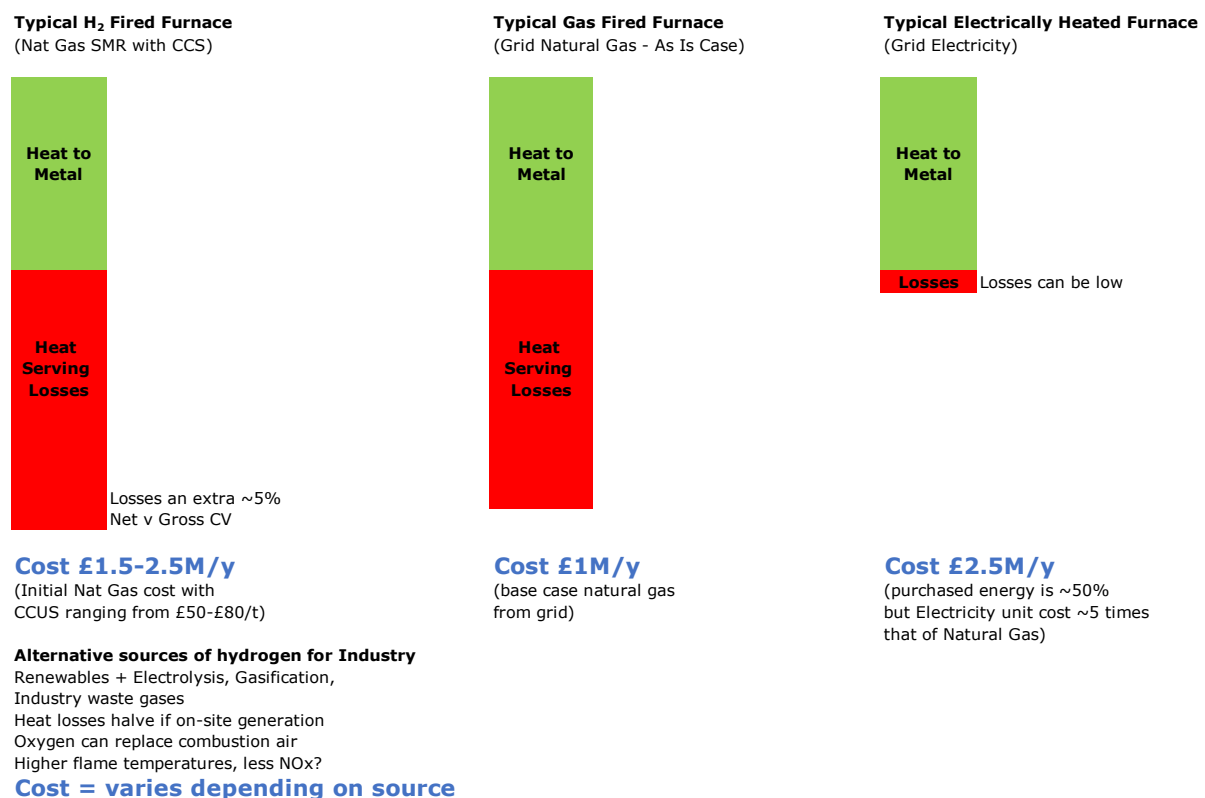
Near-term plant replacement has created a risk and a threat to the ongoing decarbonisation exercise at CNR. Firstly, engineering and maintenance teams will gear up for significant CapEx submissions for plant replacement 2-3 years in advance of any envisaged implementation. Where the plant in question is critical to the process (it commonly is) the lengthy approval and decision-making process and requirement to follow strict procurement processes including pre qualifications and supplier lists, leads to a majority leaning towards continuation with the status quo. It is regarded in as the best option since it is the least risk. Also, such plant replacement is often considered in isolation and with a focussed brief. For example, a requirement to replace steam generation equipment but not investigate and rationalise the full steam system and end heat users.

However, there could well be a greater long-term cost of ‘doing nothing’. This is steadily being recognised within sections of corporate establishment, where innovation is seen as a very positive contribution to the global company going forward. The challenge remaining therefore is how to support such large industrials in accelerating forward with innovative

plant replacement and not leaving industrial plants pausing on decisions awaiting answers from technology and policy. In this case emerging net zero carbon technologies/systems and the necessity to look at innovative 'systems' projects not just 'technology equipment' projects.

A simple analogy is the diesel car. Many of us are driving medium mileage and age diesel cars right now. Why are we not all rushing out to purchase electric or hydrogen fuelled vehicles? In most cases because the 'clean' alternative is not immediately economically viable, and uncertainty exists around the wider system infrastructure. Aggressive policy could significantly affect car users ability to travel. When the car reaches high mileage and age, the decision could be to renew with a similar fossil fuelled model once more.

For an example of a typical financial challenge facing an industry's decarbonisation plan, see the diagram overleaf comparing the cost implication of using hydrogen, natural gas, or electricity to power a furnace. The current cost of the hydrogen and electricity implementation compared to simply natural gas is 1.5 to 2.5 times as expensive for hydrogen and 2.5 times as expensive for electricity. This is despite the loss of energy being substantially lower for an electrical switch. This is just simply due to the price disparity between natural gas and electricity per kWh.



As can be seen within today's financial framework, conventional competing routes such as electric heating and/or moving to hydrogen heating will effectively result in businesses being closed as they will not be financially sustainable.

An academic, consulted through the fuel switch programme, has raised the issue of embrittlement of metals from the absorption of hydrogen at high pressures and temperatures which could be a prominent concern if the right circumstances are met. This

poses a technical challenge for many plants to overcome when moving to hydrogen systems and ensures that a simple switch to hydrogen with minor tweaks to burner systems are likely not going to be sufficient and more major overhauls to combustion systems or even process heating equipment (such as furnaces) will need to occur on sites. Even without full conversion to hydrogen, the potential for increased 'blending' of hydrogen in the existing natural gas networks would risk de-rating existing equipment due to the lower CV of the blended gas, leading to plant production and performance issues arising.

This could also be financially catastrophic for certain plants where just-in-time processes are the norm and large capital investment for process heating equipment is not immediately available. If sites lose contracts, then businesses in the UK could fail. As a mitigation to this risk, future R&D support programmes will be required to help industry with the conversion to hydrogen and hydrogen-rich gases for combustion. To tackle the issue from industry's perspective, academic research should focus on the "D" for development of solutions enabling wider scale switching and replication to take place.

ASPIRE intends to mitigate this risk through the separation of the heat generation and the user of heat by deploying new combustion equipment and combustion chambers with heat for process use exchanged indirectly to process (this is explained further in Section 4).

The ASPIRE approach also results in plant that is capable of running on natural gas as well as two other gaseous fuels currently chosen around the Kew Gasification outputs; these being Syngas (~38% H₂-rich gas) and a 98% H₂ purity gas, which is also being considered as the purity standard for H₂ networks. Therefore, the plant can operate today as well as at some future date when 98% pure potentially H₂ becomes available creating a resilient solution to one of the major challenges. This risk mitigation is paramount to many foundation industries due to the safety risks involved with process changes. The CNR site, for example, is a top-tier COMAH site positioned close to a village.

However, possibly the leading challenge is resource availability. For the typically under-resourced foundational industries, understanding what solutions may be available, as well as the support mechanisms that may exist to deliver transformational change is necessary to the decarbonisation of the UK as otherwise these industries will pursue the "carbon" route of replacing like-for-like plant as they cannot afford the resources to mitigate the risk of a process change.

4 Fuel Switch Approach

The Alternative, Smart Platform for Integrated Refinery Energy (ASPIRE) vision is to decarbonise and secure its long-term competitiveness by meeting future energy needs. CNR are well aware of the need for deep de-carbonisation across industry and are positioning themselves at the forefront of this revolution.

4.1 Phase 2 Study

The Phase 2 study was broken down into several work packages that addressed areas such as the confirmation of site wide users including best estimates for energy profiles and throughputs, initial design and analysis of full-scale plant equipment, assessment of tie-ins with process circuits, assessment of feedstocks and feasibility of gasification systems, GHG impact, CCUS potential and industrial cluster impact.

The study has also looked at the proposed solutions impact on health & safety, air quality, fuel delivery logistics and production disruption.

CNR is a top-tier COMAH site, as such safety is paramount and will not be compromised. The proposed changes to the site require a COMAH addendum and this is planned for. Demonstrating a multi-faceted fuel switching scenario at such a plant will provide confidence to other industries as the full rigours of H&S have been adhered to. Many of the health and safety issues are mitigated by robust management of process change and facility change (MoPC and MoFC) procedures that call on expertise from both internal and external sources to conduct detailed designs, HAZOPs and procedures. The Phase 2 feasibility study involved high-level hazard identification for key risk and opportunity areas for the project. A HAZID assessment was undertaken involving key plant managers for their input and then a HAZOP to assess, in further detail, any areas of risk; viable mitigation of these risks; and any opportunities of the project to ensure that no 'doors are closed' to technologies.

Extensive engagement and consultation have been held on-site with CNR's incumbent external environmental consultancy Environmental Compliance Ltd (ECL), who have worked with both CNR and CR Plus historically to deliver successful planning and permitting for proposed alternative energy projects.

Key outputs from this were:

1. A detailed scoping and cost document produced by ECL to undertake and deliver full planning and permitting for the ASPIRE vision project.
2. A detailed scoping and cost document produced by ECL to undertake and deliver full a permit variation and supporting modelling (such as air dispersion) for the Phase 3 projects A, B, C. In reviewing each project with CR Plus, ECL were able to determine that there is no risk to not achieving the required permit variation, it is purely a cost and time implication (which has been built into the schedule and cost plan).

This assessment will look at the impact of the project on both potentially sensitive human and ecological receptors and will include emissions from the road traffic associated with the development.

