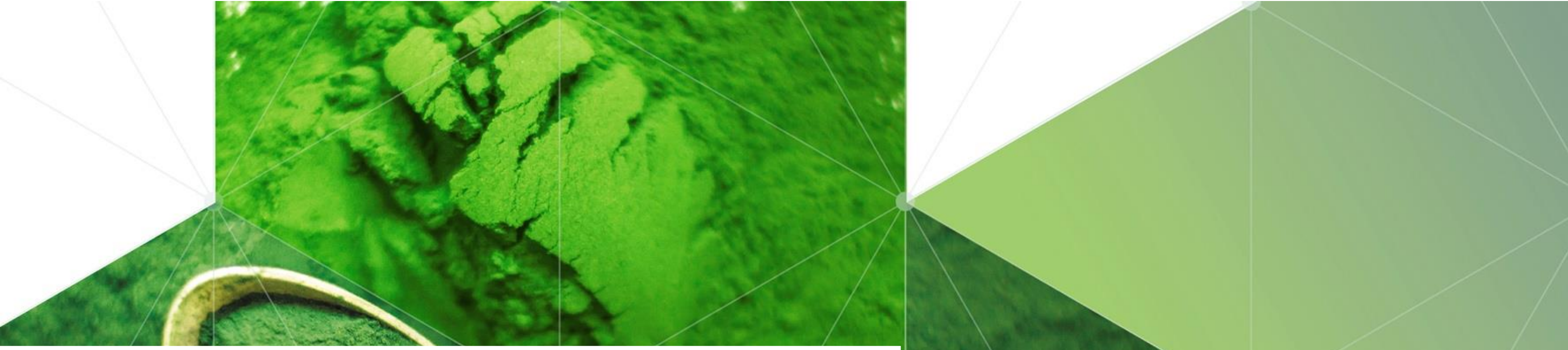
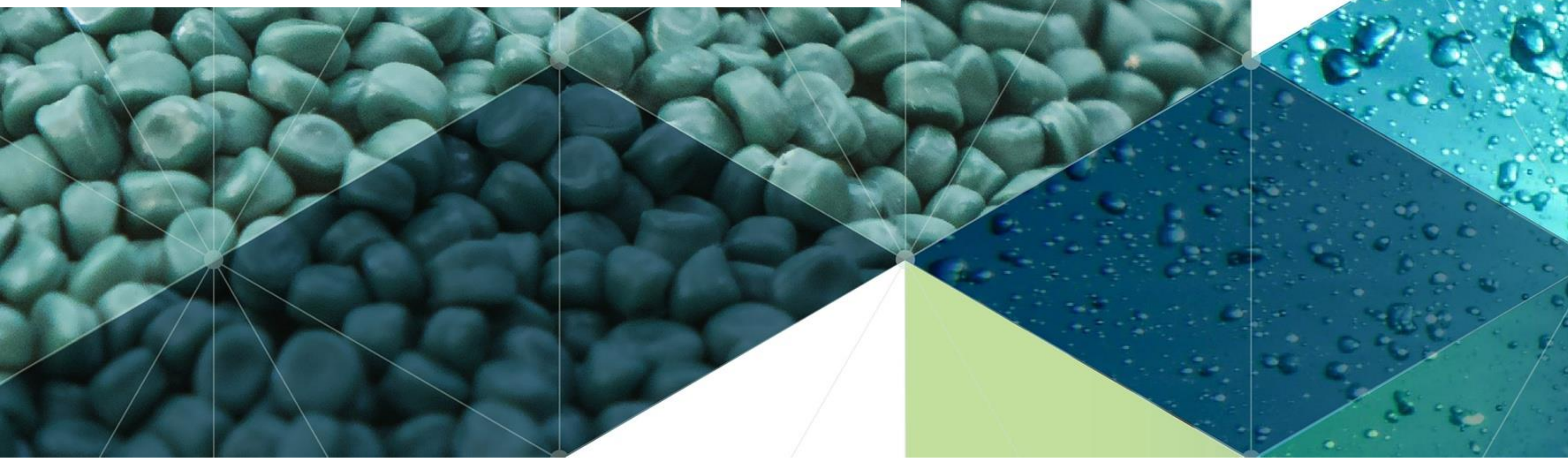


