INTESA SANPAOLO
INNOVATION CENTER

INDUSTRY TRENDS REPORT
DECARBONISATION

FROST & SULLIVAN

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EXECUTIVE SUMMARY

In the **oil & gas** (O&G) sector, the direct and indirect impacts of refining, transport, flaring, extraction and use mean the industry contributes **15%** of global emissions.

For **direct emissions**, there are three main approaches to decarbonization for heavy industries: ***material modification, process innovation and emission management*** with the most efficient methodology typically selected based on assessment of carbon dioxide (CO2) savings weighed against costs.

In the O&G sector, material modification includes integrating renewables and process innovation covers co-generation while emission management incorporates reducing leaks. Indeed, leak detection and repair is amongst the most efficient approaches to abatement and has the potential to reduce emissions by 85%.

More broadly, the ***Oil & Gas Climate Initiative***, which represents about 33% of global production, has set ambitious abatement targets. Repsol has embraced this challenge and is working to reduce routine flaring, ***Eni*** has taken a broader approach and is on track to shrink its CO2 by 43% by 2025 while ***Alphabet Energy*** is a third-party provider of modular gensets which convert the exhaust from oil field gensets into electricity.

For **indirect emissions**, future fuel use in the O&G industry currently remains limited but implementing new carbon capture, utilization and storage (CCUS) for hydrogen production offers a route to decarbonize.

"Blue" hydrogen is produced from fossil fuels such as oil, gas and coal principally via steam methane or autothermal reforming. Globally, the revenues stemming from carbon capture in this context are forecast to leap from $80 million (m) in 2022 to over $3 billion (b) in 2030, a compound average growth rate (CAGR) of 58%. Growth is also being driven by technological advances which are reducing costs while, from a competitive perspective, ***Equinor*** is the market leader for carbon capture in blue hydrogen followed by ***Eni*** and then ***ExxonMobil***. They and others stand to benefit from blending blue hydrogen in natural gas lines.

In parallel, **"pink" hydrogen** – which is generated from nuclear power – promises to be a motor for greater adoption of H2. Nuclear plants can notably use off peak power more efficiently than fossil fuels or renewables making them a lower cost alternative.

There are currently four principal pathways to generating all nuclear hydrogen. As with blue hydrogen, ***steam methane reforming*** is the most developed method, ***alkaline electrolysis*** is also widely commercially used to produce pink hydrogen and ***polymer electrolyte membrane electrolysis*** operates at low temperature levels while ***solid oxide electrolyzer cells*** are unique since they require significant heat.

For the latter, ***Topsoe*** has developed a compact and stackable solid oxide electrolyzer cell (SOEC) that offers low-cost hydrogen production using ceramic electrolytes whereas *Bloom Energy* has taken another approach, targeting low energy consumption. Overall, Europe and the US boast pockets of innovation but China leads the way in terms of nuclear hydrogen innovation activity and investment with many governments regard pink hydrogen as a way of reinforcing their energy security.

In the longer term, **"green" hydrogen** is attracting significant public sector support as a means with which to guarantee energy sustainability. Today, this accounts for only 0.1% of global production but has the potential to meet 24% of the world's energy demand through an additional $160 billion of financing.

Frost & Sullivan envisages four scenarios for green hydrogen, the most optimistic of which involves unlocking low-cost production at scale. In Europe, the sector stands to benefit from the development and implementation of national and international long term clean energy strategies and, moving forwards, green hydrogen has the potential to enable the widespread deployment of ***truly*** zero-emission fuel cell vehicles.

This will, in part, be enabled by the advent of waste to hydrogen solutions and, as the industry matures, an eventual transformation in the business model with hydrogen being provided to customers on an as-a-service basis.

In order to effectively and holistically tackle global warming, there is an urgent need for abatement in hard-to-decarbonize **heavy industries** beyond oil & gas.

In the **cement** industry, the average CO2 per ton of production has fallen drastically since the 1990s but still contributes about **6%** of global emissions. Here, as in the O&G industry, there are three main approaches to decarbonisation with material modification including recycling and reuse, process innovation covering heat recovery and emission management incorporating CCUS. Indeed, CCUS and novel materials have the highest potential.

Eco2Block, for example, offers an eco-friendly alternative to concrete building material while work is also underway to replace conventional cement with geo-polymeric substitutes. More broadly, the *Global Cement and Concrete Association* which represents about 50% of global production has set ambitious abatement targets. These have been adopted by the major market participants such as *LafargeHolcim* which is switching to alternative green fuels and Vicat which is developing new low carbon cement. Innovation is also stemming from outside of the core industry with ***Solidia*** Technologies providing turnkey CCUS technology.

Source: Frost & Sullivan

In the ***steel*** industry, decarbonization has not received any focused investment and the space still contributes between **7% and 9%** of global emissions. Here, material modification includes leveraging co-products, process innovation covers direct reduced iron while emission management also incorporates CCUS. In the short term, increased recycling and energy efficiency improvements are the most accessible and widely adopted CO_2 steel abatement strategies but electrolysis for iron ore reduction is gaining interest for the long term.

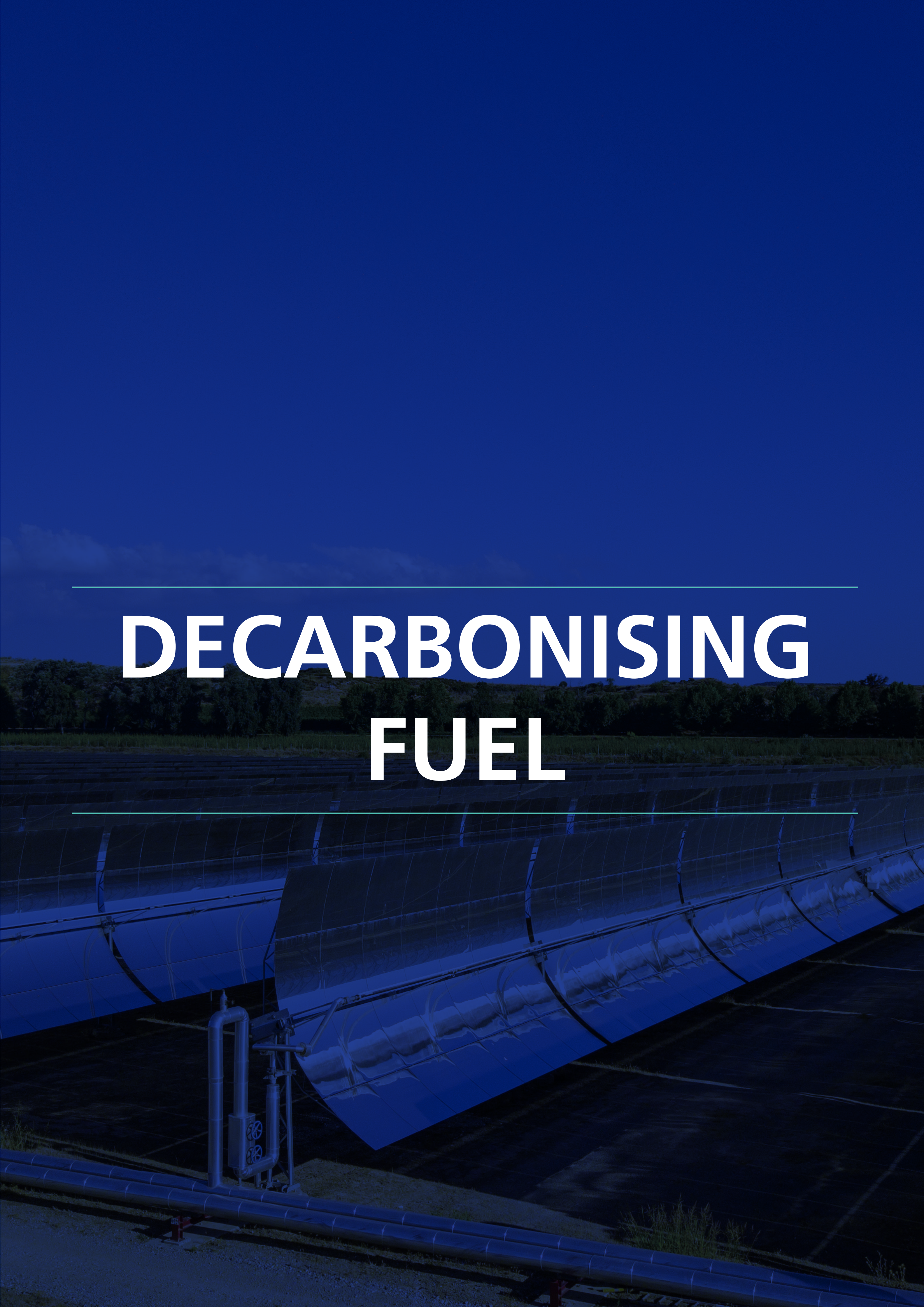
Tata Steel is increasing its scrap-based steel manufacturing while ***Hyundai Steel*** is using recycled gas from its blast furnace. Moving forwards, ***Sunfire*** is an external player which ships solid oxide reversable electrolysis modules to carbon-intensive industries like steel.

If other approaches to decarbonization fail or are unavailable, **carbon offsetting** provides market participants another way in which to reduce their footprints.

Increasingly, this is enabled by tech with ***Cloverly*** developing a sustainability as a service platform to fast-track CO_2 neutrality for businesses and carbon offsetting forming part of a broader approach to emission management in heavy industries which is supported by emerging digital solutions. ***Carbmee***, for example, provides an AI-based end-to-end environmental intelligence system which tracks, measures and helps tackle pollution.

