Making our world more productive

Hydrogen: Fuel for Change in Industry and Energy

Hydrogen (H). The simplest of all earthly elements. With virtually limitless supply, and numerous applications, hydrogen is set to play a key role in the transition to clean energy.

Hydrogen can be used as a zero-emissions fuel for trains, buses, trucks, cars and ships and as a feedstock for various industries, including chemicals, refining and steel making. It serves as a source of energy and heat for buildings and can be used as a medium to store energy from renewables and other sources.

"We are transitioning to a renewables-based economy, driven by the need to decarbonize and meet climate change target goals. Clean hydrogen will play a key role in the global effort. We see clean hydrogen as the fuel of the future."

David Burns
Linde's Vice President,
Clean Energy Development

Global Warming and Climate Change

An approximate 2 °F (1 °C) increase in the Earth's average surface temperature since the late 1800s has caught the attention of scientists, business and industry, world leaders, and individuals. In response, nations have been called upon to reduce greenhouse gas emissions (GHGs) to stabilize the Earth's temperature.

Global warming

The Industrial Revolution's Impact on Global Warming

The early 19th Century is a crucial reference point for rising temperatures. The Industrial Revolution was gearing up in Europe, transforming the continent from primarily agrarian pursuits to an industrial economy. New energy sources, mainly coal, fueled progressively larger engines and machines and amplified the production of various materials and finished goods.

As industrialization migrated across the globe, so too did the demand for coal. Recognizing its finite quantities, pioneers discovered new fossil fuels – like oil and natural gas – to create the electricity needed to power a burgeoning industry. These fuel sources quite literally changed the world, but from that progress emanated environmental impacts. The fossil fuel combustion process releases carbon dioxide (CO_2) and other gases into the atmosphere.

Because CO_2 does not dissipate quickly like reactive gases – ozone and nitrous oxides, for example – it works alongside other anthropogenic greenhouse gases (GHGs) to absorb solar energy and reflect it to Earth. In general, the greenhouse effect is beneficial to humankind, as, for centuries, it has supported warmer and more habitable living conditions. However, an amplified concentration of GHGs, mainly CO_2, traps and reflects more heat, and this phenomenon is believed to be at least partially responsible for rising global temperatures.

According to The Center on Global Energy Policy at Columbia University SIPA, the Earth's carbon cycle was effectively balanced until the Industrial Revolution. Since then, fossil fuel combustion and other human activities have released approximately 2 trillion tons of CO_2 into the atmosphere.

The IPCC and Paris Agreement: a call-to-action to stabilize the earth's rising temperature

The Mercator Research Institute on Global Commons and Climate Change's online Carbon Clock indicates the amount of CO_2 released into the atmosphere at any given moment. According to the clock, the Earth emits approximately 1,332 tons of CO_2 per second – or 42 gigatons (GT) each year - and is only 6.5 years away from surpassing a 1.5 °C degree temperature stabilization scenario recommended by experts around the world to limit global warming. This scenario calls for limiting emissions to no more than 420 additional gigatons (Gt) of CO_2 into the atmosphere for the remainder of this century (one gigaton = 1,000 megatons or 2.2 trillion pounds).

The scientific community generally agrees that climate-warming trends observed since the genesis of the Industrial Age have roots in human activities and require a coordinated human response to mitigate.

The United Nations' Intergovernmental Panel on Climate Change (IPCC), which assesses the science related to climate change, has referenced the potentially harmful effects of increasing global temperatures in several reports through the years. These include:

- Global weather patterns that exacerbate drought, heat waves, floods, wildfires, and storms, including hurricanes.
- Rising temperatures that melt ice caps, glaciers, and permafrost layers, which can lead to rising sea levels and coastal erosion.
- Impacts on fresh water and food sources, particularly in less climate-resilient areas and where staple food crops are critical for survival.

To stem these impacts, the IPCC has called for "substantial and sustained reductions in greenhouse gas emissions" to stabilize the global average temperature over time. It has analyzed several GHG emissions reduction scenarios, some of which target zero CO_2 emissions and some negative emissions by 2100. Several also recommend reducing methane (CH_4) and sulfur dioxide (SO_2) emissions.

The 2015 Paris Agreement marked a turning point in the international climate change arena. At the United Nations Framework Convention on Climate Change (UNFCCC)'s 21st annual Council of Parties (COP) in Paris, France, on December 12, 2015, more than 190 nations signed a legally binding international treaty on climate change. The agreement calls for participating countries to do their part to reduce global greenhouse emissions in a collective effort to limit the global temperature increase to 2 °C above preindustrial levels while striving to limit the rise to 1.5 °C above preindustrial levels. In addition, they agreed to cut their pollutants over time, participate in transparent monitoring and reporting, and continually elevate their climate goals.