Hydrogen: a key enabler to unlock decarbonization opportunities and value

April 2020



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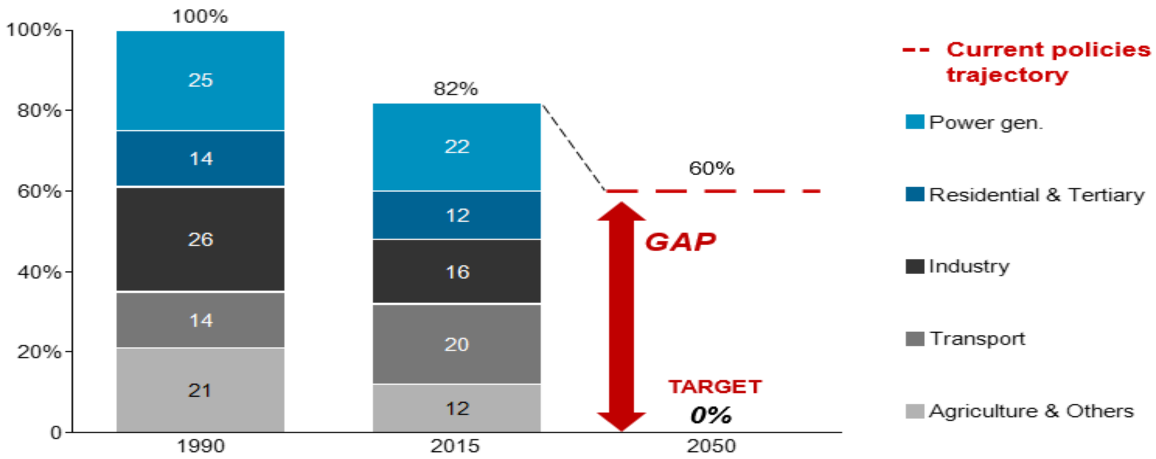
1. Context

At the end of 2019, the European Commission presented the "European Green Deal", committing to a legally binding target of reaching net-zero carbon by 2050 and therefore becoming the world's first climate-neutral continent. This measure is accompanied with a broader roadmap of initiatives, including cutting emissions (reduction target for 2030 proposed at a level of 50-55%), investing in cutting-edge R&D (Von der Leyen – *European Commission President* – proposed to make up to €100 billion a year available to finance the transition to a low-carbon economy), and preserving Europe's natural environment.

Such evolution will put pressure on all businesses, with most impact on refineries, petrochemicals, steelmaking, cement and more in general all industrial segments characterized by heavy CO_2 emissions (covering ~60% of EU emission in 2015 if including power generation, residential & tertiary and industry segment). Companies are required to take action and reach an annual GHG balance between emissions released and allowances. Firms not complying with the above requirements will be fined by their respective governments through the adoption of Carbon Tax or Emissions Trading Systems.

Figure 1: European CO_2 emission by source (1990 – 2050)



Source: Bain & Company

Commitment towards decarbonization – Companies' strategies, as well as their approach to technology development, are shifting. Different levers can be exploited by heavy CO_2 emitting industries to comply with regulations, while limiting impacts on their profitability: (1) Assets' carbon footprint reduction; (2) Greener supply chains; (3) New revenue streams. For each of these areas, companies can undertake a wide variety of actions.