Source: Frost & Sullivan

DECARBONISING FUEL



In the *oil & gas* (O&G) sector, the direct and indirect impacts of refining, transport, flaring, extraction and use mean the industry contributes 15% of global emissions

Apart from carbon dioxide (CO2), methane emissions stemming from the sector typically reach around 80 million tons (or 2.4 billion tons of CO2 equivalent) annually and are a significant contributor to global greenhouse gas (GHG) build-up.

The ***direct*** CO2 emissions per unit of energy produced from oil & gas-based sources are lower than those in other heavy industries such as coal by 20% to 30% but the ***indirect*** GHG emissions from operations in the sector amount to 5.2 billion tons of CO2 equivalent.

Market participants are therefore continuing to invest in reducing their scope 1 and 2 emissions via a number of methods while they – and society more generally – are looking to "future fuels" and notably hydrogen as a short-term complement and long-term replacement for O&G.

For direct emissions, there are three main approaches to decarbonization for heavy industries: material modification, process innovation and emission management

Material modification includes switching to low-carbon fuels, adopting renewable energy sources for power, heating or cooling demands and changing inputs by, for example, using recycled or modified raw materials.

Process innovation covers modifications or improvements for enhanced energy efficiency and/or reduced emissions.

Emission management features the adoption of Carbon Capture Utilization and Storage (CCUS) technologies to effectively convert carbon dioxide emissions into new products or for long-term storage in geological forms.

The most efficient methodology is typically selected based on assessment of carbon dioxide savings weighed against costs

In the first instance, market participants form an emissions volume forecast according to historic and present production levels and without considering the impact of any abatement measures. This allows them to identify the key emission sources before selecting the possible abatement options and estimating their pollution reduction potential. Next, they typically take into account the availability of suitable technologies before analyzing the cost and benefit of each solution and categorizing them according to their readiness level. Finally, they consider any other advantages and disadvantages such as non-technoeconomic costs and further environmental benefits as well as the growth potential of the abatement technology in question before reforming a post-implementation emissions volume forecast.

In the O&G sector, material modification includes integrating renewables and process innovation covers co-generation …

Broadly speaking, pollution in the oil & gas industry can be segmented into three types and sources including ***fuel combustion-based exhaust streams*** from compressors, heaters and other ancillary equipment, ***vents*** from flue gas venting equipment and ***flares*** from well completions and flow testing equipment.

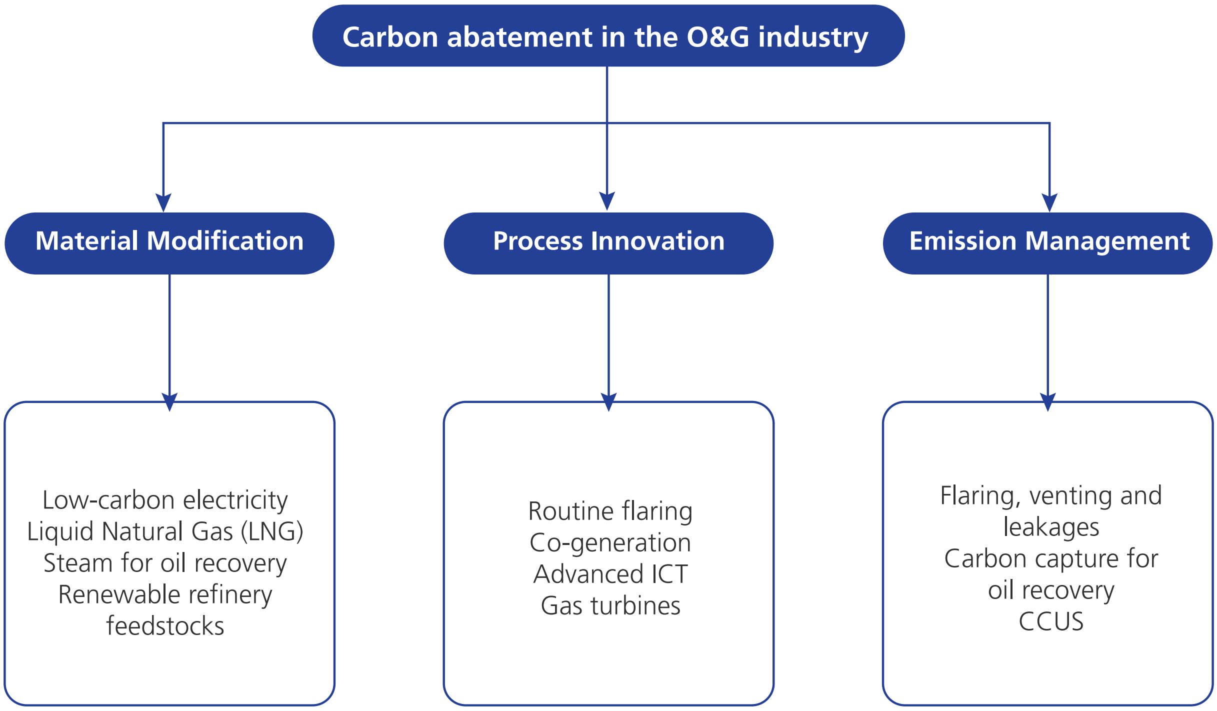
Introducing low-carbon electricity into new O&G exploration and production ("upstream") and Liquid Natural Gas (LNG) developments is a key element of **material modification** while other approaches gaining ground include generating steam for enhanced oil recovery using solar power and switching to renewable refinery feedstocks.

Process innovations center on eliminating routine flaring, encouraging co-generation, improving the energy efficiency of oil & gas plants by utilizing the power of advanced Information and Communication Technologies (ICT) and promoting enhanced energy recovery from gas turbines.

Source: Frost & Sullivan

… while emission management incorporates reducing leaks

Reducing methane releases from flaring, venting and other leakages forms part of **emission management** strategies while adopting and integrating carbon capture technologies for reuse in enhanced oil recovery applications will also be a vital tactic.



Pipeline leakages will contribute to a large proportion of emissions in the future. Their reduction will depend on improving the utilities used in gas grids or closures following the replacement of natural gas with hydrogen. The Committee on Climate Change estimates that 90% grid closures or switchovers from natural gas to H2 would have the potential to reduce total emission by 78% by 2070 in the UK. The main sources of emissions at this stage will likely be offshore oil and natural gas shale production facilities.

Indeed, leak detection and repair is amongst the most efficient approaches to abatement and has the potential to reduce emissions by 85%

Gas leaks typically emit methane but deploying Leak Detection and Repair (LDAR) technologies and continuous monitoring using advanced ICT solutions such as satellite imagery and data analytics can have a high impact.

Similarly, in upstream oil and gas production, reduced flaring and flare gas recovery has the potential to reduce methane and CO2 by 65% to 70%.

In the areas of transmission and storage and regasification (upstream gas production), carbon capture and storage could lower carbon dioxide emissions by 70% to 80% while a more general switch to renewable energies with battery storage could potentially eradicate CO2 from industrial combustion processes including O&G.

Source: Frost & Sullivan

More broadly, the Oil & Gas Climate Initiative, which represents about 33% of global production, has set ambitious abatement targets

The OGCI, an international industry-led organization which includes BP, Chevron, CNPC, Eni, Equinor, ExxonMobil, Occidental, Pemex, Petrobras, Repsol, Saudi Aramco and Royal Dutch Shell, collectively meets 17% of the global energy demand and emits a total of 724 million ton equivalent of harmful greenhouse gases.

Its members are however investing $6.5 billion in low carbon technology Research & Development (R&D) with initiatives aimed at reducing the average methane intensity of upstream oil & gas operations to less than 0.25% by 2025 from a baseline of 0.32%.

In parallel, the organization is looking to be at the forefront of decarbonizing multiple industrial hubs and kick starting a commercial carbon capture and storage industry that could significantly lower GHG emissions by 2030.

Repsol has embraced this challenge and is working to reduce routine flaring

Repsol, Spain, aims to reduce annual upstream GHG emissions by 3 Mt CO2 equivalent, upstream operated methane emissions intensity by 25% and routine flaring by 50% by 2025. As methane emission reduction is core to these targets, the company has successfully piloted new-generation membranes at one of its offshore assets in Southeast Asia. Since the gas produced has high CO2 content, multiple membrane separation trains are required to purify it to meet quality specifications. By upgrading the membranes, the company was able to increase its methane recovery rate by consecutively reducing methane emissions.

Eni has taken a broader approach and is on track to shrink CO2 by 43% by 2025

Eni, Italy, has already reduced emissions by 20% since 2014. The company has been using a broad set of initiatives to achieve this goal and begun diversifying its energy sources by shifting toward low- and zero-carbon energy sources, using carbon capture and storage, targeting methane emissions and increasing its focus on achieving efficiency gains.

Alphabet Energy is a third-party provider of modular gensets which convert the exhaust from oil field gensets into electricity

Alphabet Energy, United States, has developed ***E1***, a thermoelectric generator that effectively converts the exhaust gas from gensets in oil fields into electricity. This on-site electricity generation offsets the power produced using local gensets, reducing emissions and providing cost benefits via fuel savings.

For *indirect emissions*, future fuel use in the O&G industry remains limited but implementing CCUS for hydrogen production offers a way to decarbonize

To meet net-zero goals, governments must target emissions from all energy-intensive sectors, including hard-to-abate industries such as O&G, cement and steel as well as fertilizers and chemicals amongst others.

In heavy industries, the alternatives to fossil fuels, including using renewable energies generated from heat or greater process electrification, generally remain very expensive. In the foreseeable future, CCUS will therefore represent a key decarbonization lever for these sectors and demand from hard-to-abate industries will be a powerful market driver.

Advances in CCUS technologies have the potential to upscale **hydrogen production** but close collaboration between industrial stakeholders, process licensors, government and innovators will be required.