When looking at the logistics of fuel-switching an industrial site, there are huge implications regarding fuel delivery. For the case of CNR and the ultimate vision, daily deliveries of RDF will be made from sources in the Swansea area. These local sources of RDF have shown that they can partially meet the requirements of a fully-deployed ultimate vision. An example local waste facility has a suitable environmental permit issued by National Resources Wales, which allows for a maximum of 75,000 tonnes of waste to be accepted per year, including a range of biomass wastes and industrial & commercial wastes, which are all suitable as a feedstock for the Kew plant. If the facility supplied CNR with all their RDF material, they would satisfy a significant proportion of the feedstock demand. However, the example facility has potential to also locate and provide the full 80,000 to 90,000 tonnes of feedstock, by working with network contacts.

The permitting for a similar scheme RDF fuelled advanced thermal conversion energy plant has, in the past, been undertaken by ECL and was determined feasible for the tonnages involved in the relevant locations.

4.2 Phase 3 and Beyond

The ASPIRE project is a flexible, practical and sustainable solution that tackles the issues facing industry in a smart, tiered manner transforming the carbon platform into a platform for clean growth. The project demonstrates fuel switching for different areas of the process and successful demonstration gives confidence for the ultimate vision where the high-carbon energy vectors are transformed into low carbon vectors. The heart of the innovation comes from using existing technology in a new way that leaves the door open in the future to achieve net zero carbon and beyond.

By switching the pellet plant to heat transfer fluid (HTF), CNR are decarbonising one of the most energy intensive areas of the plant and the Phase 3 demonstration of this is vitally important. The new pellet unit to be installed in Phase 3 will be full size and will give confidence to CNR and the wider industrial community in this fuel switching approach. The demonstration of the transfer of energy via the centralised heating network or direct heat exchangers in the exhaust gas streams is seen to have strong benefits because it shows the solution working at full-scale in a commercial setting and so has immediate value. The fuel switching project targets the heart of CNR's processes thus giving confidence to stakeholders for the further roll-out of the aspire vision.

One of these technologies that have been adapted is decade-old oxidiser technology. The fundamental idea is that it has the capability to run using the existing 'carbon route' scenario using natural gas but also can run using the Syngas created from the ATC modules. The innovation involved is by employing the multiheaded burner, as previously discussed, and separating the heat generation and heat transfer sections of the plant thereby minimising potential variable thermal stress areas within the plant associated with varying flame profiles. This approach enables CNR to be set up for the future and adds robustness to the design and operation of the equipment.

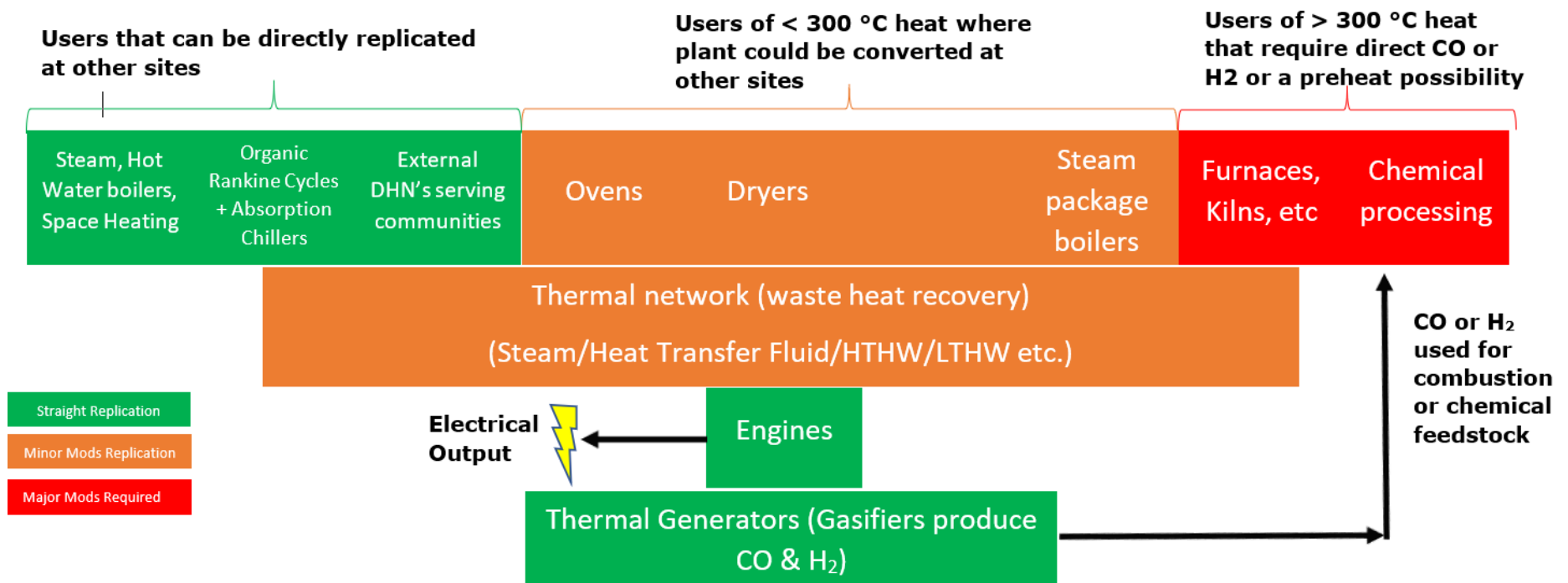
Leaving doors open, at each phase of the design is a theme of the project and gives an inherent robustness to the fuel switching approach employed. The centralised heating platform reduces the amount of emission points on the site make future CCUS more viable than at present, and more viable than if the state of the art, 'carbon route' was employed.

By taking this approach to fuel switching, the principles of this design will not only be able to be implemented across the entire site, fully decarbonising CNR, but with tweaks to the design, it could be replicated across all industrial sites requiring moderate to high thermal load. Innovative ideas with practical designs that can be implemented now or in the future due to leaving these doors open is the foundation of the approach. This leads to action NOW not LATER. ASPIRE will focus on moving ideas to reality, providing "exemplar" opportunities.

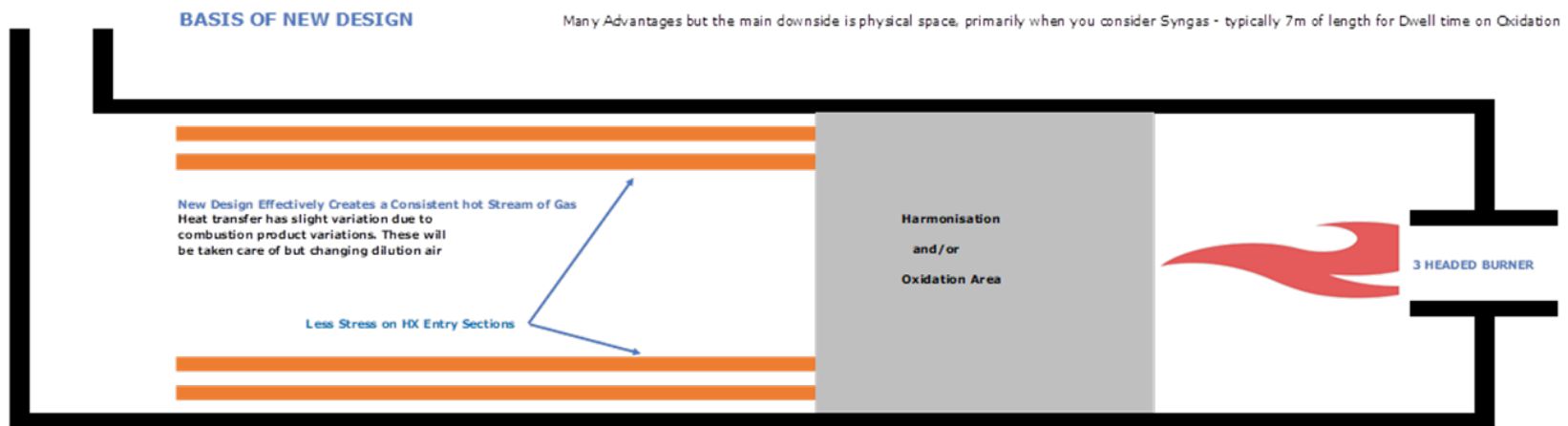
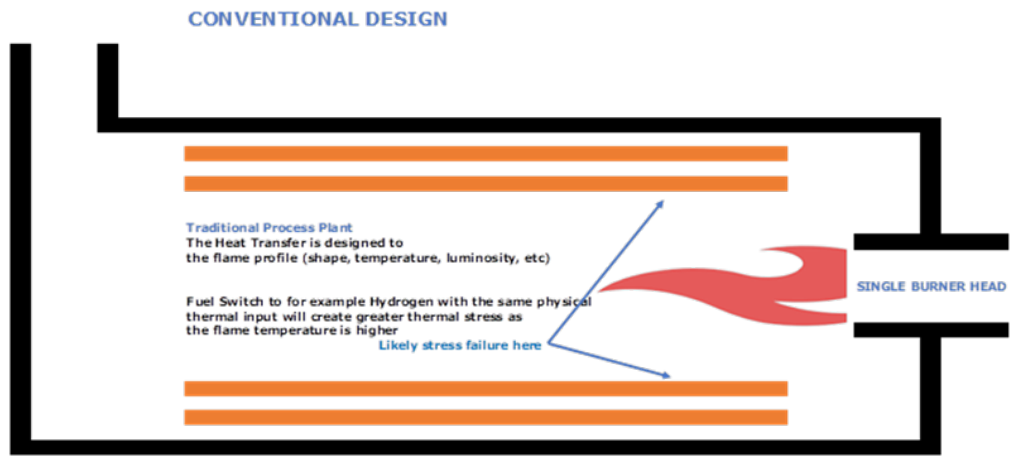
The charts overleaf show the wider implications to the SWIC and beyond as this technology could be replicated in high temperature processing plants up to 600°C. The technology has the flexibility and applicability for any future hydrogen economy. As a side note it is also important to mention that thermal oxidisers are sourced from the UK therefore limiting any Brexit related risk.

Industry-wide fuel switching will entail changes of thermal platform and the methodology of this change both in the generation & distribution of a centralised thermal platform as well as the conversion of a thermal process will demonstrate the principles by which that can be achieved in a critical process. Fuel switching will also involve changes of heat generation & distribution and the ASPIRE approach will highlight how risk areas can be identified and overcome to implement what superficially seems quite simple, but the geographic repositioning creates a challenge.