> "*Decarbonization can become a profitable opportunity for businesses*"
>
> P. Folgiero – CEO of Maire Tecnimont and NextChem

1) **Assets' carbon footprint reduction**: improving safety (e.g. decrease employee exposure with automation), reducing energy use of assets (e.g. waste heat recovery), ensuring environmental remediation of own assets, providing incentives to influence performance (e.g. compensation tied to emission), reducing venting and flaring, raising monitoring of leakage and maintenance activities;
2) **Greener supply chains**: this aspect includes collaborating or vertically integrating to improve suppliers' ESG, changing customer perspectives and consumer behaviors, renegotiating suppliers to alternative products and practices, auditing and certifying supply chain participants on ESG issues;
3) **New revenue streams**: this implies the rebalancing of traditional O&G asset portfolio to reduce carbon intensity of products or services, thus, generating new potential opportunities for the company. For instance, players could move towards renewable fuels solutions and recycling technologies, replacing single-use plastics with alternative products, and provide alternative energy storage solutions.

Even considering the importance of all the three levers, the paper will focus mainly on the first area of intervention, emerging as the most urgent one to be tackled. Concerning reduction of owned assets' carbon footprint, hydrogen can be an attractive lever to solve the decarbonization challenge. In fact, using hydrogen as sourcing feedstock (replacing fossil feedstock in the production of hydrocarbon-based chemicals) and fueling hydrogen in industrial processes to improve energy efficiency could lead to important GHG emission savings. Yet, to achieve such objectives and large-scale production of hydrogen, a series of challenges must be overcome.

2. Hydrogen as key decarbonization enabler

Generally, besides the possibility to store and use this resource as clean fuel without direct GHG emissions, hydrogen has the advantage to present clean pathways that could be adopted in its production. Three main types of hydrogen are identified, with different level of carbon intensity (Figure 2):

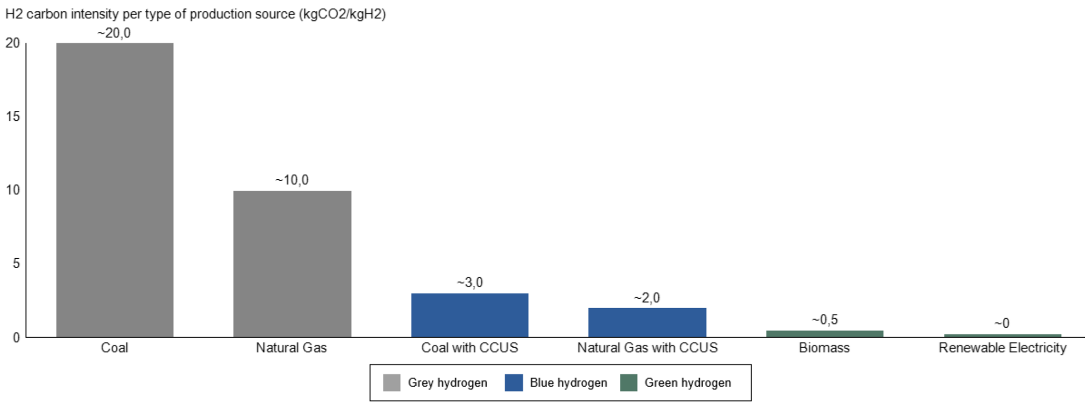
> *Hydrogen will play a pivotal role in decarbonization*
>
> P. Folgiero – CEO of Maire Tecnimont and NextChem

1) **Grey hydrogen:** hydrogen that is produced from natural gas through Steam Methane Reforming (SMR) or reforming of other hydrocarbons. The process concurrently produces CO_2. This currently represents ~75% of today's hydrogen production.

2) **Blue hydrogen:** in this case, the CO_2 associated with hydrogen production from fossil fuels is captured and permanently stored or reused (CCUS). The process can serve as a bridge to longer-term sustainable solutions. Furthermore, electrification of steam methane reforming or the gasification of plastic waste could potentially half the production of CO_2 to be captured and stored and, therefore, provide a viable economic alternative to grey hydrogen. These concepts are currently under development in the Maire Tecnimont Group under the name of "Super Blue^{TM}" hydrogen and circular hydrogen.

3) **Green hydrogen:** hydrogen is produced from renewable electricity and water through electrolysis. Using 100% renewable electricity, this process allows for the lowest carbon intensity. Yet, as of now, less than 2% of the H2 is produced in this way due to high costs.