There has been significant and encouraging progress in producing hydrogen via methods which are more efficient and reduce costs. Companies such as Air Liquide, Shell and Air Product have invested in developing new processes while policymakers are actively feeding in funds to make new hydrogen production technologies accessible to more users.

"Blue" hydrogen is produced from fossil fuels such as oil, gas and coal principally via steam methane reforming or autothermal reforming

Steam Methane Reforming (SMR) and Autothermal Reforming (ATR) combined with carbon capture technology offer high potential for reducing CO2 emissions.

SMR is a catalytic process that involves a reaction between natural gas and steam to produce hydrogen. The bi-product, carbon monoxide, then reacts with steam during the cooling process to produce CO2. The CO2 is subsequently captured when passing through an amine solvent. During steam methane reforming, the efficiency of CO2 capture is between 71% and 92%, depending upon the precise type of technology used.

ATR combines steam reforming and partial oxidation for low-cost and highly reliable hydrogen production. Compared to SMR, ATR is easy to operate with a smaller system, offers better temperature control and requires low energy consumption and less coking. It also has a superior carbon capture rate which can reach 94%/95%. However, ATR needs more catalysts and heat exchangers than SMR which translates into higher costs.

Other blue hydrogen production technologies include **methane pyrolysis** where methane, the main component of natural gas, is thermally decomposed to give clean hydrogen. The by-product carbon black can also be captured and sequestered. Compared to other technologies, methane pyrolysis is much more efficient, has lower investment costs and emits less carbon dioxide but it requires very high temperatures and a stable molten media.

Coal gasification with CCUS is another alternative and is the first step to producing hydrogen. This process converts a carbon-based material, usually coal, into a synthesis gas or syngas. Syngas, which is mainly composed of carbon monoxide and hydrogen, is further converted to carbon dioxide and hydrogen by adding steam and reacting over a catalyst in a water-gas-shift reactor.

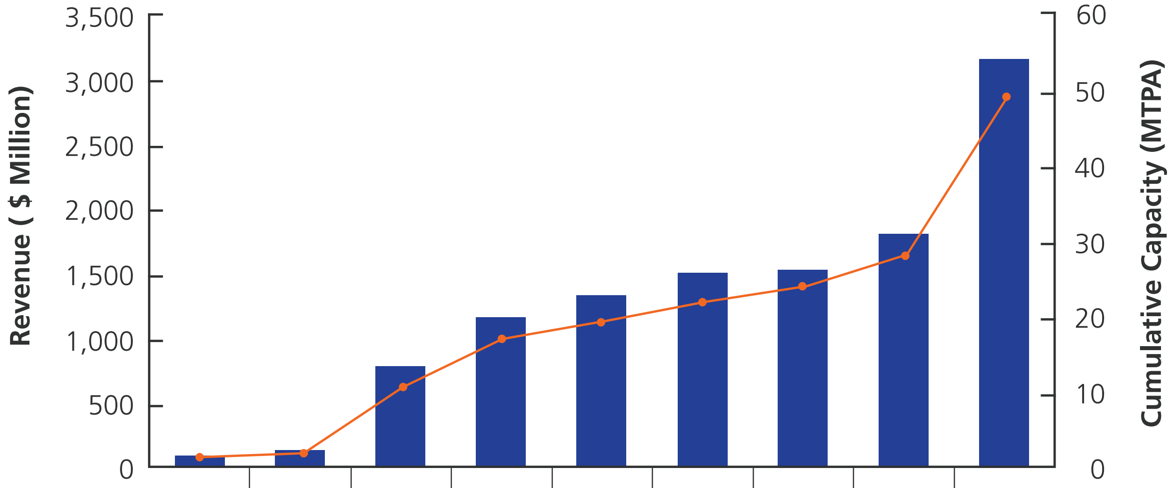
Less current approaches include **bitumen gasification** with Carbon Capture and Storage (CCS), **petcoke with biomass gasification** with CCS, **heavy oil residue gasification** with CCS and partial oxidation. Bitumen gasification and heavy oil residue gasification are mainly used in refineries for process optimization while partial oxidation is a very new technology with few demonstration projects.

Source: Frost & Sullivan

Globally, the revenues stemming from carbon capture in this context are forecast to leap from $80m in 2022 to over $3b in 2030, a robust CAGR of 58%

This corresponds to a capacity for carbon capture in blue hydrogen applications of just one Million Tons per Annum (MTPA) in 2022 rising to 48.4 MTPA by 2030.

CARBON CAPTURE IN BLUE HYDROGEN APPLICATIONS, REVENUE AND CAPACITY FORECAST, GLOBAL 2022-30
CAGR 2022–2030 = 58.2%



	2018	2019	2020	2021	2022	2023	2024	2025	2026
Revenue ($M)	3,031.0	3,182.2	2,685.3	2,917.7	3,105.8	3,290.5	3,480.2	3,675.6	3,884.0
Annual Capacity	1.0	1.5	10.3	16.5	18.8	21.4	23.4	27.6	48.4

Growth is also being driven by technology advances which are reducing costs

There have been significant advances in hydrogen production through SMR and ATR as well as emerging methods such as methane pyrolysis and, notably, gas partial oxidation (POX). These innovations have increased efficiency and also reduced costs.

Gas POX technology uses oxygen along with direct firing in a refractory-lined reactor. It is a non-catalytic process and consumes less steam than competing methods and generates no direct CO2 emissions. Partial oxidation technology reduces costs by maximizing carbon capture potential and simplifying the process lineup with a maximum saving potential of 22% compared to ATR when measured in terms of the levelized cost of hydrogen.

In addition, gas POX offers a 34% decline in Operating Expenses (OpEx) due to reduced compression duties and greater steam generation for internal power.

Source: Frost & Sullivan

From a competitive perspective, Equinor is the market leader for carbon capture in blue hydrogen followed by Eni and then ExxonMobil

Equinor, Norway, currently has 13 large-scale projects with a cumulative carbon capture capacity of 39 MTPA.

The company aims to be a market leader in the energy transition and plans to achieve this by optimizing its O&G portfolio, capturing growth in renewables and developing new market opportunities within low-carbon solutions by leveraging its technology, competences and capacity based on 50 years of experience in the oil & gas industry.

Eni, Italy, is second in the market for blue hydrogen production using CCUS. Currently, the company has 4 large-scale projects with a cumulative capacity of 18 MTPA. All these projects are at the feasibility stage and will come online in 2 to 7 years.

The company is developing low-carbon hydrogen production from natural gas reforming with emissions capture or through renewables and following a circular economy approach. Eni is also innovating to produce sustainable hydrogen from waste streams.

ExxonMobil, United States, completes the top three and has plans to set up a world-class blue hydrogen project at its Baytown (Texas) integrated refining and petrochemical complex. When combined with CCS technology, the hydrogen produced here will generate zero CO2 emissions and contribute towards the company's net-zero commitments.

Other key players include **Shell** (UK) with its ***Shell Blue Hydrogen Process*** which integrates gas partial oxidation and the company's ***ADIP ULTRA*** technologies to maximize carbon capture efficiencies and simplify lineup design. This translates into significant cost optimizations and improved nitrogen production margins for resource holders. Compared to conventional hydrogen manufacturing processes, the ***Shell Blue Hydrogen Process*** has been proven better on a levelized cost of hydrogen based on its blue variants.

ADNOC, Air Products, BP, CF Industries, CNPC, Pure hydrogen, Phillips 66, Sinopec Air Liquide, TotalEnergies also have blue hydrogen projects in their pipelines.

They and others stand to benefit from blending blue hydrogen in natural gas lines

To transition to a blue hydrogen economy, viable infrastructure is required to deliver hydrogen from the point of production to the point of end use and to make it available in the same way that a refueling station offers gas and a stationary generator provides power.

In recent years, the process of blending blue hydrogen into natural gas in the existing pipeline network has been gathering a great deal of attention in Europe, Australia and the United States as the provision of dedicated infrastructure for hydrogen transportation and storage is still in its early stages and it will require billions of dollars in investments to construct new pipelines and take many years for them to come online.

Using well-connected pipelines offers market participants the possibility of accommodating significant volumes of blue hydrogen mixed in specific ratios with natural gas while significantly improving system efficiency and contributing to decarbonisation. In the UK, the gas grid is currently being prepared for a blend of up to 20% hydrogen which is expected to correspond to a 6% reduction in greenhouse gas emissions.

Blending blue hydrogen with natural gas creates an opportunity for producers to provide end users that have relatively few investments in infrastructure with H2 for heat and energy production purposes via a means of transport which is readily available. It also eliminates the need for the development of static hydrogen storage facilities and enables significant dynamic storage opportunities for the utilization of hydrogen during times of demand.

Currently, the blending of blue hydrogen with natural gas is still in its early stages as the availability of suitable networks varies across Europe, Australia and the United States. In addition, a lack of homogenous regulations is a major barrier. Governments will need to tighten standards to support the upscaling of hydrogen injection into gas pipelines.

Source: Frost & Sullivan

In parallel to blue hydrogen, "pink" hydrogen – which is generated from nuclear power – promises to be a motor for greater adoption of H2

Nuclear hydrogen production involves harnessing heat and electricity from nuclear power with its positive characteristics including its low cost, scalability and limited footprint as well as its diversity in terms of production pathways.

Engineers are making continuous improvements in pink hydrogen production and nuclear reactor technologies to increase efficiency and further reduce costs.

With hydrogen playing an important and growing role in global decarbonization efforts, demand for clean and cost-competitive hydrogen (H2) production methods will support the adoption of nuclear energy-based hydrogen solutions.