Spotlight on Net-Zero Decarbonization

A growing number of experts, scientists, and organizations devoted to studying and analyzing global warming and climate change believe reducing or eliminating CO_2 emissions – decarbonization – plays a central role in stabilizing our global temperature.

Before and after the signing of the Paris Agreement, there was a significant movement to identify and develop CO_2 reduction methods and technologies that help reduce the carbon footprints of the industrial and power generation sectors, two of the largest CO_2 emitters. Scenarios include achieving zero emissions by switching to clean energy sources – such as clean hydrogen – that do not release CO_2 or achieving net-zero emissions by removing the equivalent amount of CO_2 emitted through power generation and industrial processes from the atmosphere through removal or sequestration.

Many argue that the zero-emissions scenario is difficult, if not impossible, to achieve in the near term. The National Academies of Sciences, Engineering, and Medicine points out that energy systems and industrial assets last for years or even decades. It is far less expensive to allow these assets to reach the end of their useful lives and then replace them with zero emissions alternatives. Business and industry could work toward achieving net-zero emission-reduction goals through other methods, which include:

Avoiding CO_2 emissions

Industry avoids emissions by incorporating emissions-free infrastructure in operations, such as building a solar- or wind-powered plant instead of a natural gas power plant. This alternative is adopted most often.

Capturing and storing CO_2 emissions

CCUS entails constructing or retrofitting a plant with equipment and infrastructure that captures and separates CO_2 from flue, fuel or process gases and transports it in gaseous or liquid form, or as supercritical fluid for further use or permanent underground storage.

Reducing CO_2 emissions

Reducing CO_2 emissions can be accomplished in various ways, including using lower-carbon materials in manufacturing processes, reclaiming and reusing materials, and introducing efficiencies into operations. These techniques are often employed in tandem with other emission reduction technologies.

Removing CO_2

Carbon dioxide removal – often referred to as CDR or carbon drawdown – is accomplished by capturing CO_2 through mineralization, direct-air capture, or biomass energy technologies and storing it in plants, oceans, minerals, saline aquifers, or depleted oil wells. These technologies are in the early stages of research and development.

The search for solutions

Hydrogen: a Fuel for Change

Industry and energy generation power our global economy – they are responsible for generating electricity and manufacturing materials and products vital to the everyday lives of billions across the globe. The demand for clean hydrogen technologies is rising, given their potential to accelerate the transition to more sustainable forms of energy while still supporting current energy models.

Hydrogen can be used as a feedstock gas for industries such as chemical, refining and steel; a source of heat for heavy industrial production processes and to heat and power buildings; a medium to store energy from renewable energy sources without carbon; and a zero-emissions fuel source for trains, buses, trucks, planes, and ships.

Hydrogen as a feedstock

Industry already uses large quantities of hydrogen as a feedstock, primarily in petroleum refining and methanol and ammonia manufacturing processes.

In the U.S. ammonia and chemicals industry, the lion's share of hydrogen is produced from methane, using the steam methane reforming (SMR) process without carbon capture. In petroleum refineries, 60% of hydrogen is created through the same process, with the remaining 40% produced internally as a by-product of naphtha reforming for gasoline production. Other industries that use hydrogen in smaller quantities include cement, glass, steel, space, and sustainable fuel producers.

Because these hydrogen processes – referred to as gray hydrogen – result in substantial CO_2 emissions, industries could transition to low-carbon (blue hydrogen) or zero-carbon (green hydrogen) technologies to reduce or negate emissions.

Low-carbon transition options include retrofitting an SMR plant with carbon capture and storage (CCS) technology and equipment, or applying water electrolysis (using low-carbon electricity) to produce low-carbon hydrogen. Zero-carbon – or green hydrogen (H_2) – is created by using bio-based feedstock in the SMR process or splitting water by electrolysis using energy generated exclusively from renewable sources, such as solar or wind.

Gray Hydrogen = substantial CO_2 emissions

Blue Hydrogen = low carbon

Green Hydrogen = zero-carbon technologies to reduce or negate emissions

Hydrogen as an industrial heat source

Thermal energy generated at extremely high temperatures is a critical component of many heavy industrial production processes. CO_2 and other gases are generated when fossil fuels are used in the combustion process, and if not captured, added to the atmosphere. An estimated 10% of total global CO_2 emissions result from industrial fossil fuel combustion, nearing that of total global emissions from transportation sources (14–15%).

"Hydrogen-based industrial heat provides an actionable pathway to start industrial decarbonization at once, particularly in the petrochemical, refining, and glass sectors, while over time reducing cost and contribution of fossil sources," states the report.

Hydrogen readily generates high temperatures required for industrial processes. A transitionary option for industry involves replacing fossil fuels with hydrogen produced from decarbonized natural gas in the combustion process. The ultimate zero-carbon pathway uses hydrogen produced by water electrolysis technologies.