The diagrams overleaf demonstrate some basic overview to the fuel switch approach being progressed by CNR.



ASPIRE Fuel Switch Concept Thermally most sites have a mix of thermal requirements ranging from space heating, hot water systems through to medium temperature (~90°C through to just over 300°C) steam boilers, ovens, dryers and finally high temperature units that range from process heaters, furnaces & kilns that operate from circa 350°C to 1600°C. The approach at CNR is to demonstrate a fuel switch approach across these grades of heat demand and link this to a potential centralised 'Energy Park' providing the required energy vectors. The above represents the replication potential of the ASPIRE project. The process equipment in the green cells allows for direct replication straight away, the orange cells contain moderate temperature process equipment and the thermal oil heating platform that would require minor modification for replication across other sites in the South Wales Industrial Cluster (SWIC); and finally, the red cells which are the high temperature users (>300°C) that would require significant modification and design to replicate across various industries.



ASPIRE Fuel Switch Concept The project incorporates novel 'multi-fuel' burners with well proven 'oxidiser' combustion chambers and downstream heat exchange systems. The use of thermal oxidisers is a key part of the ability to actually 'fuel switch'. This approach gives good flexibility in composition of fuel and is able to handle many different flame profiles without any damage to the internals of the combustion chamber. The multiheaded burner will give confidence also, as the natural gas can always remain on standby and be used to top up any alternative fuel be it Syngas or hydrogen.

5 The Overall Vision

5.1 ASPIRE

5.1.1 Brief History

During 2017, Vale CNR and CR Plus began to explore options, at a strategic level, for the refinery to take a 'quantum step' in terms of OpEx reduction, carbon emission and environmental impact. CNR have a good track record of achieving significant sustainability related improvements including zero to landfill and more recently completion of phase 1 of a refinery-wide recycled water project.

From this exercise the Alternative Smart Platform for Integrated Refinery Energy was born.

Achieving such significant reductions in emissions is, of course, no mean feat. The scale of change required to what is a relatively established and complex industrial process is large. Furthermore, without cost or legislative drivers (natural gas remaining relatively low cost for process heating for UK Industry compared to alternatives), taking the first steps towards achieving ASPIRE milestones is challenging to sell within the higher-level corporate environment.

5.1.2 BEIS Industrial Fuel Switch

Following active engagement with local and regional networks (chiefly the South Wales Industrial Cluster of which Vale is an active member), CNR pursued the opportunity to progress ASPIRE via the BEIS IFS challenge and, having been successful with a Phase 2 feasibility study bid, undertook work that enabled the scoping of both a demonstration phase (Phase 3, See Section 4.1.3 and see Section 3) and also helped to build on both a development plan for new energy for the Refinery. The work undertaken also produced useful outputs to inform the wider replication potential for UK industry who will be in a similar situation to CNR.

In addition to the feasibility works undertaken by CNR and their appointed subcontracted team for the demonstration of end user fuel switching approaches, CNR also collaborated with Kew Projects for the Phase 2 feasibility bid to establish the feasibility for deployment of new on-site energy generation systems namely Advanced Thermal Conversion (ATC). Kew Projects have developed a high-efficiency advanced thermal conversion process (ATC) which converts a wide-range of biomass and residual waste into clean hydrogen-rich gas (Syngas). Used to produce electricity, hydrogen, or fuels whilst providing waste heat from the ATC process to local users – enabling over 70% of the energy in feedstocks to be utilised. This cutting-edge technology has been developed over 7 years alongside the ETI and is being demonstrated at the Sustainable Energy Centre (SEC) in Wednesbury in the West Midlands.

The collaboration included joint visits to the SEC and to the Clydach refinery, detailed gathering of CNR energy vector data for input into process modelling to determine an appropriate scale of modular ATC system to satisfy CNRs future energy needs in terms of power & heat and also in terms of hydrogen and CO.

In 2019, CNR, their appointed specialist sub-contractor, and Kew delivered feasibility work to investigate the potential for development of ATC based fuel switching at CNR, whereby on-site energy needs will be provided by ATC modules consuming locally sourced biomass and residual waste, utilising integrated energy vectors to work towards a net-zero carbon goal. CNR investigated distinct sub projects that could be delivered as part of the Phase 3 fuel switch demonstration. The technical challenges in this plan being the end user switching of medium temperature 'pellet-units' and higher temperature 'reduction gas heaters' from natural gas. The pellet-units produce the high-purity product, maintaining correct process conditions is critical for safety and quality.

5.1.3 Phase 3 – Industrial Fuel Switch Demonstration

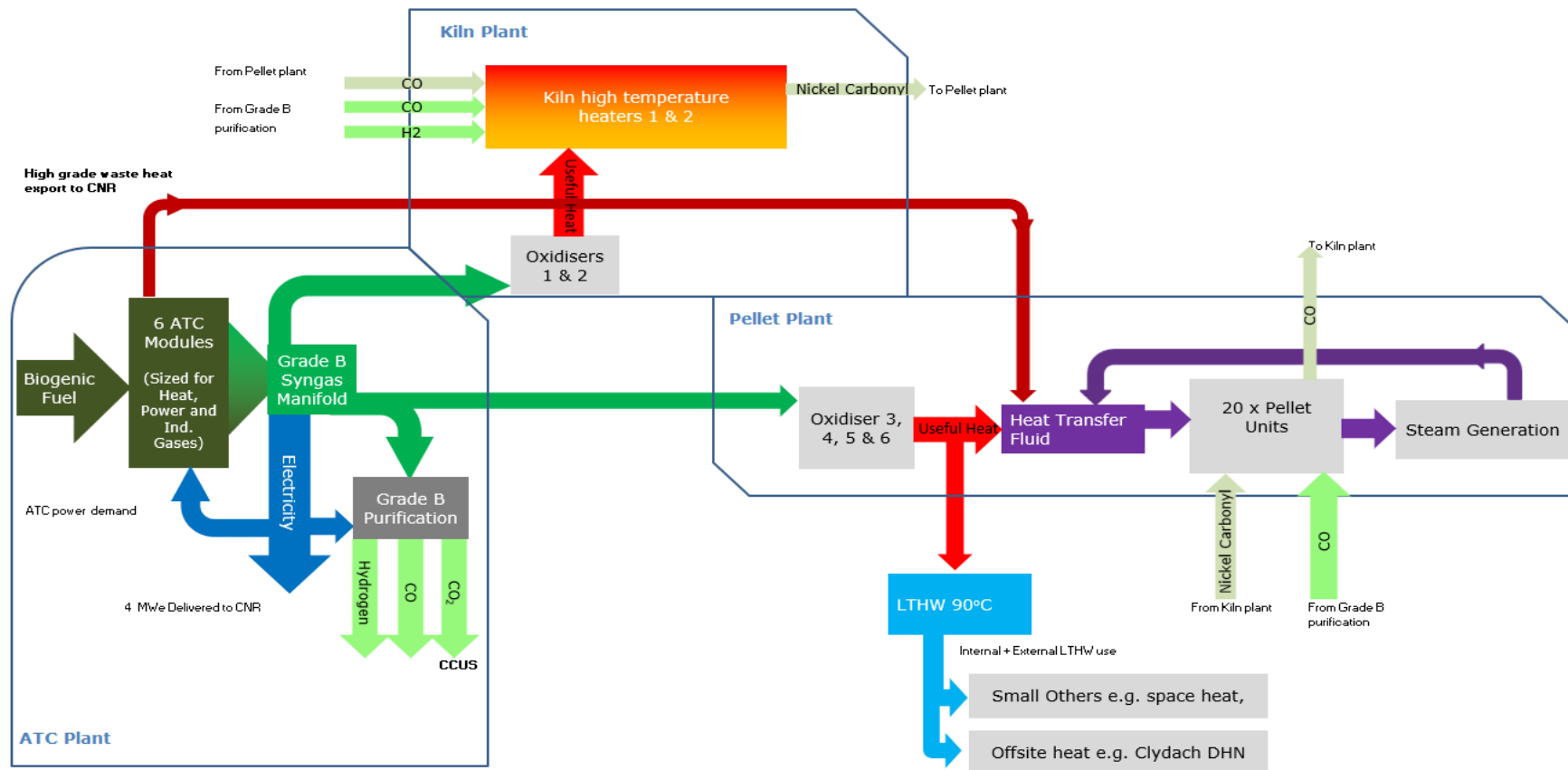
Phase 3 of Vale CNR's ASPIRE plan focuses on the end aspects of fuel switching, with focus on delivery of 'fuel switch ready' thermal equipment to replace low, medium and high temperature process heating applications. This has been discussed more extensively in other Sections.

5.1.4 Phase 4 and Beyond – Industrial Fuel Switch Demonstration

Phase 4 intends to see one to two ATC modules installed at CNR as a commercial demonstrator and steppingstone to further installations.

The full ASPIRE vision (Phases 5 and beyond) includes a total array of six ATC modules providing the site's entire energy and industrial gas needs, with innovative small-scale Carbon Capture and Utilisation, which could enable a net zero Carbon approach.

Overleaf presents the energy flow scenario for the ultimate vision.



ASPIRE Ultimate Vision. Natural gas will become a backup to hydrogen-rich Syngas and waste heat produced by ATC modules; the energy will be transferred to the process, heating end users, via hydrogen-rich Syngas and/or 98% pure hydrogen for combustion in new combustion equipment (proposed to be demonstrated in IFS Phase 3). Refined hydrogen and CO will be produced, replacing the requirement for the existing SMR or investment in a new SMR. CO₂ capture methods will be trialled and put into operation, with some CCU options being explored in tandem with the fuel switch via local and regional small-scale demonstrator schemes (e.g. Reducing Industrial Carbon Emissions - 'RICE'). Residual Syngas energy will also be utilised to produce on site electricity to effectively take CNR off the electricity grid. Finally, remaining lower grade energy (heat) will be used to service the site's space heating and possibly also heat demand for the local village of Clydach ('free heat' to the local residents).