Nuclear plants can notably use off peak power more efficiently than renewable sources making them a lower cost alternative to "green" hydrogen

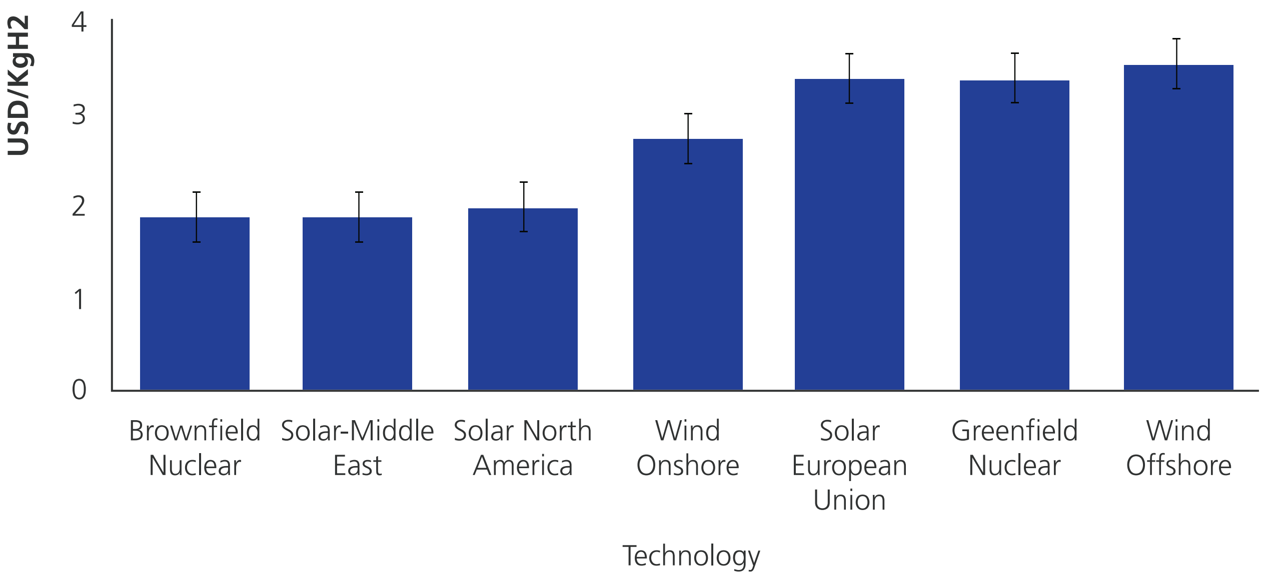
According to the International Energy Agency (IEA), hydrogen consumption will increase from approximately 90 million tons in 2020 to more than 500 million tons by 2050.

At present, professionals mostly use hydrogen in industrial settings while its future applications include heating, power and transportation applications.

However, the biggest challenge to developing a hydrogen economy is producing H2 at competitive prices. In this regard, nuclear energy, with its low carbon profile and ability to provide dispatchable electricity, can play a key role in enabling hydrogen electrolysis and shielding the sector from the gas price volatility in SMR-dominated production.

The graph depicts the levelized cost of hydrogen production for various electricity generation technologies. While newly built nuclear plants are already cost-competitive with offshore wind and solar power, facilities which operate over time will offer the lowest-cost hydrogen production solutions via electrolysis. As a point of comparison, H2 production through SMR at gas prices of $100 per MWh does not compare favorably.

LEVELIZED COST OF HYDROGEN, GLOBAL, 2022



Source: Frost & Sullivan

There currently exist four principal pathways to generating all nuclear hydrogen

As with blue hydrogen, *steam methane reforming* is the most developed method

In a nuclear **SMR** process, first sulfur from natural gas is removed. The cleaned gas is then fed to a reformer where an endothermic reaction with the help of a catalyst (typically nickel) produces hydrogen and carbon monoxide. This mixture enters a water-gas-shift reactor where carbon dioxide and H2 are produced by making the carbon monoxide react with steam.

The process typically occurs at 700 to 1,000 degrees Celsius and at 4 Megapascals (Mpa) of pressure. In a nuclear-SMR hybrid, heat from medium- or high-temperature reactors can minimize the use of up to 30% of the natural gas and therefore reduce emissions. Furthermore, carbon capture plants can harness the CO2 released to make the reaction even cleaner.

Overall, nuclear SMR offers efficiencies of between 75% and 85%.

Its **advantages** include the fact that the process results in a high hydrogen yield of more than 50% when operating at high temperatures. In addition, using nuclear heat can reduce the need for natural gas for steam generation and minimize carbon dioxide emissions.

Its **disadvantages** include a slow start-up time because of the high-temperature requirement of the reformer reaction and the complexities of a system which requires transfer devices. Furthermore, it is incompatible with (the most common) light water reactors.

Alkaline electrolysis is also widely commercially used to produce pink hydrogen

Alkaline electrolysis is the most mature electrolyzer technology that industries use to produce hydrogen commercially. The system typically operates at a temperature of between 40 and 90 degrees Celsius with a pressure of nearly 0.1 Mpa.

Alkaline electrolyzers use sodium hydroxide (NaOH) or potassium hydroxide (KOH) as a liquid electrolyte with water electrolyzation taking place at the cathode and oxygen production occurring at the anode. The electrode material is nickel (Ni).

Its **advantages** include the ability of alkaline electrolyzers to produce high-purity hydrogen and offer stability while the use of non-noble catalysts has the potential to reduce costs. Alkaline electrolyzer cells are also stackable and thus scalable.

Its **disadvantages** include the fact that H2 production purity from alkaline electrolyzers is still less than that achieved from polymer electrolyte membrane electrolyzers while there is a risk that the electrolyte can corrode the electrodes over time and impact production efficiency. Alkaline electrolysis systems also suffer from gas permeation issues stemming from the diaphragm and, although scalable, their low-pressure operation makes them unsuitable for very high-volume hydrogen production.

Polymer electrolyte membrane electrolysis operates at low temperature levels …

PEM typically operates at a similar temperature range to alkaline electrolyzers but uses, as the name suggests, a polymer electrolyte. This consists of a perfluorosulfonic acidic polymer membrane and only allows protons to pass through the anode to the cathode. Water electrolysis occurs at the anode which comprises iridium (IR) while the cathode comprises platinum (Pt). PEM electrolyzers operate at a pressure of 0.1 MPa with a temperature range of between 30 and 90 degrees Celsius. Both alkaline and PEM electrolyzers can perform cold electrolysis i.e., without any heat input from a nuclear reactor or other source.

Its **advantages** include the production of extremely high-purity hydrogen and, due to the use of a solid polymer membrane, its contact system design. Using IR and Pt electrodes results in a fast response time of typically less than 10 minutes whilst the technology is highly scalable. Professionals have commercialized PEM electrolyzers for MW-level operation.

Its **disadvantages** include the acidity of the electrodes which can lead to degradation. In addition, PEM electrolyzers have a shorter operating life than alkaline

Source: Frost & Sullivan

electrolyzers and the use of polymer membranes results in relatively high equipment costs. This is exacerbated by the inclusion of IR and Pt in the electrodes.

… whilst *solid oxide electrolyzer cells* are unique since they require significant heat

Both alkaline and PEM electrolyzers can operate at ambient temperatures with minimal other inputs but **SOECs** need both heat and electricity. The system uses steam for electrolysis instead of water and deploys a solid ceramic electrolyte. SOEC has an operating temperature of between 700 and 1,000 degrees Celsius and requires a pressure ranging from 0.15 to 3 MPa. The cathode typically comprises a nickel-yttria-stabilized zirconia composite while the anode is made up of strontium-doped lanthanum manganite or lanthanum strontium manganite and Yttria-stabilized zirconia.

Its **advantages** include the fact that SOEC has high application flexibility, such as a reverse mode, and can generate electricity by using fuel cells. Solid oxide electrolyzer cells can also pair with a vast range of current and advanced medium- to high-temperature reactors while requiring minimal capital expenditure and remaining highly scalable and compact.

Its **disadvantages** include the reduced hydrogen output purity compared with alkaline and PEM electrolyzers. In addition, the high-temperature operation of the electrolyzer can degrade the ceramic electrolytes and electrodes which results in low durability. SOEC is also less stable compared to alkaline and PEM electrolyzers.

For the latter, Topsoe (Denmark) has developed a compact and stackable SOEC cell that offers low-cost hydrogen production using ceramic electrolytes

Innovation

Topsoe's system utilizes ceramic electrolytes with several automation features. This gives the system an auto-response capability and minimizes the requirement for human oversight and the need for any training operators.

The company's technology significantly improves H2 production versus competing technologies offering, for example, 30% greater capacity than alkaline and PEM electrolyzers. Furthermore, it is scalable and can integrate with existing plant layouts to optimize production while the system can also utilize low-value heat from industries to provide improved energy efficiency and cost savings.

The Topsoe SOEC electrolyzer can pair with renewable energy and nuclear power plants to produce clean electrolytic hydrogen.

Technology Readiness Level

The company has successfully commercialized its technology and is engaging in several hydrogen and green ammonia production projects. Its most notable pilot is the NEOM project where its solution is working in the world's largest green ammonia plant.

The company has also formed a consortium with Copenhagen Atomics and Alfa Laval to produce green ammonia. This will rely on a thorium-fueled reactor and electrolysis with Topsoe acting as the technology provider for ammonia synthesis and SOEC electrolysis while Copenhagen Atomics together with its partner Alfa Laval providing nuclear reactor and heat exchanger technologies respectively.

Bloom Energy (US) has taken another approach, targeting low energy consumption

Innovation

Bloom Energy has developed SOEC cells that, in pilot testing conditions, can produce 1 kilogram (kg) of hydrogen at 37.7 kilowatt-hour (kWh) of energy. PEM and alkaline cells, in comparison, consume more than 52 kWh per kg of hydrogen produced.

The Idaho National Laboratory in the United States has validated these results while the company has improved its product further with its commercial solution offering efficiency in the range of 39% to 46%.