Figure 2: H2 carbon intensity – comparison between grey, blue and green H2 ($kgCO_2/kgH_2$)



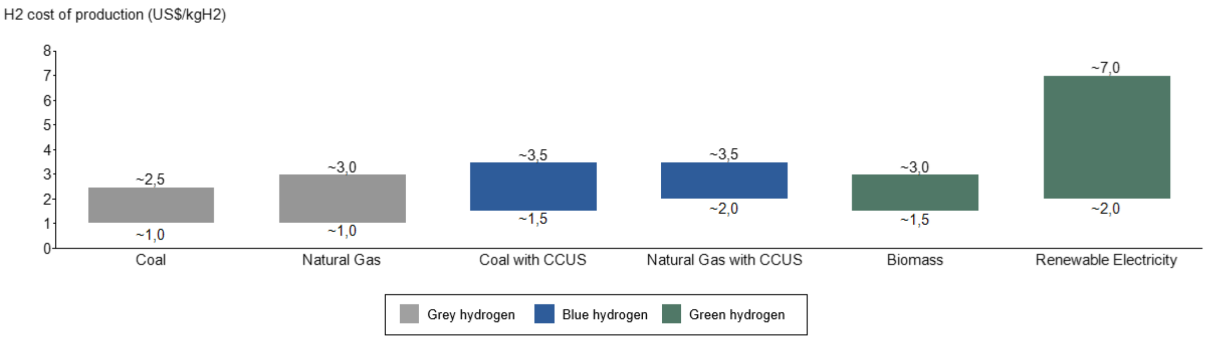
Note: 1) CCUS = Carbon Capture Utilization and Storage; (2) The above graph takes into account 100% use of the underlying sources (e.g. coal, NG, biomass, renewable energy). By lowering the respective proportion of production source, CO_2 emissions could increase or decrease according to the case. For instance – in the case of green hydrogen – assuming a lower utilization of renewables, CO_2 emissions could increase sensitively
Source: Goldman Sachs (Equity Research, February 2020)

Green hydrogen, as discussed above, is the lowest carbon intensive option, nonetheless several challenges related to its production exist. In fact, while the technology is well-known, currently the costs associated with it are industrially prohibitive. Therefore, current industrial hydrogen consumers (e.g. refineries, petrochemicals) and potential future consumers, like steelmaking and heavy-duty mobility, are called to act and contribute to industrialize the existing technological solutions in the realm of green hydrogen rendering it financially feasible.

Current hydrogen challenges – Today, hydrogen is mainly produced through Steam Methane Reforming, hence a grey type. Only a minor role is left to green hydrogen. The main reason for this is attributable to a green hydrogen's non-competitive cost of production, mainly driven by the following factors: complex supply chains, high CAPEX for the electrolyzer, which is the main component of a green hydrogen production plant, high renewable energy costs, un-continuous availability of renewable energy, relative low ratio of renewable energy (vs. total energy supplied) and low operational scale advantages.

In facts, as shown in Figure 3, while the cost of conventional hydrogen is in a range of ~1.0$/kg to ~3.5$/kg (according to raw materials used and whether or not carbon capture storage is applied), green hydrogen shows higher production costs landing in a range of ~2.0$/kg to ~7.0$/kg, depending on green energy availability and pricing. Therefore, besides the associated CAPEX expenditure mainly related to electrolyzer, operating times and their conversion efficiencies, the key obstacle in enabling decarbonization through green hydrogen lies on the hydrogen cost of production. (Figure 3)

Figure 3: Hydrogen range costs **–** comparison between grey, blue and green hydrogen cost of production (US$/kg$H_2$)



Note: 1) CCUS = Carbon Capture Utilization and Storage; (2) The above graph and respective costs take into account 100% use of underlying sources (e.g. coal, NG, biomass, renewable energy). The use of a different feedstock production mix may affect prices.
Source: Estimates based on Goldman Sachs (Equity Research, February 2020)

With an eye to the future, CAPEX and marginal cost of electricity could dramatically lower the hurdle and therefore increase green hydrogen competitive positioning. On top of that, “regulatory sandbox” and key stakeholders’ partnership could play a role to accelerate its adoption. The former in the shape of proper incentives schemes, while the latter through cost socialization and development of necessary conditions for large-scale adoption.

