

Sector Coupling: Leveraging synergies to accelerate industrial decarbonisation





Introduction

At io consulting we are executing projects across the hard to abate landscape. Our team has successfully supported projects that will reduce the emissions from marine, aviation, cement, steel and energy facilities. The success in these areas is in no small part due to io's systems thinking approach to project development; we view projects as an integrated system and identify the relationships between each element such that they can be balanced and optimised to produce the most valuable project architecture for our clients.

This holistic view of projects across multiple sectors has enabled the io team to identify significant opportunities to integrate multiple decarbonisation projects across various sectors to truly optimise the decarbonisation of hard to abate industries. This sector coupling is not without risk due to the increased complexity, but io's unique approach to the front-end of projects is adept at de-risking this complexity and delivering economically and technically viable projects with greater certainty.

What is sector coupling?

In the context of grid stability, the EU describes sector coupling as "the increased integration of energy end-use and supply sectors with one another." They claim the benefits include efficiency, flexibility and reliability enhancements, while delivering overall cost reductions¹. At io, we are a molecules focussed business with deep domain expertise in all aspects of process engineering across industries including hydrocarbon, petrochemical, CO₂ and hydrogen and its derivatives. For us, sector coupling is more than just the integration of energy use and supply, it also includes the increased integration of feedstocks, end products and waste streams to create a circular value stream of decarbonisation initiatives.

As we increasingly support the hard to abate sectors, we see the heavy industries, such as the **steel industry**, grappling with the challenges of electrification, where they need to negotiate Power Purchase Agreements (PPA) or incorporate off grid Variable Renewable Energy (VRE) supply to their facilities. Both require developing

relationships or co-developing projects with renewable energy companies. As part of the pathway to reducing emissions and developing "green steel", the steel industry is also developing hydrogen Direct Reduction Ironmaking (DRI) as an alternative to the current fossil based DRI process. Currently there are two main approaches to the development of this technology: the introduction of hydrogen reduction technology where hydrogen is used as the reductant in the ironmaking process and emissions are "virtually eliminated"²; and the blending of hydrogen with natural gas to significantly reduce the emissions from the fossil based reductant ironmaking. In both these examples, the steel industry must "couple" with the industrial gas / hydrogen production industry. This introduces a new complexity to the steel industry, introducing operations that are out with their core skill set.

A similar challenge exists in the **cement industry**, which is developing a range of approaches to decarbonisation including alternative fuels and carbon capture. Similar to the steel industry requiring the integration with the hydrogen industry, carbon capture introduces a requirement for the cement industry to couple with other sectors. The need to select and integrate a capture technology; treat the CO₂ to achieve appropriate purity for onward transportation and sequestration; the nuances of transportation by rail, road, marine or pipeline and the associated CO₂ phase requirements; and the interactions with the geostore all bring complexities to the cement producer's operations that are out of their core skills.

However, these challenges notwithstanding, we believe that sector coupling also brings significant opportunity and by taking a holistic view decarbonisation projects can be made more economically viable through increased integration where a circular relationship of waste streams and feedstocks can be leveraged.

¹ Sector coupling: how can it be enhanced in the EU to foster grid stability and decarbonise? Luc Van Nuffel, November 2018.

² [chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://worldsteel.org/wp-content/uploads/Fact-sheet-Hydrogen-H2-based-ironmaking.pdf](https://worldsteel.org/wp-content/uploads/Fact-sheet-Hydrogen-H2-based-ironmaking.pdf)

Examples of the advantages of sector coupling

Considering again the cement industry, one of the most impactful ways of reducing the emissions from cement production is to introduce an oxy-fuel kiln to the clinker. The benefit of oxy-combustion is that when fuel is combusted in pure oxygen the flue gas contains mainly CO₂ and water vapour with only trace amounts of other combustion products, mainly in the form of NO_x, SO_x and other particulate matter. Capture of CO₂ from this highly pure stream is significantly easier than from flue gas produced in conventional combustion, which contains significantly more impurities (e.g. mainly nitrogen from the air). This compatibility with existing fuel sources and the ease of capture makes oxy-combustion an attractive potential solution for the cement industry. This process requires a source of pure oxygen, which is often obtained by the introduction of an Air Separation Unit (ASU) to the process. ASU's are proven technologies and used throughout the industrial gas industry. This coupling between the cement, or indeed between any industry considering oxy-combustion, and industrial gas industries is a novel relationship with novel complexities on both sides. However, it also presents a significant opportunity for a holistic approach to industrial decarbonisation.