Bloom's technology offers a 28% cost reduction in hydrogen production if the capacity doubles which is twice as much as PEM electrolyzers. In addition, as it utilizes low-cost ceramics, no supply issues remain concerning availability for production.

High-temperature SOECs such as this are especially suitable for clean hydrogen production utilizing either renewable or nuclear energy.

Technology Readiness Level

The company unveiled its commercial product in 2021, offering it to industries which require large-scale hydrogen production. So far, Bloom has installed 1.5 Gigawatt (GW) of SOEC cumulatively and, in September 2022, announced a collaboration with Xcel Energy to install its electrolyzers at the Minnesota-based Prairie Island nuclear generating plant. Construction of this 230kW demonstration facility is taking place with operations starting in 2024.

While Europe and the US boast pockets of innovation, China that leads the way overall in terms of nuclear hydrogen R&D activity and investment

Between 2019 and 2021, global patent offices granted a total of 6,903 patents and applications relevant to nuclear reactors and hydrogen production technologies.

Top applicants include Haldor Topsoe, Huaneng Group Tech Innovation Center, Honda, Agc and the Commissariat Energie Atomique.

China has the highest number of patent publications globally at 48%.

Governments regard pink hydrogen as a way of reinforcing their energy security

As the world moves gradually away from using coal and oil, a growing need exists for an optimal energy mix which supports the move to net zero without sacrificing or negatively impacting the costs that business or individuals face.

Hydrogen is often touted as wonder fuel in this context due to its superior energy content and wide-scale availability in water and natural gas and it will almost certainly play a crucial role in the energy transition.

However, green hydrogen has the potential to compromise energy security since renewable energy sources can contribute towards grid stability. Green power is notably less able to follow fluctuations in demand, a challenge which is expected to become more pronounced with the further advent of electric vehicles and electrolyzer technologies.

Regulators and network operators will therefore have a role to play in supporting the integration of pink hydrogen production as demand-responsive nuclear energy can prevent grid instability in cases where power needs increase suddenly.

Its ability to provide base load power while also enabling clean hydrogen production makes it attractive in the long run.

Moving forwards, policy-based encouragement for Small Modular Reactor (SMRe) developers would enable the sector’s development. SMRes can reduce the reliance of industries on renewables, helping onsite power and hydrogen production and significantly decarbonizing the manufacturing sector.

Governments’ overall focus in enabling a hydrogen economy should be on achieving the right mix of renewable energy sources supported by base load power generation technologies, including nuclear power.

Source: Frost & Sullivan

In the longer term, however, "green" hydrogen is attracting significant public sector support as a means with which to guarantee energy sustainability

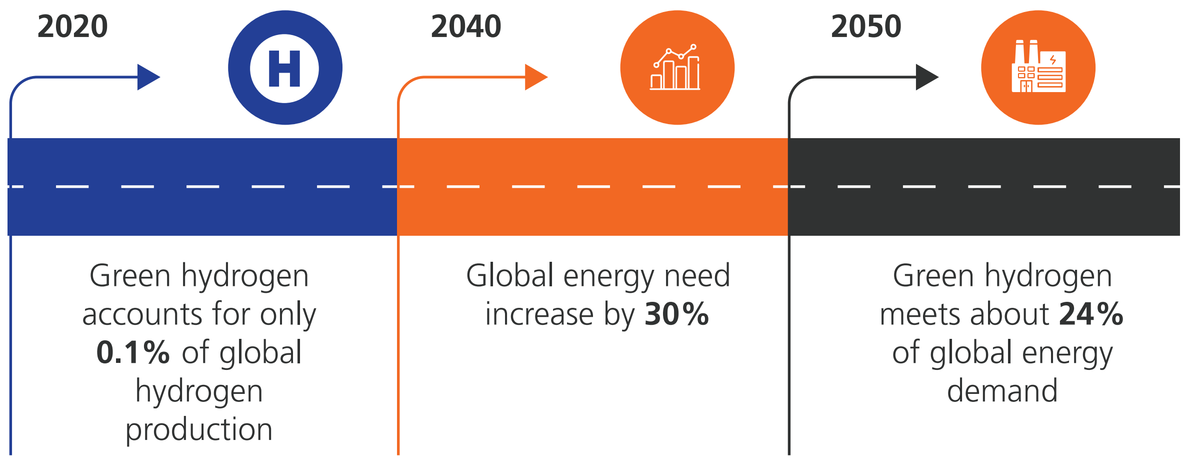
Green hydrogen production involves a sustainable process of generating H2 that uses renewable electricity to split water into hydrogen and oxygen. Its uptake is gaining momentum with government investment a key driver.

In the shorter term, green hydrogen has a role to play in addressing the energy crisis. The Russia-Ukraine War has brought high volatility in power prices which has resulted in many countries seeking alternative clean and decentralized energy solutions.

Today, this accounts for only 0.1% of global production but has the potential to meet 24% of the world's energy demand through $160 billion of financing

Implementing widespread green hydrogen production processes offers the prospect of removing 830 million tons of annual CO2 emissions globally which stem from the use of fossil fuels to produce H2. However, harnessing this opportunity will require greater and accelerated efforts from stakeholders across the value chain. To produce more than 18 megatons (Mt) of green hydrogen annually by 2030, an investment of more than 100 billion dollars is required but only $20b is currently committed to infrastructure development.

GREEN HYDROGEN ROADMAP, GLOBAL, 2020-50



Source: Frost & Sullivan

Frost & Sullivan envisages four scenarios for green hydrogen the most optimistic of which involves unlocking low-cost production at scale

Limited resourcefulness

Low technology innovation and low government impact

Under this scenario, the lack of a regulatory framework would result in low acceptance of green hydrogen at the consumer level with no global companies placing significant bets on the future of the sector owing to the absence of reliable proof of concept. Production would therefore generally remain low-cost and fuel intensive.

Long term clean energy

Low technology innovation and high government impact

Under this scenario, several pilot projects would be deployed to focus on developing clean hydrogen hubs, trade routes and value creation. Government subsidies for technology deployments such as CCU would be available but low levels of innovation would result in a high demand-supply gap.

Technological diversification

High technology innovation and low government impact

Under this scenario, leading energy companies would drive green hydrogen production on a large scale. Commercial adoption would be feasible but green H2 would only be available to those who could afford it while the high cost of production and low level of government support, in the form of inconsistent regulations, could result in supply shortfalls.

Green hydrogen unlocked

High technology innovation and high government impact

Under this scenario, affordable green hydrogen would be available due to close collaboration between industry leaders and policymakers. The presence of cheap and efficient electrolyzers would enable large-scale production and the provision of H2 as a low-priced and sustainable fuel for transportation.

Eventually, this would result in the development of a holistic green hydrogen ecosystem serving heavy and hard-to-abate as well as other industries.

In Europe, the sector stands to benefit from the development and implementation of national and international long term clean energy strategies

Overall, less 2% of the European Union's energy demand is currently met by hydrogen of which 96% is produced using natural gas. To achieve their net-zero commitments, countries in the region have launched major initiatives while many Member States have rich renewable energy sources which they can harness for green H2 production.

In France, for example, where solar power is plentiful, the government provided $7.2 billion of funding in 2020 to support the industry. $3.3 billion of this will be used to installer electrolyser capacity of 6.5 GW while the authorities are also looking to encourage research into innovative green hydrogen technologies.

In the Netherlands, where there is a large offshore wind capacity, the government has made similar commitments whereas in Germany, where onshore wind is more common, authorities are looking to partner with their immediate neighbours to import green hydrogen through existing natural gas pipelines.

Source: Frost & Sullivan

Moving forwards, green hydrogen has the potential to enable the deployment of *truly* zero-emission Fuel Cell vehicles

Currently, hydrogen production typically uses huge volumes of fossil fuels which makes the overall process energy intensive. Deploying natural gas via steam methane reformation, for example, emits 8 kg to 9 kg of CO2 per kg of H2.

However, a transition to completely clean hydrogen fuel cell vehicles (FCVs) has the potential offset the overall emissions stemming from cars and buses. Gradually, renewable energy is becoming more available and more affordable which makes the use of green hydrogen a viable option for the transport industry.

In parallel, many OEMs, such as Toyota and Hyundai, have brought hydrogen-based FCVs to the market although 100% green hydrogen vehicles remain in the planning phase and are expected to largely launch in the years after 2030.

On the demand side, FCV owners and drivers stand to benefit from many of the financial incentives and tax rebates which are afforded to all zero-emission vehicles. For instance, under the Clean Vehicle Rebate Project in California residents are offered $4,500–$7,000 for the purchase of an electric, plug-in or fuel cell car while the US government provides a benefit of $8,000 on the purchase of light FCVs.

For green hydrogen FCVs to gain real traction, a need exists to develop proper fuelling infrastructure while OEMs could offer subscription-based models to gain consumers' trust and confidence. Cross-industry alliances will also be required to facilitate the growth of the industry. OEMs should build strong partnerships with green H2 producers to be able to closely monitor and analyse new products and applications.

This will, in part, be enabled by the advent of waste to hydrogen solutions …

Waste-to-hydrogen solutions are gaining momentum and involve a hydrogen production process which converts organic and agricultural waste, plastics and sewage sludge to a fuel that can be commercialised as green hydrogen. This can further be paired with renewable energy to help convert the waste into H2.

Various approaches exist to produce hydrogen from waste. Gasification, which is one of the most common, requires thermal heating which causes CO2 emissions, although these can be offset through the use of carbon capture technology.

Many countries are investing in waste-to-hydrogen technologies. Egypt has developed the largest plant which will recover 4 million tons of waste to produce 300,000 tons of green hydrogen annually while the European Union (EU) has initiated a project called Waste2H2 which focuses on supporting innovation in waste-to-hydrogen solutions.