As shown previously, high uncertainty fluctuates around green hydrogen costs. Whether or not this hydrogen would reach competitiveness in terms of production costs is strictly dependent on country-specific dynamics. Only when the rate of renewable energy prevails over the total electricity supplied (range between 50% and 70% on a case-by-case level), then electrolyzers (and therefore green hydrogen) could become self-sustaining. Developed countries like Norway, Sweden, Denmark and Canada can be taken as a leading example in the field of renewable energy availability, and in these regions green hydrogen projects are starting to be implemented.

NextChem low-carbon hydrogen proposition – In this transitory phase, before green hydrogen reaches its maturity level, blue hydrogen and circular hydrogen produced from waste gasification could play an important role in the production of a low-carbon substitute. In particular, the electrification of steam methane reformers followed by CO_2 sequestration, represents a great vehicle to support the hydrogen development while minimizing the impact of CO_2 emissions. In this field, Kinetics Technology (KT) – a subsidiary of Maire Tecnimont and NextChem’s sister company – is not only a global leader of steam reforming technologies, but it is also developing a proprietary technology in the field of electric steam reforming, namely “Super Blue™” hydrogen. Production of circular hydrogen, on the other hand, involves the gasification process, consisting in heating plastic waste with oxygen to produce syngas. In this field, NextChem is currently developing projects for the industrial scale deployment of this technology.

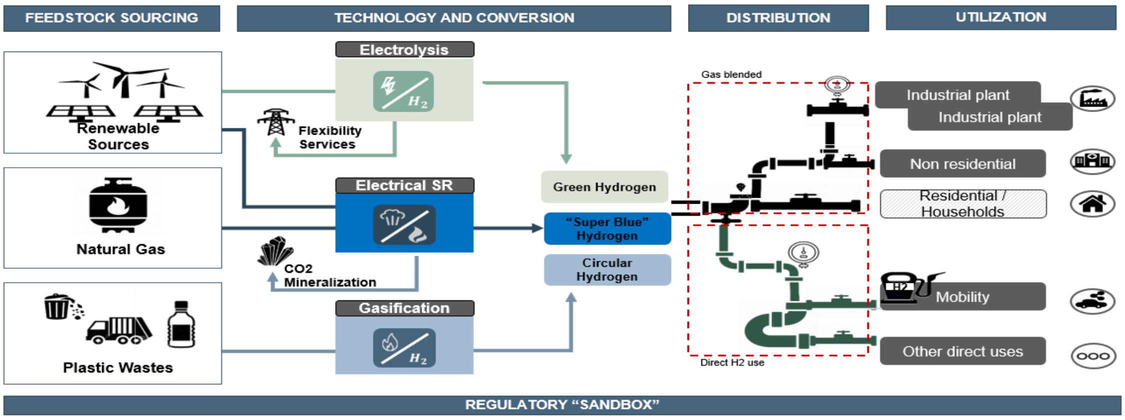
Moving forwards and discussing in depth the future hydrogen context, NextChem is emerging with a broad and clear value proposition:

- Leveraging on renewable energy, natural gas and plastic waste to open new routes for low-carbon hydrogen production (Case Study 1);
- Leveraging on production of green hydrogen and green methane to de-carbonize the gas distribution network (Case Study 2);
- Introducing green hydrogen as industrial feedstock to ramp-up renewable diesel production (Case Study 3).