5.2 Development Plan at CNR

5.2.1 2020 to 2025 – Sub Projects A, B, C

In the conclusion of Phase 2, CNR have produced detailed Gantt charts to plan the successful delivery of 3 installed sub-projects by March 2021.

These projects will focus on utilising public funding to overcome the significant challenge relating to process change using an alternative fuel switching approach (discussed in other Sections of this document).

Achieving proof of the switching of process heat end users for lower, medium and higher grade heat processes and being able to install and demonstrate alternative heating platforms (for example heat transfer fluid), will significantly enhance and accelerate the deployment of the proposed core ATC technology (or alternative). In short, being more certain that the energy vectors derived from a new ATC module/s will be an enabler for significant capital decision making when compared against the 'like-for-like' approach, thus increasing the chances of a fuel switch and alternative hydrogen supply future for CNR instead of at least 2 to 3 more decades of standard natural gas fired process heating.

5.2.2 2020 to 2025 – Sub Projects D and Beyond

The phase 3 proposal also includes Project D which includes specific 'post Phase 3' enabling activities. One example is the undertaking of planning, permitting and COMAH addendum for the ASPIRE vision (6 ATC module system) and further process modelling to inform correct design and specification. To repeat previous points, this is to maintain enough momentum to enhance the chances of successful fuel switch exemplar roll out at CNR.

5.2.3 Ultimate Vision Cost Estimations (CapEx and OpEx)

Detail within costing exercises undertaken remain commercially sensitive. However, the high-level anticipated capital required to achieve the complete ASPIRE vision is just over £100M (including phase 3 costs). Some aspects of the breakdown of the capital costs are commercially sensitive however the following table provides the best estimate of CapEx for the complete version of an implemented ASPIRE project including the normal contingencies.

Ultimate ASPIRE Vision – CapEx

Items	Budget
Kew ATC System (6 module system)	
Commercially sensitive but includes modules required to create a clean Syngas (CO & H₂) as well as the equipment required to generate 98% pure H₂ and 99.8% CO.	£58,200,000

CNR Works Associated with New ATC System/New Energy Vectors	
CNR Integration Works	£4,000,000
CNR CO Purification	£1,000,000
Civils & Buildings	£4,000,000
Abatement & Stack Mods	£3,000,000

CNR Plant Changes required to optimise Vectors and Fuel Switch	
2nd Reduction Gas Heater (Oxidiser #2)	£1,200,000
19 Pellet Unit Preheater "Conversions" incl. Distribution	£9,500,000
Oxidisers for Steam Back-up & Wider Thermal Oil System	£3,000,000
Hot Water Systems	£1,000,000
ORC's	£4,000,000
Design, PM, H&S	£5,000,000

Total beyond Phase 3 if successful =	£93,900,000
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Approximate costs including all contributions for Phase 2 & Phase 3 (if successful)	£8,800,000
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Overall Total	£102,700,000
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Benefits & New OpEx

The overall completed ASPIRE benefits can be grouped as follows:

Reduction of Grid Supply Costs

Natural Gas Grid Cost Reduction:	250,840 MWh	£5,097K
Electricity Grid Cost Reduction:	40,358 MWh	£3,430K

OpEx for current CNR Plant that will be Replaced

In this case there is significant cost centred around the OpEx for existing plant that will be eliminated with the implementation of ASPIRE. **£2,000K**

Commercially sensitive for breakdown

Income from RDF Gate Fee

Gate fees are difficult to quantify as they are subject to high degree of commercial sensitivity. The Letsrecycle.com website assumes £90-£100 typical range 2019.

<https://www.letsrecycle.com/prices/efw-landfill-rdf-2/efw-landfill-rdf-2019-gate-fees/>

Assuming £65/t for 83,000t/y RDF project use the income = **£5,395K**

OpEx for Proposed Gasification Plant

There is significant cost to operating a gasifier including chemicals, labour, engine maintenance. **£5,500K**

Commercially sensitive for breakdown

Overall Net Benefits off ASPIRE to the site would be £10,422K

As CNR are exempt from EU ETS which would increase benefits to those mentioned above.

Thus, the high-level simple payback period is circa 10 years.

Overleaf presents:

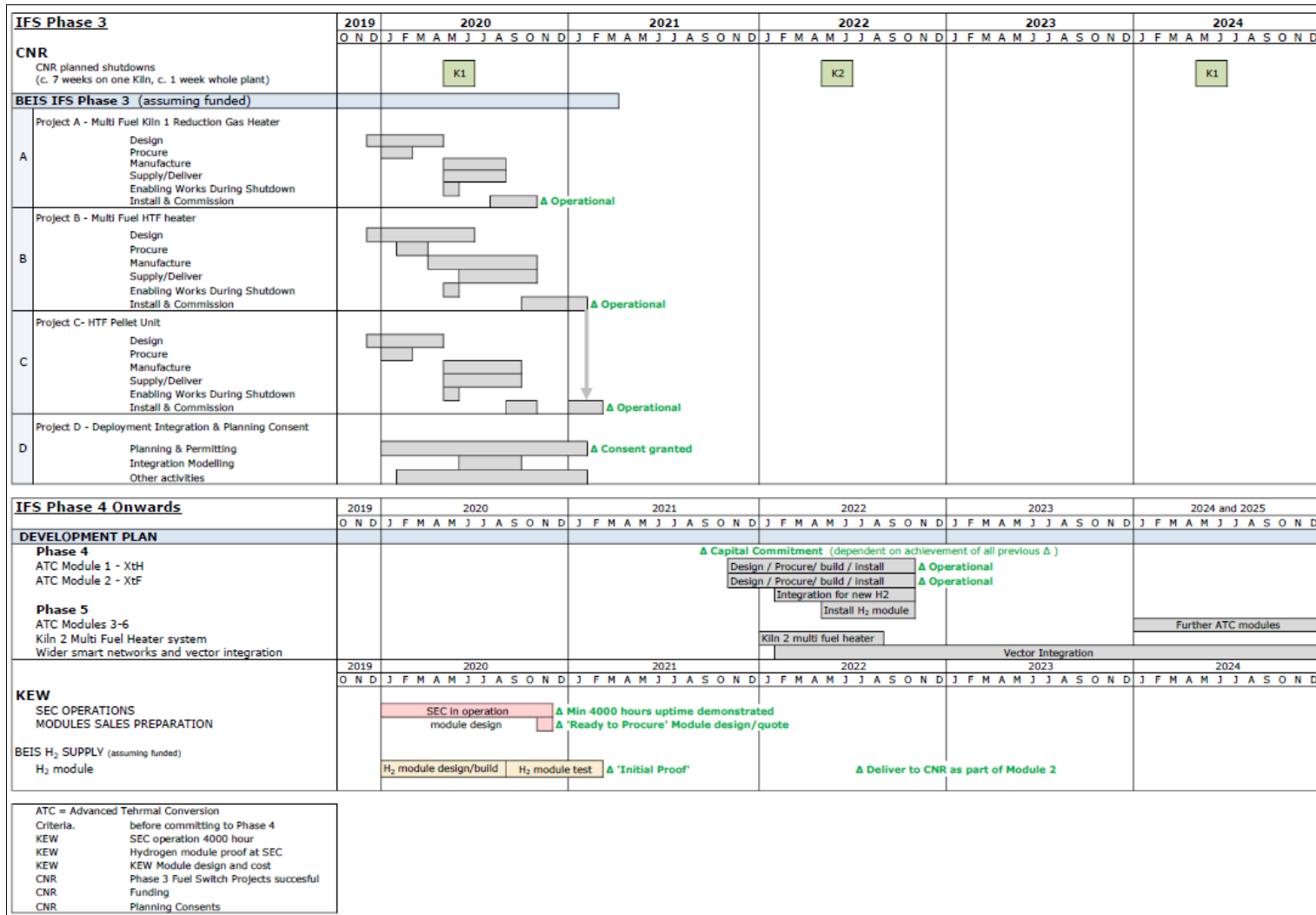
1. The shorter term ASPIRE delivery matrix as planned during Phase 2 IFS.
2. The Development Plan for ASPIRE at CNR.
3. An example of the fully deployed 'Energy Park' sized to deliver all the required energy vectors for CNR (based on current demand + incorporating an uplift factor for an increased Nickel production output from CNR).

5.2.4 Timescales and Development Plan within CNR

The ASPIRE project is, by its very nature, a long-term project and the timescales of the project plan reflects that. The timescales surrounding the project are reflective of the risk mitigation involved on the CNR site; due to the COMAH status of the site, any change of process has to be sufficiently de-risked to ensure safety onsite and this simply takes time and resources. The following diagrams highlight the timescales and deliveries expected by the end of Phase 3 (2021) and then beyond.