Indeed, as part of its Horizon programme, the EU has recently closed a tender for a demonstration project in a sector which it believes could generate 30m tonnes of hydrogen in the region from 300m tonnes of waste. The EU feels that there is the potential for a levelized cost of hydrogen below 3 €/kg and approaching 1.5 €/kg in the best-case scenario. Its tender is seeking a system prototype with a technology readiness level (TRL) of 7.

In order for this approach to take off, market participants will need to invest in waste-to-hydrogen facilities that facilitate production at scale. Waste collection and segregation could pose a challenge to this but leveraging advances in robotic technology can aid the exploitation of suitable waste for generating hydrogen.

Furthermore, the development of thermochemical technologies has the potential to streamline the waste-to-hydrogen process through pyrolysis and gasification while, at the same time, facilitating the compression of landfills to save space.

Here, as in the automotive sector, cross-sector alliances will accelerate deployment and eventually could make

Source: Frost & Sullivan

hydrogen from waste a mainstream fuel. Chemical and waste management companies can work together to benefit from the opportunity while the ICT sector can play a vital role by offering advanced technologies to support process efficiency.

… and, as the industry matures, an eventual transformation in the business model with hydrogen-as-a-service emerging

Owing to its potential to ease the energy crisis and accelerate the transition towards net-zero goals, green hydrogen has been attracting huge interest and investment globally. The chemical sector notably stands to benefit by offering advanced electrolyser technology to facilitate production with Amazon, for example, supporting, Electric Hydrogen, from the United States, and a European company, Sunfire (Germany) via its Climate Pledge Fund.

In parallel, the complexity surrounding H2 has created opportunities for hydrogen producers which can offer green "hydrogen-as-a-service" to sectors that need green hydrogen to accelerate their own efforts toward decarbonization. Under this business model, a company will offer an end-to-end service to provide hydrogen to its customers, looking after the design, construction and operation renewable energy plants and hydrogen production systems, as well as the associated storage, energy management and distribution solutions.

Companies providing green hydrogen as a commodity will need to develop the associated infrastructure to deliver better products and avail themselves of the benefits. They must also prepare to be cost competitive as, once the technology matures, new entrants will emerge and enter the market. For example, Siemens Gamesa Renewable Energy (Spain) has initiated R&D efforts towards large-scale green hydrogen production which aims to provide high volumes at low prices at its Brande Hydrogen facility.

Here, once again, market participants will need to seek potential partnerships and form joint ventures with a view to leveraging synergies. For instance, a green hydrogen provider could work with a renewables provider to enable cost-efficient production.

Suppliers will also look to deploy advanced technologies to gain an edge over competitors. For example, the use of predictive analytics to foresee potential failures at a plant level can help to enable the optimization of production plants.

Source: Frost & Sullivan

DECARBONISING INDUSTRY

In order to effectively tackle global warming, there is an urgent need for abatement in hard-to-decarbonize *heavy industries* beyond oil & gas

The continued creation of carbon dioxide, notably in the cement and steel sectors, plays a significant role in climate change resulting in **global warming**, shifting rain and snowfall patterns and more weather events including rainstorms, heat waves and flooding. By taking action to reduce emissions from heavy industries now, there is a window of opportunity to minimize the risk stemming from extremes in the future.

CO2 from **heavy industries** also accounts for much of all **air pollution** which leads to high incidences of chronic diseases. By mitigating the harmful impacts of carbon emissions, it will be possible to prevent up to three million premature deaths annually by the year 2100, according to a study by the World Health Organization.

The deployment of effective carbon abatement strategies and tactics promises not only to ***mitigate the challenges*** but to ***create real opportunities***.

Internally, managing CO2 enables businesses to differentiate themselves with **sustainability** becoming a key success factor in competitive environments. O&G majors have, for example – as shown in the first chapter of this report – begun to invest in innovative technologies and to diversify their energy mix in order to reduce their emissions whilst also setting ambitious climate targets and creating environmental risk assessments programs.

Externally, curbing carbon dioxide in heavy industries leads to improved energy **efficiency** in many processes across both small- and large-scale applications. Technology transfer to sectors such as construction enables improved insulation and more efficient boilers as well as the use of heating controls and lighting systems with smart sensors. Such opportunities combine reduced carbon emissions with improved product performance.

NEED FOR ABATEMENT IN HEAVY INDUSTRIES

Source: Frost & Sullivan

In the *cement* industry, the average CO2 per ton of production has fallen drastically since the 1990s but still contributes about 6% of global emissions

The cement industry is estimated to release about 1 kg of carbon dioxide for every 1kg of cement that is produced. The average CO2 emissions per ton has decreased by 18% since the 1990s, mainly due to improvements in the efficiency of production plants and by switching to waste materials for energy generation needs. Nonetheless, with the demand for buildings and infrastructure set to rise due to rapid urbanization across the globe, the need for sustainable construction techniques is gathering pace.

Unlike other industries, the release of carbon dioxide in the cement sector is largely attributed to the chemical reactions which occur during the manufacturing process itself and notably in the course of the conversion of limestone (CaCO3) into calcium oxide (CaO) which is the primary precursor to cement. It is chemically impossible to transform CaCO3 into CaO and then into cement clinker without emitting CO2.

Pollution stemming from the cement industry therefore mainly depends on the clinker ratio used in cement while the widest scope – and the highest potential – for reducing emissions lies in developing new or substitute solutions for clinker. Although there are a handful of innovators working to developing carbon abatement technologies in this respect, a lack of policy incentives is the key reason for the subdued interest in significant research & development into any "direct" material modification.

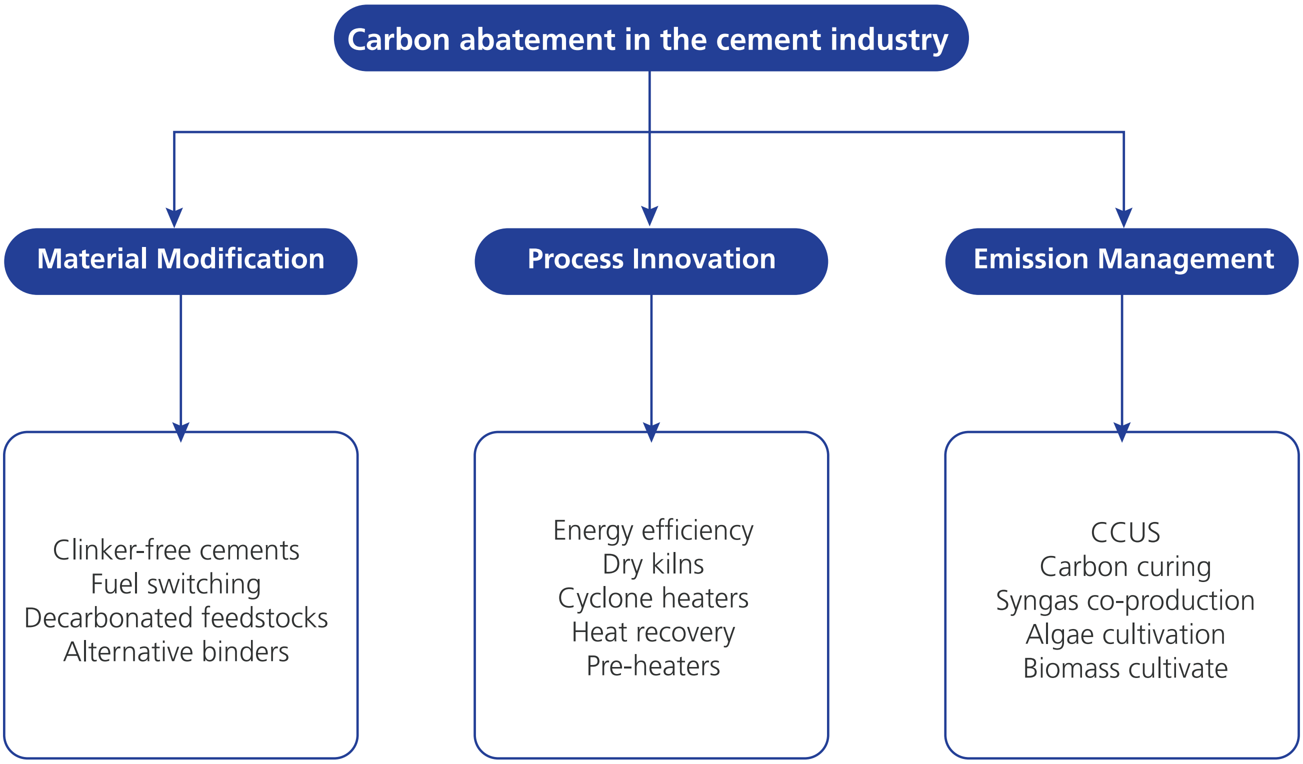
Source: Frost & Sullivan

Here, as in the O&G industry, there are three main approaches to decarbonisation with material modification including recycling and reuse, process innovation covering heat recovery and emission management incorporating CCUS

In addition to some activity focused on clinker-free cements, **material modification** has focused on a circular approach as well as fuel-switching and deploying decarbonated feedstocks or alternative binder materials.

For **process innovation**, efforts are centered on energy efficiency improvements for conventional raw material and clinker preparation, including switching to dry kilns and using multistage cyclone heaters and waste heat recovery and leveraging additional preheaters for productivity and energy efficiency improvements.

Carbon capture, utilization and storage is the main approach to **emission management** with market participants investigating carbon curing, syngas co-production and algae and biomass cultivation for fuel and chemical production.



Source: Frost & Sullivan

Indeed, CCUS and novel materials have the highest potential

The high concentration of CO_2 present in the flue gas emitted from the kiln stacks that are used in cement production offers a tangible carbon abatement route for the industry. Carbon captured here can be reused in the manufacturing process or for other purposes and has the potential to reduce emissions by up to 95% to 99%.