Case Study 1 – Green, circular and "Super Blue™" hydrogen production scheme: leveraging on renewables, natural gas and plastic wastes to open new routes for low-carbon hydrogen production

Below a graphical representation of NextChem proposition to produce and inject green, "Super Blue™" and circular hydrogen in the gas distribution networks. The potential initiative would leverage the increasing appeal of renewable energy sources as well as the vast abundance of natural gas and plastic wastes to produce respectively green hydrogen, "Super Blue™" hydrogen and circular hydrogen, through technologies of electrolysis, electrical steam methane reforming and gasification. Once produced, this hydrogen could be used as feedstock for steelmaking plants or refineries or could be distributed and used to feed a wide variety of areas both indirectly and directly. In the first case, industrial plants, non-residential structures (e.g. hospitals) and residential places could be the main clients, while for the direct utilization, the heavy-duty mobility segment is considered as key target. (Figure 4).

Figure 4: Overview of potential green experimental initiative related hydrogen



Source: NextChem

Case Study 2 – Green hydrogen and methane for Power-to-Gas: storing renewable power decarbonizing the gas network

Besides the efforts in the production and injection of both green and "circular" hydrogen in the gas distribution networks, NextChem is also developing Power-to-Gas (P2G) applications.

P2G as a way to connect the power grid with the natural gas network, adding flexibility to the grid and enabling to store potential peaks of renewable energy production peaks in the form of Synthetic Natural Gas (SNG), avoiding its waste (i.e. *curtailment*).

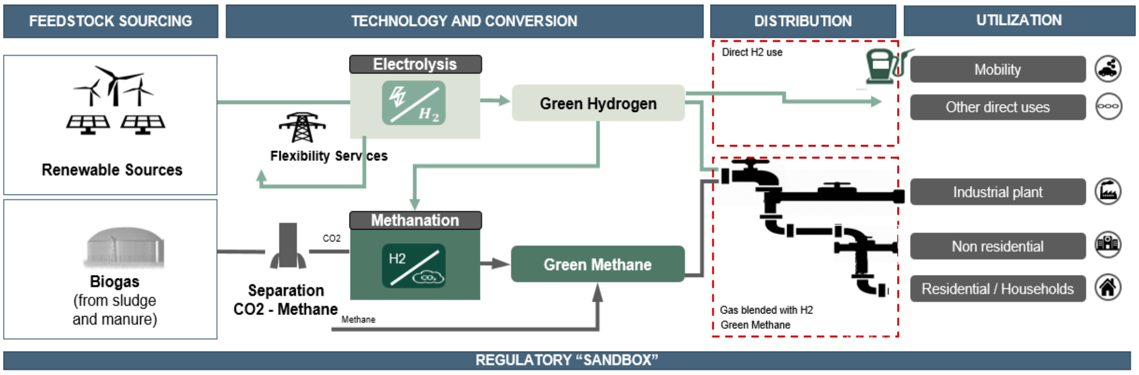
SNG, like bio-methane obtained from biogas production, is in any way the same molecule found in fossil natural gas, with a notable exception: it is carbon neutral. By being the same molecule, thus, having the same properties of fossil natural gas, a seamless injection in the gas network could be achieved. This could contribute to the decarbonization of the system without the need for significant upgrades to the infrastructure, and without any impact on the final users.

P2G technologies produce SNG from green hydrogen and CO_2, water and heat being the only byproducts of the reaction: this use of CO_2 and green hydrogen as feedstock enables a zero-sum emissions game, while also displacing the use of more carbon intensive fossil natural gas.

One of the immediate source of the CO_2 feedstock that can be identified is biogas production: when producing biogas from anaerobic digestion, only half of the resulting gas is bio-methane, the balance being CO_2. If this CO_2 is converted to SNG with P2G technologies, it could double the bio-methane production of the biogas plant, exploiting potential synergies like the connection to the gas network and the reuse of water and heat in the biogas production.

The production of decarbonized natural gas in the form of SNG could also represent an immediate answer to the need to transition the heavy-duty transportation to a less carbon intensive future, relying on a more established fuel (e.g. heavy-duty mobility based on Liquefied Natural Gas or Compressed Natural Gas is already a reality).