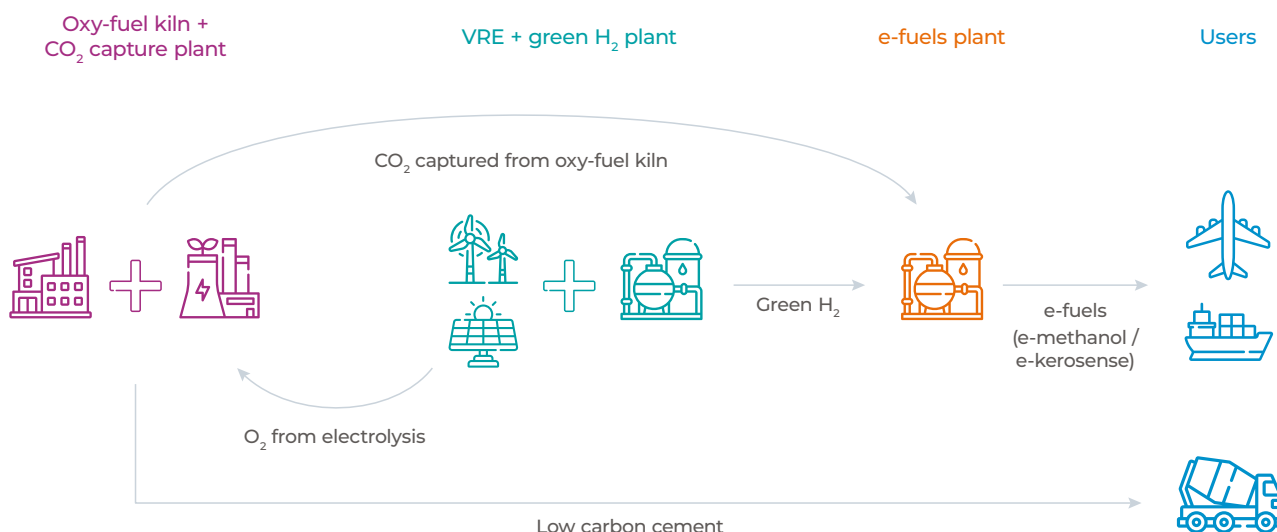
As described above, hydrogen has an important role to play in the decarbonisation of the steel industry. It also has an important role to play in the decarbonisation of refining, maritime transportation and the aviation industry. This multifaceted role is driving the rapid increase of "green" hydrogen facilities where hydrogen and oxygen are produced by the electrolysis of water. Most hydrogen facilities treat the oxygen as a waste product and dispose of it through venting to atmosphere.

Yet, where oxy-combustion is a decarbonisation lever, oxygen becomes an important feedstock: if an electrolysis facility is co-located with a cement facility using oxy-combustion, the utility of the natural resources is maximised – there is a use for the previously wasted oxygen.

The integration does not have to stop with this coupling. One of the key pathways to decarbonise marine and aviation sectors is the development of e-fuels, where captured CO₂ is combined with electrolytic hydrogen to synthesise hydrocarbons such as e-methanol and e-kerosene. E-fuels producers require three key feedstocks: "clean" power, hydrogen and CO₂. It is most common that e-fuels producers have access to power, either through a PPA or a VRE facility, and plan to develop a hydrogen plant; however they must source the CO₂. This is where the opportunity for sector coupling comes to the fore. Where an industrial sector, such as the cement industry, implements oxy-combustion to enable CO₂ capture there is a strong synergy with the e-fuels industry, which produces oxygen that can be used in the oxy-combustion, the captured relatively high purity CO₂ from which can be used as the feedstock for the e-fuel.

Given the rapid development of e-methanol as a marine fuel, there is a compelling synergy for cement facilities located at or near port locations to exploit this circularity. The co-location of a VRE powered hydrogen electrolysis with an oxy-kiln and e-methanol production facility, maximises the utilisation of the available resources, reduces interim transportation and storage, and reduces the Scope 1, 2 and 3 emissions of the cement.

Sector coupling example



It should be noted that the latest amendment of the EU's Renewable Energy Directive (RED III) currently contains a phase out date of 2041 for the use of CO₂ from industrial point sources, of which cement kilns are one, in Renewable Fuels of Non-Biological Origin (RFNBO). This introduces a time limit for the non-biogenic component of CO₂ from cement to be used for low emission marine fuels and reduces some of the circularity benefits. However, this is not the only use case for sector coupling.