In parallel, the use of alternative materials that are rich in calcium and which are either in a de-carbonated form or contain calcium as a non-carbonate mineral is another impactful way in which to limit CO_2 emissions from cement manufacturing. This approach can be between 90% and 99% effective but is limited by raw material availability whilst some materials are only suitable for certain end-user applications.

Other carbon abatement options include;

- The use of alternatives to clinker such as fly ash and furnace slag which, the lack of policy incentives aside, is a viable option for emission reduction but limits the scope of application due to its inferior mechanical properties vs. conventional cement
- The adoption of renewable energy sources, including a switch to solar, wind and biomass, which will mitigate the volume of CO_2 emitted from burning the fossil fuels that are currently required for various operations in cement manufacturing

Eco2Block (Portugal), for example, offers an eco-friendly alternative to concrete building material …

The company develops recyclable materials from industrial waste, carbon dioxide and wastewater for precast building applications with its product line including ***ECO2Pavers***, a recyclable pavement block, and ***ECO2Masonry***, eco-friendly masonry blocks.

Eco2Blocks' solution is carbon-negative so environmentally friendly while also being cost-effective; the technology uses less energy and raw material, saving 50% in comparison to conventional cement. It also adds value by solving waste disposal challenges.

… while work is also underway to replace conventional cement with geo-polymeric substitutes

Renca (United States) specializes in the manufacture of geo-polymer cement by using inorganic mineral substances that are obtained as by-products from electrometallurgical industries and power plants. Its solutions are chemically inert and offer excellent dimensional stability even under extreme conditions.

The company has successfully commercialized a range of products including ***geocement*** and ***geosilicate*** binders. Renco also provides turnkey solutions for geo-polymer cement production which require end-users to invest up to ten times less Capital Expenditure (CapEx) as compared to that needed for establishing conventional Portland cement facilities.

Geo-polymer cement offers further advantages in that it is highly resistant to fire, acids, alkalis and chemicals. Its setting time is also only around three hours as compared to conventional cement which takes around ten hours. Geo-polymer cement is highly resistant to thermal shocks and has strong insulation properties.

Source: Frost & Sullivan

More broadly, the Global Cement and Concrete Association which represents about 50% of global production has set ambitious abatement targets

The GCCA is an international industry-led organization which includes cement companies from across the world including Asia Cement, Cementos Progreso, Dalmia Cement, HeidelbergCement, LafargeHolcim, Ultratech, Orient Cement, SCG Cement, Taiwan Cement Corporation, Vicat, Votorantim and West China Cement.

Collectively the GCCA accounts for 38 members and 18 affiliates.

Companies belonging to the Global Cement and Concrete Association have pledged to develop climate change mitigation strategies, publish targets and report on their progress and to provide annual environmental data to the GCCA following its guidelines.

The GCCA has identified Climate Change, Energy, Environment and Nature and the Circular Economy as some of its sustainability chart pillars and report areas.

It has also launched *Innovandi*, a research network of 28 members including industrial and scientific institutions. The network's focus areas include CCUS implementation, alternative materials and low-carbon concrete technologies as well as re-carbonation.

These have been adopted by the major market participants such as LafargeHolcim which is switching to alternative green fuels …

LafargeHolcim, Switzerland, currently has a carbon intensity per ton of cementitious material of 561kg CO2 and is targeting 550kg CO2 by 2022 and 520kg CO2 by 2030. Its efforts in this respect are focused on improving energy efficiency, switching to alternative fuels (which currently make up 20% of its mix), reducing the clinker intensity, capturing CO2 emissions and investing in other low-carbon solutions.

… and Vicat which is developing new low carbon cement

Vicat, France, currently has a carbon intensity of 610kg CO2 and is aiming for 540kg by 2030. Its carbon abatement approach is centered on developing innovative low-carbon cements and concretes, improving industrial processes from the extraction of raw materials through to construction, achieving a 75% clinker rate in cement and using 40% alternative fuels in its energy mix (of which 15% will stem from biomass).

Innovation is also stemming from outside of the industry with Solidia Technologies providing dedicated turnkey CCUS technology

Solidia Technologies, United States, offers solutions which can simultaneously capture and utilize the CO2 from concrete curing processes. This enables the company to replace the use of freshwater with carbon dioxide. Solidia's manufacturing process also leverages the same equipment and raw materials to produce concrete at a faster rate and with better durability than conventionally. It is easily adaptable to existing concrete production processes.

In the *steel* industry, decarbonization has received less focused investment and the space still contributes between 7% and 9% of global emissions

Overall, the industry is highly localized, capital intensive and operates with low margins. Unlike the cement or O&G sectors (the latter of which is covered later in this chapter), a single roadmap cannot be adopted across the globe, and it requires stakeholders in each region to take individual initiatives to drive decarbonization in the steel industry through the development and adoption of low-carbon technologies.

On average, for every ton of steel produced, 1.85 tons of CO2 are emitted.

The conventional steel production route is Blast Furnace-Basic Oxygen Furnace (BF-BOF) with coal used to generate high temperatures and extract iron from iron ore before converting it to steel. Many stakeholders are looking to modify the BF-BOF process or to adopt new production routes to reduce their emissions.

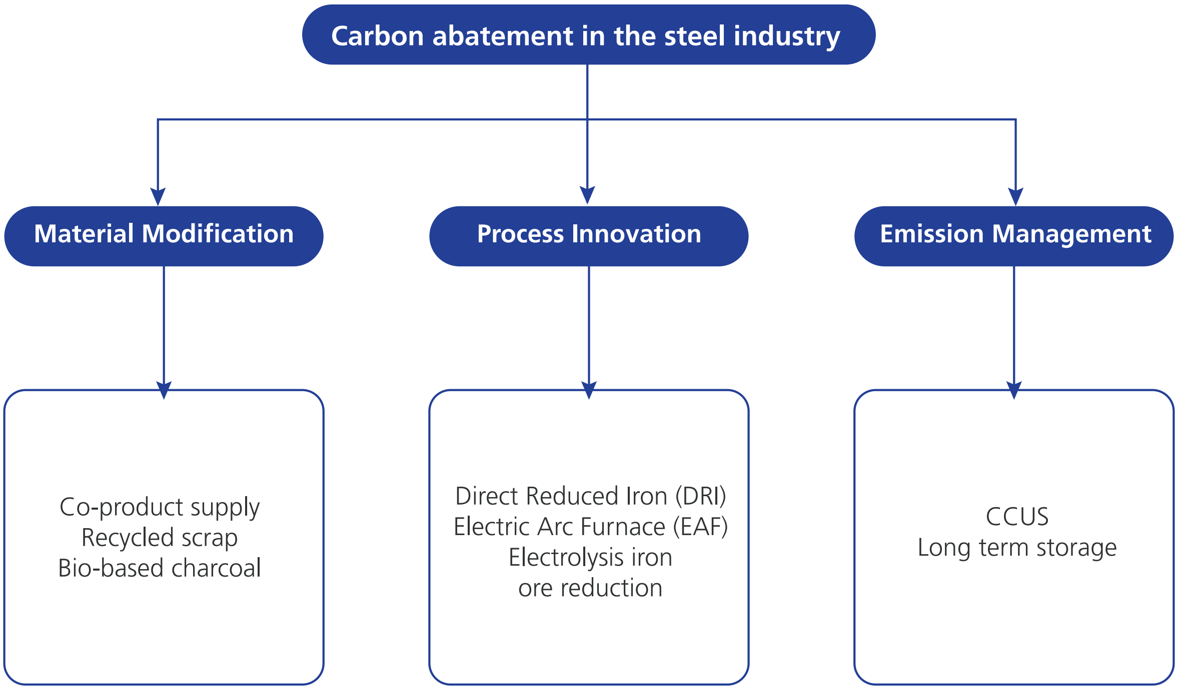
Source: Frost & Sullivan

Here, material modification includes leveraging co-products, process innovation covers direct reduced iron while emission management also incorporates CCUS

The supply of co-products such as blast furnace slag to the cement industry to offset the use of natural resources is joined as a **material modification** approach by the use of recycled scrap and the production of biomass-based charcoal for iron ore reduction.

Process innovation covers natural gas or hydrogen-based Direct Reduced Iron (DRI), the adoption of Electric Arc Furnace (EAF) technology and the implementation of electrolysis-based iron ore reduction.

As in the cement industry, carbon capture, utilization and storage for the manufacture of chemicals and fuels is the main **emission management** tactic together with carbon capture and long-term storage under geological formations.



In the short term, increased recycling and energy efficiency improvements are the most accessible and widely adopted CO2 steel abatement strategies

By reusing steel in the form of scrap, the industry can drastically reduce its carbon footprint across its product life cycle. Since fundamentally steel can be recycled continuously without the loss of any properties, this approach has immense potential with emission reductions of up to 100% possible. On the downside, however, the availability of scrap is limited owing to the inherently long life of steel products.

Energy consumption in the steel industry has already witnessed a 61% drop in the last 50 years. Although there is still room for improving the efficiency of production processes, the potential for achieving further significant emission reductions is limited to 15% to 20%.

Other carbon abatement options include;

- Using hydrogen instead of carbon to reduce iron ore, thereby mitigating the release of CO2 while producing water instead
- Leveraging biomass, in the form of charcoal, as a substitute for coal

Source: Frost & Sullivan

Electrolysis for iron ore reduction is gaining R&D interest for the long term

Deploying electricity from electrolysis to reduce iron ore has the potential to lower emissions by 100% but is only in the pilot-scale testing phase.

Widely adopted established and emerging steel production routes include coal-based BF-BOF, natural gas-based-DRI EAF and hybrid configurations (such as liquid iron in EAF and DRI + BF-BOF).