Figure 5: Power-to-Gas system: overview scheme



Source: NextChem

Case Study 3 – Creating new routes for renewable diesel production by introducing green hydrogen as feedstock

Concerning the biorefinery segment, NextChem is currently developing a new proposition aimed at using green hydrogen as an industrial feedstock. In fact, the renewable fuel market offers increasing regulatory incentives to producers of fossil fuel substitutes with low CO_2 footprint.

In particular, HVO (Hydro-treated Vegetable Oil) – an emerging type of renewable fuel able and direct substitute of petroleum diesel – is produced via hydrotreatment of triglycerides and FFAs into long-chain hydrocarbons. Thus, the production requires significant amounts of hydrogen from an on-site facility or pipeline. In parallel, an increasing number of states such as California and Oregon provide credits (through Low Carbon Fuel Standard and Oregon Clean Fuels Program) according to the carbon intensity of fuel, and the efficiency by which a vehicle converts the fuel into usable energy. Therefore, by replacing the current use of grey hydrogen with green hydrogen, HVO producers could see a significant increase in their revenue model, mainly tied to the incentive schemes applied on a state-by-state level. The lower carbon intensity of green hydrogen could in fact provide producers with a higher credit, ultimately lowering financial burden associated with the high HVO costs and making renewable diesel production even more profitable.

To achieve the above objective scheme, NextChem can offer its competences to carryout project development activities; connecting HVO producers with potential investors willing to build and operate green hydrogen plants, hence making green hydrogen available as an over-the-fence feedstock. Moreover, NextChem has the capabilities to undertake the full-wrap engineering, procurement and construction activities.

3. Key transition enablers

Shifting towards green hydrogen and therefore accelerating the decarbonization phenomenon requires industrial players to collaborate in order to implement firstly pilots, and, more importantly large-scale project. This strategy could allow players to share costs and risks, while at the same time reducing the complexity associated with projects and implementations.

> *We see a world of opportunities from co-development of disruptive technologies and JV to create green chemistry capacity and joining forces to further the debate*
>
> P. Folgiero – CEO of Maire Tecnimont and NextChem

An increasing number of players are moving in this direction. For instance, just to mention one of them, the Swedish steel company SSAB, in the attempt to produce a completely fossil-free steel by 2026, has launched a joint venture with the iron ore supplier LKAB and the energy company Vattenfall. The partnership, also supported by the Stockholm Environment Institute and the Swedish Energy Efficiency, focuses on replacing coal with hydrogen in the steelmaking process.

Partnerships and experimental initiatives among industrial operators (including large incumbents and new-entrant startups) must continue to grow in the short term to socialize costs and develop technological advantages for a future large-scale application. Sharing investments will be important for developing significant expertise and capabilities. Companies should therefore set up organizations and business alliances across key stakeholders, vertical as well as horizontal to overcome major barriers (related to costs and risks) associated with technologies at an early maturity stage such as green hydrogen.

For industrial players, green hydrogen can be a strategic opportunity to maintain competitive positioning in the industry; yet, to do so, they need to collaborate across the value chain, hence, becoming an integrated part of the solution to decarbonization.

NextChem is the partner to accelerate transition towards green hydrogen and therefore decarbonization. Thanks to our technological background, our long-lasting experience on hydrogen production and our leadership in the natural feedstock, we are the ideal partner for the industrialization and commercialization of sustainable innovation.

Following the principle of low capital intensity, collaborations and scouting, we are able to bridge the gap between the idea born in the laboratory and production on an industrial scale. We are industrializers of innovation and we are already collaborating with major players in the industry to develop technology fit for each of their purpose.

More information on NextChem can be found online: www.nextchem.com

Disclaimer

The above document and all its related analysis have been executed between January and February of 2020. Therefore, possible implications and consequences tied to the spread of COVID-19 are excluded.

As COVID-19 situation, as well as oil price shock, continues to evolve and companies (across industries) are temporary forced to shut down their activities – thus, creating frictions in the overall business environment – estimates might be re-considered.