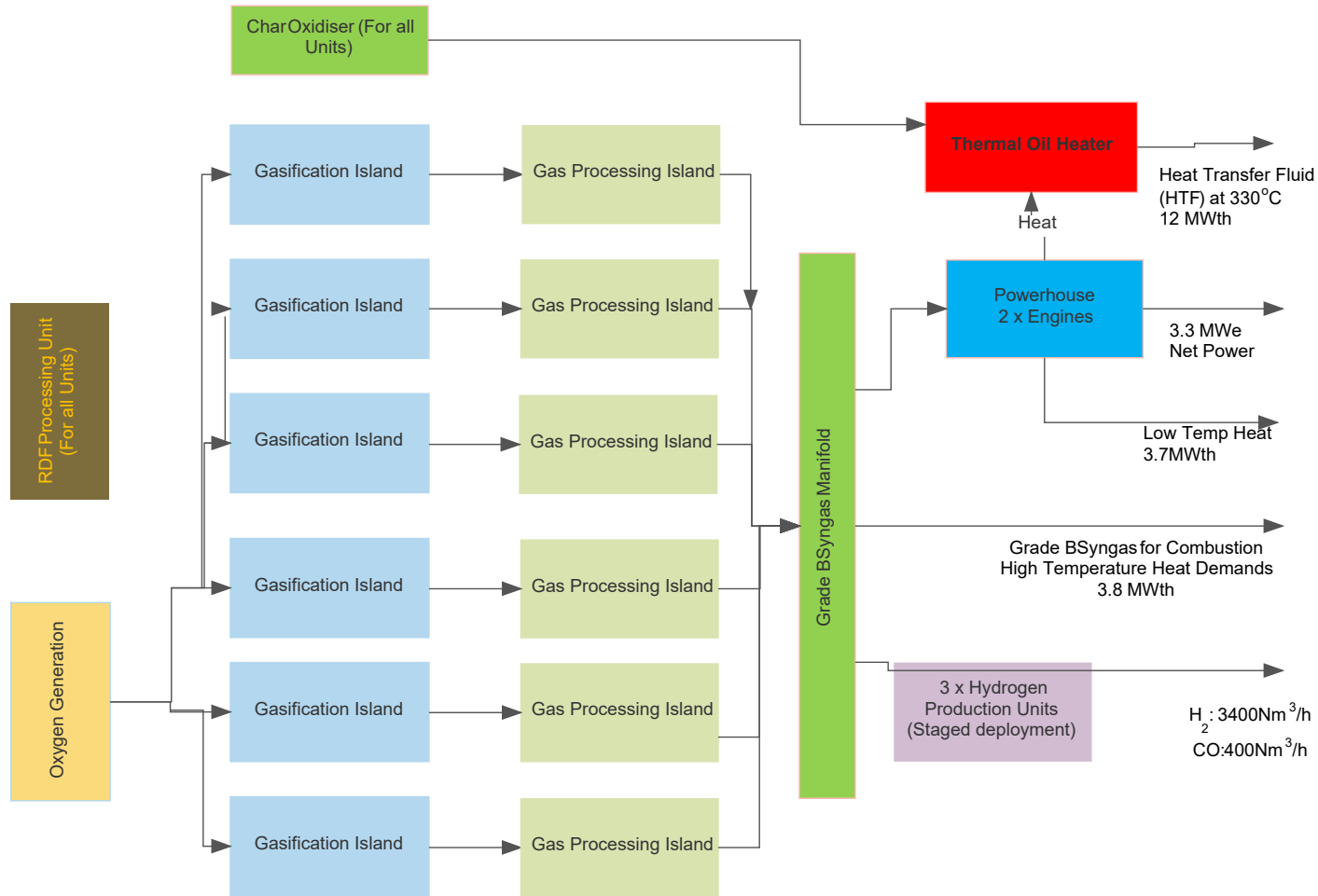
Target Achievement at End of Industrial Fuel Switch BEIS Phase 2 (Oct 2019) and End of BEIS Phase 3 (March 2021)										
Stage Reached >	Concept & Light Feasibility	Detailed Feasibility	Outline Design + Costing	Detailed Design + Costing	Specification	Procurement	Installation	Commission & Optimise	Action & Comments	
Project A	1. Duel Fuel Heat (Oxidiser 1) to KILN #1 Hydrogen Heater	✓	✓	✓	✓	✓	✓	✓	✓	Installation remote from Kiln plant commission offline ready for final connection Kiln #1
Project B	2. Duel Fuel Heat to HTF and LTHW (Oxidiser 3)	✓	✓	✓	✓	✓	✓	✓	✓	Installation linked to BEIS Phase 3
	3. New HTF Steam & LTHW Generation	✓	✓	✓	✓	✓	✓	✓	✓	Installation linked to Mid 2020 Shutdown
Project C	4. New HTF Pellet Unit	✓	✓	✓	✓	✓	✓	✓	✓	Installation not wholly shutdown dependent
Project D	5. Gasification Module On Site	✓	✓	✓	✓	✓	✗	✗	✗	Specify first Gasification Module for deployment at CNR. Hydrogen Supply comp taking to detailed feasibility
	6. Electrical Generation	✓	✓	✗	✗	✗	✗	✗	✗	Ensure Syngas based electricity gen implementable with site and DNO infrastructure (embedded generation)
	7. Smart Networks	✓	✗	✗	✗	✗	✗	✗	✗	Define MWth future vision. Define opportunity for possible H ₂ Network
	8. Process Gas Plant (SMR) replacement	✓	✗	✗	✗	✗	✗	✗	✗	Any development (Grade A Syngas) as part of further Hydrogen Supply further works
Key	✓	= Delivered Phase 2 (Oct 19)			✓	= Deliver Phase 3 (Mar 21)		✗	= Not Delivered Phase 2 or 3	

ASPIRE Phase 3 Project Progression Matrix. The above matrix demonstrates the phase of project progression in relation to BEIS' Industrial Fuel Switch funding support Phases 2 and 3.



ASPIRE Development Plan at CNR (Phase 3 and beyond). Fuel switch end user proving projects will be delivered during proposed fuel switch phase 3, during which time ATC technology will be progressed. In subsequent years the first module/s will be deployed as first commercial demonstrators, followed by deployment of the full ATC array and integration into site energy systems.

Energy Park - Fully Deployed

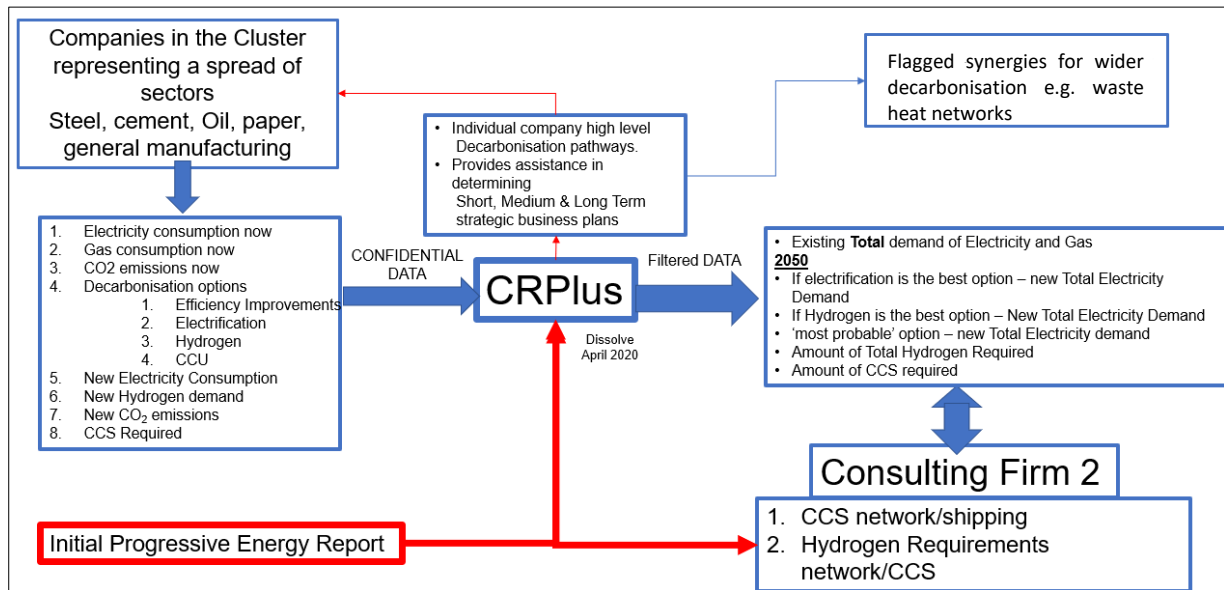


ASPIRE 'Energy Park' at CNR (Overall Vision): an array of 6 ATCs sized to deliver the required mix of energy vectors at Vale CNR.

5.3 Development beyond CNR

5.3.1 Replication Potential and Additionality

South Wales Industrial Cluster (SWIC) is developing a holistic approach to net zero carbon with CNR & CR Plus playing a prominent role in developing a practical route to net zero carbon. This approach is encapsulated in the below diagram.



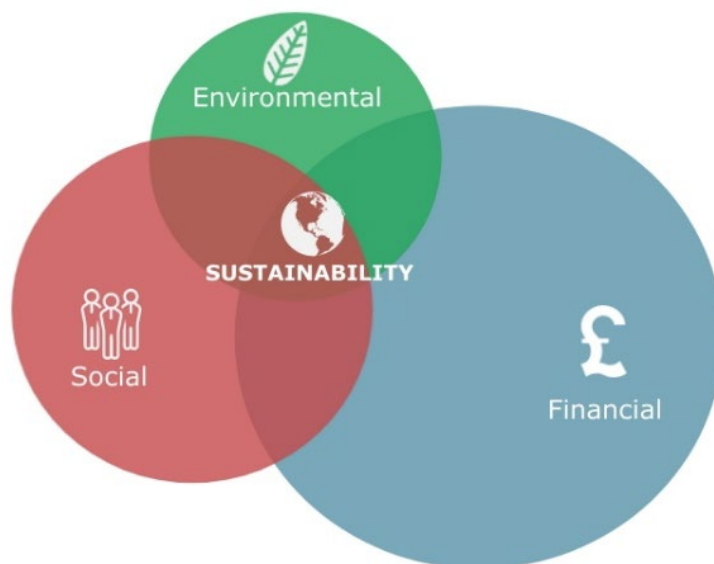
Energy efficiency is still the most cost-effective step towards net zero carbon but must be followed by additional steps. At some point in the future, there will be an economic framework that will enable larger changes to be made, but in the short & medium term SWIC is taking the view – “what can be undertaken that provides industry with clean growth” as continuing with the carbon route is not desirable. However, if a fuel switch to electric heating wherever possible was made by UK industry tomorrow, the day after most industry would close. The Kew modular system combined with the fuel switching equipment, that also uses the waste heat vectors allows some equipment to be changed now without compromising future opportunities.

Achieving a correct balance to maintain global competitiveness will be the UK’s greatest challenge. The ASPIRE vision or flexible framework will contribute towards a “here & now” contribution whilst still being able to interface with longer term changes in, say, 2050.