Industrial-scale deployments of biomass-based BF-BOF and biogas-based DRI-EAF are also currently occurring.

Hydrogen-based DRI-EAF, BF-BOF + CCS and Hlsarna-BOF + CCS and BF-BOS with top-gas recycling + CCS remain **under trial**.

Hydrogen-based BF-BOF, like electrolysis, remains at an **early stage** of R&D.

Tata Steel is increasing its scrap-based steel manufacturing

Tata Steel, India, currently has a carbon intensity of 2.34t CO2/t crude steel and is targeting <2t CO2/t crude steel by 2025. The company's Jamshedpur site is considered to be a national benchmark for CO2 emission mitigation and is where it is developing a pilot-scale CCU plant. Tata also plans to increase its scrap-based steel manufacturing by leveraging its wide availability across India and increasing its use of renewable energy across all locations.

Hyundai Steel (Korea) is using recycled gas from its blast furnace

Hyundai Steel, South Korea, currently has a carbon intensity of 22.51 million tons of CO2 and is aiming for an 80% reduction by 2050. The company's *Verified Carbon Standard* (VCS) has the potential to remove 1.98m tons of emissions annually by producing electricity using saprophagous gas that is recycled from its blast furnaces. Additionally, Hyundai has made a range of energy efficiency improvements to many of its existing manufacturing processes.

Moving forwards, Sunfire is an external player which ships solid oxide reversable electrolysis modules to carbon-intensive industries like steel

Sunfire, Germany, which recent received investment from Amazon, has developed the world's largest commercial Reversible Solid Oxide (RSOC) electrolysis solution which can be used for large applications across sectors. Its technology allows annealing, hardening, sintering and gas quenching in the steel industry.

If other approaches to decarbonization fail or are unavailable, *carbon offsetting* offers market participants another way in which to reduce their footprints

As illustrated in detail in this report, the daily operations of participants in the O&G and other energy-intensive markets have a significant negative impact on the environment. Operators in these sectors are adopting a range of approaches to abatement – including material modification, process innovation, emission management and the adoption of CCUS for hydrogen production – but **carbon offsetting** solutions increasing provide an alternative and sometimes complementary method.

Carbon offsetting refers to the process of reducing or removing CO2 or other GHGs from the environment in order to compensate for emissions made elsewhere while a *carbon credit* is the transferable (financial) instrument, certified by governments or other independent bodies, which represents an emission reduction and that can then be bought, sold or traded.

Business and private consumers increasingly seek out operators that focus on sustainability. Carbon offsetting therefore has the potential to play a key role in helping players to mitigate their impact, achieve carbon neutrality and align to customer expectations.

Source: Frost & Sullivan

Increasingly, this is enabled by tech with Cloverly (US) developing a sustainability as a service platform to fast-track CO2 neutrality for businesses

Cloverly, founded in 2018, provides a platform which allows customers to access high-quality renewable energy credits and achieve carbon offsets for their daily operations.

The company purchases verified renewable energy credits and offers carbon offsets to neutralize carbon emissions to its clients. Southern Company, the US electricity and natural gas provider, has for example successfully deployed the solution to accelerate its transition towards meeting its net-zero goal and contributing to a carbon-neutral society.

Cloverly deploys an Application Programming Interface (API) which enables O&G and other operators to calculate the carbon emissions during daily operations. The API also determines the carbon offsets required and purchases the corresponding renewable energy credits from verified sources to ensure quality and reliability.

The company has raised $2.1m funding from TechSquare Ventures, SoftBank, Panoramic Ventures, Circadian Ventures, Knoll Ventures and SaaS Ventures.

Carbon offsetting forms part of a broader approach to emission management in heavy industries which is supported by emerging digital solutions

Digital platforms increasingly underpin;

- **Planning and advisory** solutions including reduction plans, roadmaps, goal setting, performance contracting, climate action plans and financing
- **Measuring and monitoring** solutions including real-time monitoring, diagnostics, sensor deployment, mapping, scenarios, forecasting, satellite imagery and drones
- **Mitigation** solutions including equipment efficiency, new systems, operating changes, material and fuel choices, energy procurement and renewables integration
- **Removal** solutions including carbon capture, usage and storage, air pollution control and air filtration
- **Reporting** solutions including carbon accounting, emission reporting, compliance, tracking, benchmarking, Corporate Social Responsibility (CSR) and Environmental Social Governance (ESG) reports and carbon budgets

Source: Frost & Sullivan

Carbmee (Germany), for example, provides an AI-based end-to-end environmental intelligence system which tracks, measures and helps to tackle pollution

Carbmee's solution combines Artificial Intelligence (AI) and science-based Life Cycle Assessment (LCA) capabilities to automate carbon management for enterprises. Its platform drives industrial value chain decarbonization via;

Enterprise Resource Planning (ERP) data integration

Carbmee allows customers to use APIs or to directly upload their existing operations data into its environmental intelligence system platform. The company streamlines this ERP data across multiple departments and business units to generate emissions calculations for customers' end-to-end operations.

Value chain collaboration

The platform simplifies stakeholder collaborations to enable seamless carbon emissions mapping and ensures uninterrupted access to captured data, inviting suppliers, customers, and other stakeholders to share high-quality and real-time primary data.

Emission hotspot analysis

The company employs automated analytics with advanced data cleansing and integration capabilities to offer thorough overviews of its customers' emissions and identify hotspots with maximum potential for a high return on investment.

With its carbon management platform, Carbmee offers a comprehensive list of unique, purpose-built capabilities to address current industry pain points. While most contemporary carbon management solutions provide generic dashboards tracking scope 1 and 2 emissions, the company's intuitive and user-friendly dashboards help customers to thoroughly understand the complex emissions distribution across their entire value chains. This facilitates scenario planning and emission reduction forecasting. Moreover, the data accuracy of Carbmee's centralized, workflow-based platform enables accelerated decision-making and helps convert customers' decarbonization efforts into solid investments.

Source: Frost & Sullivan

Offsetting is limited not only to production activities but also plays a key role in aviation as part of the ICAO's CORISIA program for CO2 neutral flights

The United Nations and the International Civil Aviation Organization (ICAO) developed its Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) to enable carbon-neutral international flights after 2020. Although the Paris Agreement addresses domestic sector emissions, studies show that international travel contributes to 65% of the aviation industry's pollution which is equivalent to 1.3% of global CO2.

More than 192 countries will implement CORSIA's plan to reduce fuel burn and optimize operational practices in a phased manner. According to the International Council of Clean Transport, the expected net climate impact reduction will be 6% of the total projected CO2 exhaust stemming from international aviation.

Under the CORSIA program, participating operators are required to buy carbon credits to offset their emissions above 2020 levels. This baseline was subsequently revised to 2019 for the 2021-2023 period to take into account the drop in air traffic during the COVID pandemic. In the pilot and first phases, only flights between participating states will be concerned by CORSIA but from 2027 all international flights will be subject to offsetting.

Source: Frost & Sullivan

PRINCIPAL ABBREVIATIONS

AI	*Artificial Intelligence*	**KOH**	*Potassium Hydroxide*
API	*Application Programming Interface*	**kWh**	*Kilowatt-Hour*
ATR	*Autothermal Reforming*	**LCA**	*Life Cycle Assessment*
B	*Billion*	**LDAR**	*Leak Detection and Repair*
BF-BOF	*Blast Furnace-Basic Oxygen Furnace*	**LNG**	*Liquid Natural Gas*
CaCO3	*Limestone*	**M**	*Million*
CaO	*Calcium Oxide*	**Mpa**	*Megapascals*
CCS	*Carbon Capture and Storage*	**Mt**	*Megaton*
CCUS	*Carbon Capture Utilization and Storage*	**MTPA**	*Million Tons per Annum*
CO2	*Carbon Dioxide*	**MW**	*Megawatt*
CSR	*Corporate Social Responsibility*	**MWh**	*Megawatt-Hour*
DRI	*Direct Reduced Iron*	**Ni**	*Nickel*
EAF	*Electric Arc Furnace*	**O&G**	*Oil & Gas*
ERP	*Enterprise Resource Planning*	**OpEx**	*Operating Expenses*
ESG	*Environmental Social Governance*	**POX**	*Partial Oxidation*
EU	*European Union*	**Pt**	*Platinum*
FCV	*Fuel Cell Vehicle*	**R&D**	*Research & Development*
GHG	*Greenhouse Gas*	**RSOC**	*Reversible Solid Oxide*
GW	*Gigawatt*	**SMR**	*Steam Methane Reforming*
H2	*Hydrogen*	**SMRe**	*Small Modular Reactor*
ICT	*Information and Communication Technology*	**SOEC**	*Solid Oxide Electrolyzer Cells*
IR	*Iridium*	**UK**	*United Kingdom*
Kg	*Kilogram*	**US**	*United States*

Source: Frost & Sullivan

ABOUT INTESA SANPAOLO INNOVATION CENTER:

Intesa Sanpaolo Innovation Center is the company of Intesa Sanpaolo Group dedicated to innovation: it explores and learns new business and research models and acts as a stimulus and engine for the new economy in Italy. The company invests in applied research projects and high potential start-ups, to foster the competitiveness of the Group and its customers and accelerate the development of the circular economy in Italy.

Based in the Turin skyscraper designed by Renzo Piano, with its national and international network of hubs and laboratories, the Innovation Center is an enabler of relations with other stakeholders of the innovation ecosystem - such as tech companies, start-ups, incubators, research centres and universities - and a promoter of new forms of entrepreneurship in accessing venture capital. Intesa Sanpaolo Innovation Center focuses mainly on circular economy, development of the most promising start-ups, venture capital investments of the management company Neva SGR and applied research

For further detail on Intesa Sanpaolo Innovation Center products and services, please contact

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