The oxygen produced from the electrolysis can be used in other oxy-combustion applications, such as the Allam-Fedvet cycle where methane is combusted in oxygen to produce near pure CO₂ that is used in its supercritical phase as a working fluid to generate power (the NetPower application). In this example, the hydrogen could be used in a DRI facility to produce low carbon steel. In the case where a hybrid DRI facility uses a combination of methane and hydrogen for the reduction, there is an opportunity to optimise the mix of hydrogen, oxygen and methane to ensure a required mix of feedstocks to the DRI while methane and oxygen are used for an industrial scale application of NetPower. At a lower level, waste heat from exothermic processes can be utilised for endothermic processes thus increasing energy efficiencies within the systems.

If an oxygen consuming process chooses to use an ASU to produce oxygen, there will also be a nitrogen stream produced. This nitrogen can be combined with electrolytic hydrogen to produce "green" ammonia, which can be used to displace "grey" ammonia or as an alternative zero carbon marine fuel.

Moving away from the integration of CO₂, hydrogen and oxygen. Energy storage, particularly long duration energy storage (LDES), requires sector coupling. For example, the StratStore consortium of io consulting, EDF Energy and Hydrostor's Cheshire Energy Storage Centre which integrated compressed air energy storage (CAES) with repurposed gas storage caverns. This project involved a cycle of electrons to molecules to electrons and required an integration of the subsurface characteristics of the caverns with the CAES technology and the energy markets governed by the UK grid. The CAES technology itself is a blend of industrial heat exchangers and turbomachinery that was developed for the oil and gas industry. This example highlights the benefits that come from integrating oil and gas expertise (turbomachinery, subsurface and major projects execution) with technology start-ups (the novel Advanced-CAES design) and electricity companies (power market and grid integration).



An attractive but complex solution

These are all examples of a systems thinking approach, one where a more holistic examination of the energy transition and imperative to decarbonise industry identifies synergies and benefits that often outweigh the associated complexities. Whether it is the coupling of expertise across multiple sectors, such as the StrataStore example, or the integration of the feedstocks and waste streams from hard-to-abate sectors, there is a clear opportunity to identify and leverage synergies and use circularity to strategically accelerate the decarbonisation of these sectors. It is not without challenge, in addition to the complexities of implementing each subproject: the integration of VRE and hydrogen production; the implementation of carbon capture and purification technologies; and the synthesis of e-fuels, for example, the interdependencies between each element are critical. The feedstock supply and demand must be balanced, which requires an optimisation of each subproject production rate and buffer storage; the specifications of each element must be matched to the relevant process; and the operating philosophies of each plant must be cognisant of the others.

This complexity is exacerbated by the nascent nature of each project: carbon capture in cement; large scale electrolytic production of hydrogen and oxygen from water; e-fuels synthesis; DRI steel; green ammonia at scale are all developing processes. This complexity borne of integrating significantly complex projects introduces compounding risk, which must be managed if large scale sector coupling is to be successful.

De-risking complex projects: io's systems approach to managing complexity

At io, we specialise in the de-risking of complex projects. We believe in the value of front-end loading to enable the critical decisions to be taken at the optimal time in the project lifecycle such that we can reduce uncertainty and allow clients to take investment decisions with confidence. For a complex system of projects required for effective sector coupling, we are unique in having our Systems Optimiser tool, which has been developed using systems thinking and Model-Based Systems Engineering (MBSE) principles. This tool enables us to create a digital representation of the projects and their interdependencies across all domains, including process, mechanical, electrical, physical, cost, schedule, economic and strategic. By creating this representation of the project(s) in the tool, we can rapidly execute multi-variable optimisations to accurately determine the optimal architecture of the project, including sizing of each plant and the sub-processes within them.

At the earliest stage of the project, the tool enables the relationships between each element, which are often non-linear, to be understood and used to leverage efficiencies. The balance of VRE; hydrogen production, including balance of plant, electrical and molecule storage; CO₂ capture, treatment and interim storage; and e-fuels production, storage and transportation is identified and iterated as the project progresses and more detailed technical and cost estimate data is developed, ensuring that the optimal value created in the early phase is protected and enhanced through the lifecycle. The ability to model, test and continually validate and verify the decisions being taken allows io to derisk these highly complex, integrated developments and deliver paradigm changing value to all the stakeholders.



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