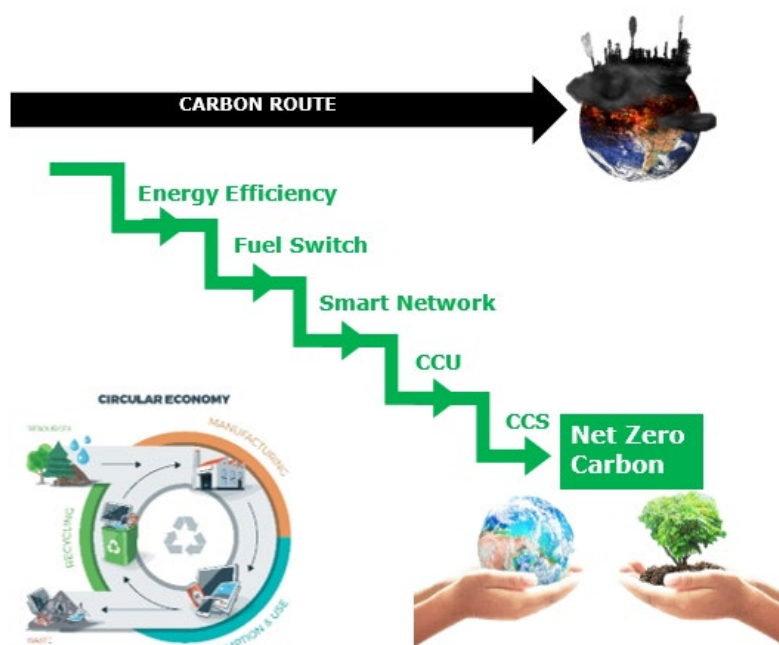
6 Pathway to Net Zero Carbon

6.1 Core Principles

Sustainability, at its core, must always satisfy three principles: people, planet, and profit. In the context of industry, profit is always going to be large and is often the deciding factor, as to whether an idea is viable and therefore sustainable. Vale's Clydach Nickel Refinery (CNR) recognises this and has conceptualised a project that not only fulfils the goals of the refinery's decarbonisation and financial plans but can extend to wider applications and benefits for Government and UK industry.



6.2 The ASPIRE Pathway



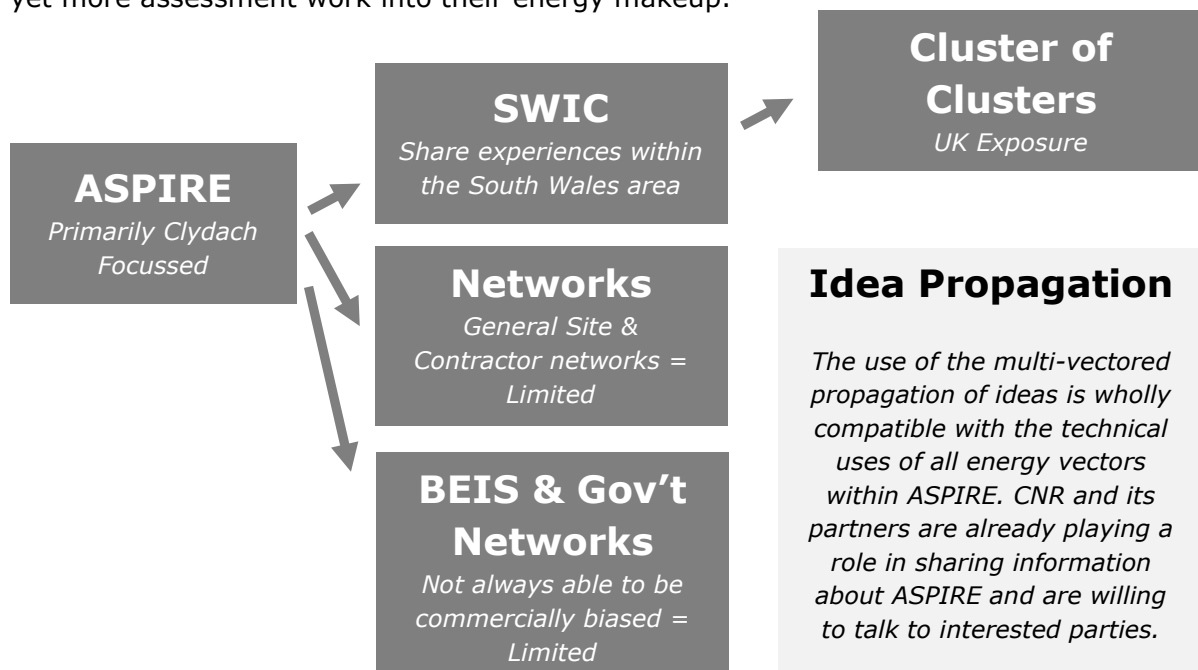
The nickel refinery has, in recent years, been taking strides to reduce its carbon impact by implementing many energy efficiency projects and some environmentally beneficial projects to move towards true sustainability. The ASPIRE project is the only sustainable way forward that CNR sees to moving the site wholesale to decarbonisation and remaining competitive in the global nickel market. Without this project, the

site will be forced to replace plant equipment with like-for-like due to risk mitigation and potentially then have to replace this equipment again in 10 years' time (with only half of the plant's lifetime utilised) to implement a low-carbon alternative. To avoid this CapEx hit in the future, and do the right thing, CNR are pursuing the decarbonisation route now.

CNR is a top-tier Control of Major Accident Hazards (COMAH) site, positioned near the village of Clydach, meaning that any project that changes the process at the refinery must be guaranteed to succeed. Although, CNR is unique in this area, industry generally suffers from the fundamental fact that the lower risk option for replacing plant equipment on site is 'like-for-like' due to the large upfront CapEx cost of sufficiently de-risking the change of process. Also, and crucially, plant must be reliable and maintainable. This provides a large amount of inertia against decarbonisation in industry.

Therefore, the main issue to overcome is the obstructive CapEx cost of de-risking key changes of processes surrounding energy vector deliveries. Hence, through the demonstration of key switching technologies on live plant and processes, the safety and performance are proven, ready for other plant equipment of the site to be switched to low-carbon fuel supplies either through retrofitting or when the plant is ready to be replaced.

ASPIRE is similarly beneficial as the replicability of the core principles of fuel switching within ASPIRE is far reaching within many sectors that Vale has been conversing with the South Wales Industrial Cluster (SWIC). The other options foreseen in the future for switching energy vectors on the Clydach site, namely a hydrogen system supplied with Steam Methane Reformers with Carbon Capture Storage attached (SMR/CCS) and electrification, each have immediate issues surrounding them that will impact the direct switching from, say, natural gas to one of these energy forms. Thus, the replicability of these competing technologies, from a wider industry standpoint, is not simple and requires yet more assessment work into their energy makeup.



CNR have always been very open to sharing information with others both internal and external to the company. A recent example of this is the involvement in the Onsite Insights program where visits are hosted twice a year to share experiences in lean, continuous improvement and engagement of our staff. Historically, these visits have been attended by a wide range of industries from Welsh Water to Cummins to Fisher Scientific Instruments and CNR have attended visits in other companies like BMW and Altro flooring to learn from them and provide feedback on areas they could potentially improve on.

Through this programme, ASPIRE's success and core discoveries can be disseminated to other industries.

The site's membership with SWIC also provides a unique set of circumstances to develop the fuel switching principles that will be applicable to many sites; publicise them; and, with the related SWIC activities, assess the overall applicability beyond this site. The current head of SWIC is aware of this project and is also part of the Cluster of Clusters meaning he can present progress to decision makers. Through SWIC, the site has access to academic programmes in the region, such as RICE & FLEXIS, which is allowing access to information that is helpful to establishing data on competing routes and integrating ideas on possible future technology into the project programmes by leaving doors open.

Other industry is undoubtedly in the same position as the CNR, with ageing equipment that needs replacing, but without enough resources, in time or CapEx, to investigate the low carbon routes. Therefore, without demonstration of the fuel switching technologies in ASPIRE, equipment will be replaced 'like-for-like' and industries will have to accept the carbon impact as technically avoidable but not financially viable at the time. This will then reflect onto one of the key aims of Government going forward: Clean Growth. Where this matched replacement of plant fits neither tenet of 'Clean', reducing CO₂ emissions, or 'Growth', since the same potential can be expected from any similar piece of equipment with little redesign.

As ASPIRE covers a range of thermal low-carbon solutions, the number of industrial demonstrating projects can be included under one umbrella in a truly integrated holistic approach.

6.3 Potential High-Level UK Government Impacts

Another benefit of project ASPIRE is the avoidance of a large sum of subsidy on the part of UK Government with SMR/CCS hydrogen networks. To remain competitive on the global market, the provision of energy must be comparable to what it is currently, to avoid the mass closure of UK industry that simply cannot afford an OpEx rise from utilities.

Although this is difficult to find external references for, the following internally supported assumptions have been made.

- The current cost of hydrogen gas production using an the SMR at CNR (existing 40-year-old process gas plant) is circa 7 p/kWh.
- BEIS references a report within their "*HYDROGEN SUPPLY PROGRAMME – PHASE 2, An SBRI Competition: TRN 2039/09/2019, Programme Guidance Notes*" stating a range of 2-5 p/kWh for SMR with CCS.
- Based on CNR knowledge of its own costs, the feedstock can't change but the energy consumption can reduce, and labour & operating costs will be lower. However sustaining CapEx and/or depreciation costs are significant.
- CCS nor carbon emission charges are not included in CNR's figures.

- Based on known operating costs and potential efficiencies the lowest cost would be circa 3 p/kWh moving towards 5 p/kWh.
- Therefore, a low case assumption is to use the lowest plausible figure of ~3 p/kWh for H₂ supply with CCS.
- Thus, a subsidy of approximately 1 p/kWh will be required in a hydrogen-network future.
- One gasifier unit supplies ~5,000 kW of Syngas plus additional vectors not included.
- Then for 8,000 h/y operation over 25 years a UK Gov't subsidy of ~ £10M would be required in order not to penalise industry.
- If 100-125 modules were installed, then the lifetime savings in SMR/CCS subsidies would be circa £1bn depending on how the carbon storage cost progresses. If the higher price of H₂ is used the subsidy could increase to 3 p/kWh or ~£3bn.
- 100 modules represent approximately half the exported RDF market, meaning this quantity of installations does not detract from the current UK market serving existing EfW plants.