Hydrogen is also an alternative heat source for commercial and residential buildings. It can be blended in small quantities with natural gas and used without making significant infrastructure or end-use appliances and equipment changes. A pure hydrogen network uses existing networks and equipment but requires adaptations, such as pipeline replacements and hydrogen appliances.

“Hydrogen could be a form of dispatchable power (in the case of generation) or load (in the case of hydrogen production with electrolysis) to meet or manage peak demand (“peaker” plants or “interruptible load”), on a path to 100 percent zero-carbon power, especially in isolated areas or in states with few flexible power supply options. In a 100 percent zero-carbon scenario, with large shares of wind and solar power, grid operators need a dispatchable, low-carbon energy source to provide electricity during extended periods of low renewables supply.”

McKinsey & Co.
“Decarbonization of Industrial sectors: The Next Frontier Report”

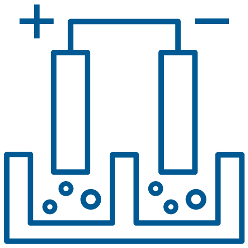
Hydrogen’s role in power generation and grid balancing

The steady adoption of renewable energy sources by the power generation sector is helping to reduce GHG emissions. Still, a degree of uncertainty accompanies wind and solar power when the elements aren’t cooperating. Other generators – typically powered by coal or natural gas – take over to balance the interconnected power grid when these energy sources are scarce.

Hydrogen can inject a clean energy source into the power generation process via the following methods:

Electrolyzer powered by renewable energy (solar, wind, hydro) to create electric currents that split water (H_2O) into its components – hydrogen and oxygen – with zero GHG emissions.

Hydrogen can serve as a source of intermittent power generation alongside renewable energy sources when those resources need to be curtailed for market or supply reasons.

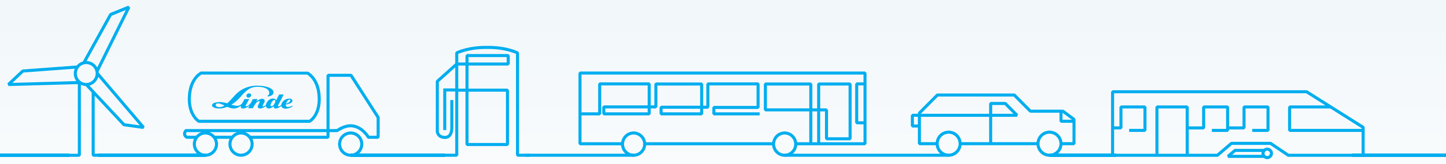


Using a hydrogen/natural gas blend to drive hydrogen-fueled gas turbines – or retrofitted natural gas turbines – to produce electricity or for electrochemical conversion back into electricity using fuel cell technology.

Hydrogen as a Fuel

The transportation sector accounts for a significant percentage of carbon emissions, so it makes sense to consider alternatives to high carbon-producing fossil fuels. Hydrogen can be used to power any vehicle that is equipped with fuel cells (FCEVs) – thus, its value as a clean fuel is far-reaching.

When hydrogen is converted to electricity in a fuel cell, the only output is water vapor and heat, unlike internal combustion engines fueled by gas, which release CO_2. In addition, hydrogen-fueled vehicles are more energy-efficient than battery-powered vehicles because hydrogen fuel cells don't need to be recharged and won't run down if they have a supply of hydrogen fuel, according to the Columbia Climate School. Adopting FCEVs will play a transformative role in transitioning to a zero-emissions transportation society, especially for medium- and heavy-duty vehicles; however, this will require substantial investment in public and private hydrogen fueling infrastructure.



Path to Net-Zero

The Path to Clean Hydrogen: Transitioning From Gray to Blue and Green

Business and industry are searching for viable alternatives to fossil fuels to reduce carbon emissions. Hydrogen has emerged as a leading contender to fuel the transition for a multitude of reasons, including:

- Its use will eliminate CO_2 emissions at the point of use.
- It can be produced from renewable power sources (solar and wind, for example), natural gas, nuclear power and biomass.
- It can be used at the production source or transported to other locations in liquid or gas form.
- It is an energy carrier that can store, move and deliver energy produced from other sources.

Hydrogen atoms bond with other elements to form compounds – such as water (H_2O), ammonia (NH_3) and methane (CH_4) – so it must be detached from these elements through a variety of methods to produce the clean hydrogen needed to serve as an energy source or carrier.

According to the Global CCS Institute, approximately 98% of global hydrogen production is from fossil fuels from the reformation of methane or the gasification of coal or similar fossil fuels. The vast majority is "gray hydrogen" production, which emits 830 million metric tons of CO_2 each year. Only 1.4% of hydrogen produced from fossil fuels is accomplished with carbon capture and storage (CCS) (blue hydrogen). Approximately 1.9% of hydrogen is produced as a by-product of chlorine and caustic soda production or renewable energy via electrolysis (green hydrogen).