6.4 Pathway to Net Zero Carbon Summary

ASPIRE plans to begin to deliver the necessary skill set, infrastructure and economic justification to progressively deliver a carbon neutral site, with fuel switching at the core, with iterative implementation of energy efficiency projects and smart network integration. The methodology creates a solid foundation on which to base the next step. In this way, the ASPIRE vision can respond to the inevitable changes in political, financial, technological and environmental drivers/pressures and grow the site forward cleanly in a globally competitive market.

Additional to the clean growth aims, the ASPIRE ultimate vision is to provide a clean source of low-grade waste heat to the well-placed village of Clydach and to bring the site's current system up to a competitive position with the implementation of a smart, flexible monitoring system that foundation industries have struggled to keep up with. This digitalisation is at the heart of Vale's future plans and ASPIRE will implement the instruments and sensors that feed into developing models necessary for the industrial site.

CNR and members of the South Wales Industrial Cluster (SWIC) also have a pathway laid out (presented in Section 6.2) to achieve clean growth through the following routes of reducing carbon, in order of their priority: energy efficiency, smart networks, fuel switching, CCU (chemical & biological), and CCS.

CNRs strategy for decarbonisation aligns with governmental policy on "clean growth", its own corporate pressures, South Wales regional ambitions and local geographic opportunities.

7 Risk and Opportunity Summary

7.1 Understanding Risk and Opportunity for Complex Decarbonisation Projects

Understanding how an organisation manages risk & opportunity (R&O) through the project Journey is key to achieving as successful an outcome as is practically possible and CNR use a variety of techniques to help this process.

As ASPIRE is comprised of a portfolio of projects with interaction between each, the nickel refinery recognises that it is crucial that risk is managed, and opportunities are capitalised on throughout the project's journey in definition and completion. To do this effectively, key stakeholders have to be continuously involved and informed throughout the whole journey rather than simply at key milestones when it may be too late to mitigate or capitalise upon the points raised.

Internal Stakeholders Engaged

For the feasibility study of ASPIRE the following key teams were identified and engaged early on.

- **Senior Department Management Team** – covering Production, Projects, Procurement, Finance, Technical and QSHE.
- **Operational Teams** – Pellet Plant, Kiln Plant, Gas Plant.
- **Technical Team** – to understand some of the detailed chemical processes that are being undertaken on site.

External Stakeholders Engaged

Liaison with external stakeholders to gain support or assistance has been undertaken in several areas as well:

- **Welsh Government (WG)** – account manager has been informed and brought up to date together with WG representatives at SWIC. This is helping to collate positive feedback and potentially act as a forum for any criticism that may exist.
- **Sub-contractors** – engaged as often as is practical; CR Plus, Kew, ECL, Flex Process and University of South Wales. This has enabled feedback as to the potential alternatives to the inputs and outputs of ASPIRE that could interact with other stakeholders.
- **South Wales Industrial Cluster (SWIC)** – platform to disseminate and gather ideas than can develop the ASPIRE fuel switching concept.
- **Local Government** – to start considering the long-term possibilities. This included the long-term possibilities of providing heat to Clydach Village (c. 7,500 people and 3,400 homes). (Information, Research & GIS - Swansea Council, January 2019).

7.2 Technical Risk of integration into industrial processes

Changing the thermodynamic flows will have associated risks to processes that have contracts to fulfil with customers.

One of the main features to arise from the Phase 2 feasibility study is the requirement to model the industrial processes affected in order to mitigate technical process/product risk. Detailed modelling has been included for the areas of plant that will be affected by the change. Modelling combined with the appropriate Risk & Opportunity control will help minimise the changes that have to occur in a fuel switch. Covering off the process technical risk as opposed to the thermal energy Technical risk should not be underestimated and any Fuel switching programme must deliver this to industry in a way that it understands.

Modelling will ultimately have a side benefit as digitisation will have to be improved to obtain and monitor those changes through the switching programme.

7.3 Challenge of CCS at a Large/Medium Industrial Site

Phase 2 highlighted 28 significant emission points from combustion plus several small points relating to space heating. One of the process plants proposed in Phase 3 will address 3 different energy vectors with the conversion of natural gas decentralised units to a centralised thermal platform paving the way to a single point of emission (the existing main stack). This will enable CCS to occur when viable. Utilising work undertaken for SWIC; it has been estimated that CCS could be possible by connecting CNR to the proposed Port Talbot CO₂ collection point.

Transport, including costs associated with; compression and cooling, temporary onshore storage, loading, shipping, unloading, gasification, CO₂ emissions and other operation costs to the Liverpool CCS hub would cost £17.4/tCO₂ (*based on data provided to the South Wales Industrial Cluster from Progressive Energy who in turn utilised data from work undertaken by Element Energy for BEIS in 2018* consisting of a review of the costs of shipping carbon dioxide). Additional costs would include the capture at the CNR main stack and land local based transport via a 17-mile pipeline that passes several other SWIC members sites.

This demonstrates how sites can prepare for CCS, which in combination with part or fully renewable fuels, allows some sites to go beyond “net zero carbon” helping the geographic region, in this case Clydach Ward, move towards their goal of “net zero carbon”.

7.4 Utilising Waste Heat

The systems proposed in Phase 2 lay the foundation to utilise other energy vectors such as Waste Heat that is created in the formation of the Kew Syngas grade B (CO & H₂ mix) and grade A (purer CO & H₂ streams). Understanding the further integration and developing the specifications to take advantage of the potential in later phases is key to maximising local progression to “net zero carbon”. Demonstrating Waste Heat Recovery (WHR) energy vector potential within the gasification process is key in establishing those future sites that are more suited to optimising to the greatest possible extent the waste heat vectors that are possible.

8 Greenhouse Gas Summary

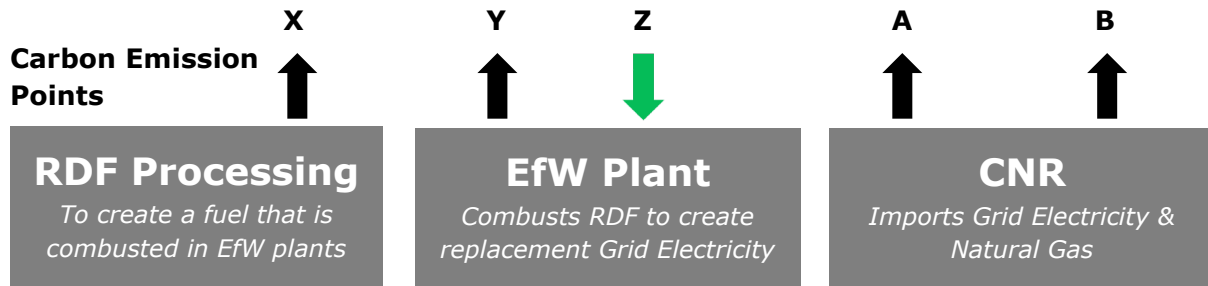
8.1 ASPIRE Decarbonisation

This section briefly summarises the conclusions drawn from the carbon modelling to assess the high-level impact on greenhouse gas emissions for the proposed solution.

The carbon savings set to be realised in Phase 3 alone are minimal due to the risk mitigation necessity to rely upon natural gas as the medium to deliver thermal energy to the heat transfer fluid. However, it is the imperative first step that CNR has to take to enable its energy intensive end users to decarbonise. Project ASPIRE begins by laying the foundations for progressing along a decarbonisation route over the next 10 years at the Clydach site to ultimately reduce CO₂ emissions and transition towards net zero carbon with later iterations including integration of novel carbon capture and utilisation. This is stepped in nature due to the site's COMAH status and necessity for 24/7 production, but the technologies proven in phase 3 allow the refinery to incrementally decarbonise. This is always expected at the outset of any decarbonisation effort: there is no quick fix to the issues facing industry, but project ASPIRE, and emulations in other sectors and sites, will permit CNR and other suitable industry as a whole to progress towards net zero carbon and achieve clean growth.

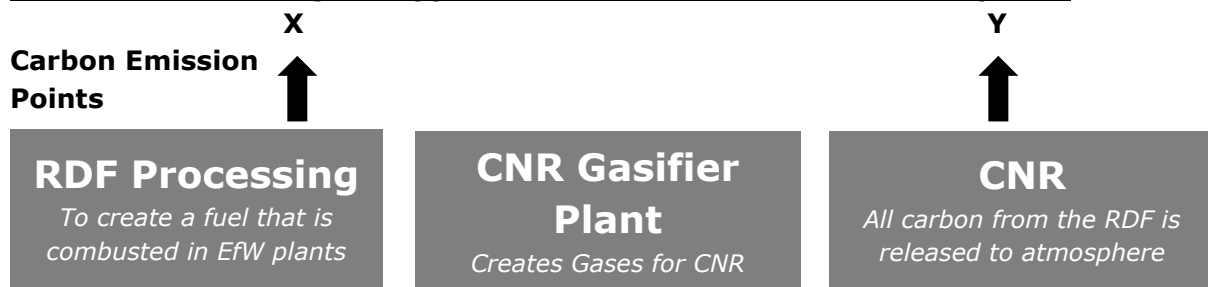
When considering the CO₂ implications of ASPIRE on the UK as a whole a number of methodologies have been investigated but by far the most simple and realistic assessment was to assess what happens to CNR and what happens to the RDF that ASPIRE will consume to make CNR independent of importing grid electricity and natural gas.

Counterfactual^{#1} – CNR uses grid supplies, whilst RDF is used within EfW plants



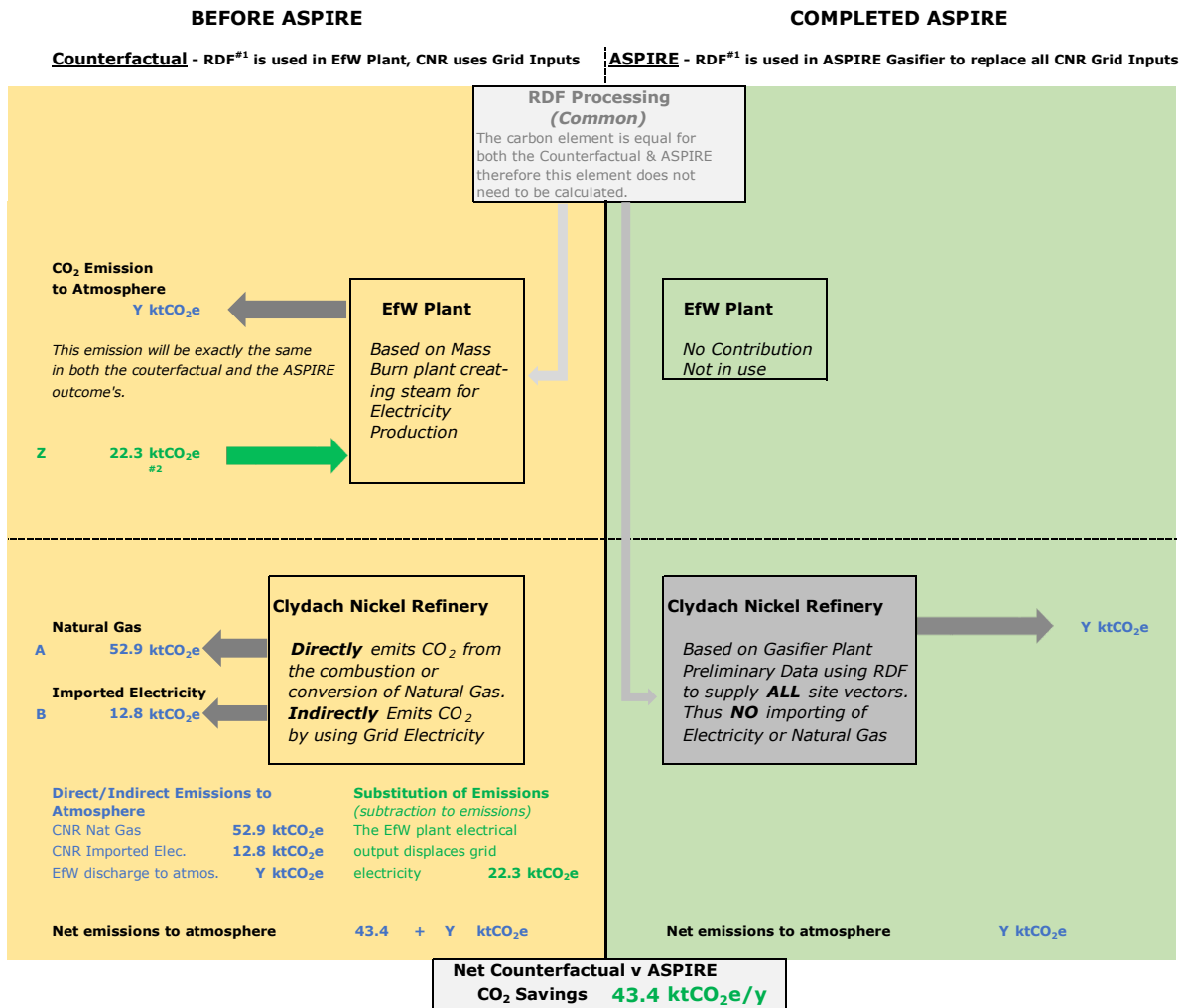
- X** – The emissions associated with the production of RDF (*amount of RDF required by ASPIRE*)
 - Y** – The emissions released to atmosphere from chemical conversion of RDF (*Counterfactual = incineration. ASPIRE = advanced thermal conversion, downstream use of Syngas*)
 - Z** – The emissions replaced by substituting grid electricity (*power exported by EfW*)
 - A** – CNR direct release of emissions by combusting natural gas
 - B** – CNR indirect emissions by importing grid electricity
- ^{#1} – There are other RDF outlets including; landfill and exporting, both of which may decline.

ASPIRE – CNR uses grid supplies, whilst RDF is used within EfW plants



Counterfactual Carbon	ASPIRE Carbon
X + Y - Z + A + B	X + Y
Simplified Difference when eliminating common variables	
- Z + A + B	

Emissions associated with both the RDF preparation processing and the EfW or gasifier outputs are common to both sides of the equation and therefore can be eliminated when considering the difference between the counterfactual v ASPIRE. The figure below summarises the net carbon benefit for ASPIRE implemented at CNR.



^{#1} - RDF - Refuse Derived Fuel is currently used in EFW plants (Energy from Waste) either in the UK or Exported with occasional Landfill

^{#2} - The calorific value of RDF can vary but is equal on both sides of the equation (Counterfactual v ASPIRE)

This simplistic view of the net carbon benefits has many interesting outcomes that support the robustness of the calculation.

- 1) The RDF composition will change with time as variables change, an example being the amount of plastics recycled in the waste market. This will increase or decrease the amount of mass of RDF that is required by ASPIRE however, the energy required by the plant will be consistent. **Y** may change again on both sides of the equation.
- 2) If the gasifier system or the users of the gasifier energy or chemical outputs are inefficient, the net carbon savings will decrease as **Z** will increase i.e. the electrical contribution to grid replacement by the EFW plant. Thus, to deliver the largest contribution towards net zero carbon, ASPIRE lends itself to industrial sites that can make use of as many vectors as is practically possible (*Syngas for combustion, Syngas for hydrogen, electricity, waste heat*).

Details of the calculations for Z, A & B are as follows:

ASPIRE - Carbon Modelling

Grid Natural Gas used by CNR (Annual)

0.2078 kgCO₂e/kWh 255 GWh
#3 254,840,045 kWh natural gas

A = 52,946 tCO₂e

Grid Electricity used by CNR (Annual)

0.3160 kgCO₂e/kWh 40.4 GWh
#2 40,358,256 kWh delivered electricity

B = 12,752 tCO₂e

A+B = 65,698 tCO₂e

RDF required for ASPIRE or the Counterfactual use of RDF (Annual)

83,000 tonnes RDF required
15,300 kJ/kg RDF #4
1,269,900,000 MJ
352,750,000 kWh

20% #1 efficiency of electrical generation at standard EfW
70,550,000 kWh electricity 850 kWh electricity per tonne
70,550 MWh electricity
8.4 MWe 8,400 hours

Z = 22,292 tCO₂e

Net Carbon Change A+B-Z

43,406 tCO₂e
66% tCO₂e

#1 Energy recovery for residual waste. A carbon based modelling approach. Feb 2014 paragraph 133, paragraph 149, paragraph 150

#2 Uses BEIS published grid carbon factors (including T&D)
Energy recovery for residual waste. A carbon based modelling approach. Feb 2014 paragraph 69 - actual higher marginal for CCGTs = 0.373 kg/kWh
Please note using "Marginal" figures increases carbon savings

#3 Uses BEIS published grid carbon factors (including T&D)

#4 Based on market research carried out by KEW as part of IFS phase 2.

8.2 Beyond ASPIRE Decarbonisation?

ASPIRE has been constructed to leave the door open for additional carbon benefits that are currently outside of CNR's control and have not been included in the above analysis.

CCUS

As ASPIRE is reducing its carbon emissions to a single point it will be relatively straightforward to capture carbon when the economics are sufficiently formed to de-risk future investment. ASPIRE has several different routes:

- Water gas shift the CO to create concentrated CO₂ within the gasifier gas stream allowing CO₂ capture.
- CO₂ capture from the exhaust emission point from the various systems at CNR.
- Utilisation of CO₂ – CNR is exploring the use of CO₂ in cultivating Algae for its potentially valuable component products, though initial results show low values of carbon are used in this way.

It could be argued that the counterfactual case would also be capable of the last two bullet points, though residual contamination in the counterfactual EfW case (incineration) may result only the CO₂ sourced from the first bullet point being suitable. The ASPIRE approach offers greater technical solutions for CCUS and the opportunity to design in allowance for CCUS from the outset. This demonstrates how potentially confusing it is to create carbon claims that need few caveats.

External Energy Vector Users

ASPIRE aims to optimise multi vector energy use internal to an industrial site but also explore opportunity to optimise multi vector energy use external to an industrial site. There will be residual low-grade heat after the on-site usage of energy/chemical vectors has been optimised. This will be in the form of hot water somewhere between 5-7MW at circa 90°C and a similar amount of energy that could be extracted from the single emission point but at the lower temperature of circa 50°C. In the case of CNR which is located adjacent to a village with a population of >7,500 and housing stock of c. 3,400 (2017 ONS data), there is the opportunity for aligning stakeholders early on, so a modest sized District Heat Network (DHN) serving the Clydach area could further decarbonise its heating demands.

Beyond ASPIRE Conclusion

ASPIRE has effectively been designed to leave future decarbonisation routes open so that when the social, economic, technical and environmental conditions converge are implemented extra decarbonisation steps can be taken to take the impact of ASPIRE well beyond NET ZERO CARBON.

The ability of the gasifier to take different feedstocks, maybe ending up with predominantly biomass feed (alternative inputs), makes the ASPIRE route resilient to change.

Appendix A - Glossary

Abbreviation	Definition
CNR	Clydach Nickel Refinery
IFS	Industrial Fuel Switching
CCUS	Carbon Capture, Utilisation, and Storage
ASPIRE	Alternative, Smart Platform for Integrated Refinery Energy
ATC	Advanced Thermal Conversion (pressurised gasification)
ETI	Energy Technologies Institute
RDF	Refuse Derived Fuel
HTF	Heat Transfer Fluid
LTHW	Low Temperature Hot Water
SMR	Steam Methane Reformer
SWIC	South Wales Industrial Cluster
R&D	Research & Development
COMAH	Control of Major Accidents and Hazards
GHG	Greenhouse Gas
MoPC	Management of Process Change
MoFC	Management of Facility Change
ECL	Environmental Compliance Ltd
BEIS	Department for Business, Energy & Industrial Strategy
SEC	Sustainable Energy Centre
CCU	Carbon Capture and Utilisation
ETI	Energy Technologies Institute
PM	Project Manager
H&S	Health & Safety
EU ETS	European Union Emissions Trading Scheme
CCS	Carbon Capture and Storage
R&O	Risk & Opportunity
WG	Welsh Government
EfW	Energy from Waste