Hydrogen can play a crucial role in meeting climate change targets. Still, worldwide investment in infrastructure and technologies that promote the transition from gray to blue or green hydrogen is needed to help the power generation, transportation, and industrial manufacturing sectors implement net-zero and zero-carbon emissions strategies.

Transitioning from gray to blue hydrogen

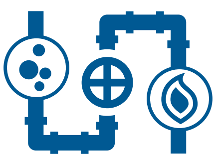
Blue hydrogen can – and will – play a key role in industry's transition to low-carbon technologies. Global Data reports that interest is growing in projects that combine conventional technologies with CCUS because production costs are (currently) lower than processes that produce zero emissions, such as electrolysis. Six large-scale blue hydrogen projects were in operation at the end of 2019, and more than 20 new projects are expected to launch in the 2020s, according to the International Energy Agency.

Gray hydrogen transitions to "blue hydrogen" when, during the production process, CO_2 emissions are captured and used or permanently stored using CCUS technologies. CCUS capture and compress carbon (CC) from stationary sources that burn and convert fossil fuels to energy. The captured carbon can be used (U) to create products, such as chemicals, fuels, and building materials, or transported to a permanent storage location (S) underground in geological formations.

Step 1

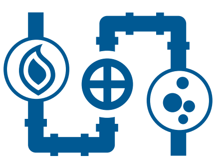
Carbon capture

The first step entails capturing carbon at the source.
Carbon capture technologies fall into three categories:



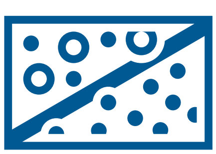
Pre-Combustion

Separate CO_2 before the combustion process. The pre-combustion process combines fossil fuels with air or oxygen to create a gaseous fuel comprised of hydrogen (H_2), carbon monoxide (CO), and CO_2. The CO_2 molecules are captured and removed before combustion, while the hydrogen can be used for industrial processes, electricity generation or to feed fuel cells.



Post-Combustion

Separate CO_2 from the exhaust after the combustion process. This is the most widely used CCUS technology for retrofitting industrial and power generating facilities. During the post-combustion process, flue gas resulting from burning fossil fuels passes through an absorber column with circulating liquid solvent, which absorbs the CO_2 molecules. A heating medium like steam enables the adjacent regeneration column to release the CO_2 from the solvent, and the CO_2 is captured and piped away before it reaches the atmosphere.



Oxy-Fuel Combustion

Burns fuel in an almost purely oxygenated environment. Nitrogen is separated from oxygen and then combusted with a fossil fuel to produce CO_2 and water vapor. This combustion, for example, drives turbines and generates electricity, then the water vapor is cooled, condensed, and removed while the CO_2 is captured, purified and piped away.

Step 2

Transportation

After the carbon is captured and piped away so that it does not enter the atmosphere, it can be transported by pipeline, ship, train or other vehicles for utilization in other processes or to a permanent storage location.

Step 3

Utilization or storage

Once captured, CO_2 can be purified, liquefied, and used in various applications from horticulture and welding to cryogenic cleaning and carbonated drinks. When not used for feedstock or commercial applications, it must be stored permanently in geological formations to mitigate the climate impact of industrial processes.

As the use of CCUS in industry scales up, the cost of blue hydrogen is likely to come down, which will, in turn, speed up the adoption of this abundant clean energy source.

Blue Hydrogen

Transitioning to green hydrogen

Green hydrogen is produced from renewable power or renewable feedstock using water electrolysis and biomass gasification technologies. These processes produce no net GHG emissions.

"Most experts agree that green hydrogen will be essential to meeting the goals of the Paris Agreement, since there are certain portions of the economy whose emissions are difficult to eliminate," according to the Columbia Climate School.

Global Data reports that the fastest-growing markets for green hydrogen are those that target energy and climate goals, including:

- → Vehicle fueling
- → Feedstock for industrial processes
- → Energy storage
- → Hydrogen injection into the gas grid

Global interest is growing in green hydrogen, with several pilot projects underway. For example, in early 2021, Linde announced plans to build, own and operate the world's largest PEM (Proton Exchange Membrane) electrolyzer plant at the Leuna Chemical Complex in Germany. The 24-megawatt electrolyzer will produce green hydrogen to supply Linde's industrial customers through the company's existing pipeline network. In addition, Linde will distribute liquefied green hydrogen to refueling stations and other industrial customers in the region. The total green hydrogen produced can fuel approximately six hundred fuel cell buses, driving 40 million kilometers and saving up to 40,000 tons of carbon dioxide tailpipe emissions per year.

Green Hydrogen

The search for solutions

Getting Started With Clean Hydrogen: Reducing Your Business' Carbon Footprint

The demand for the industrial and power generation sectors to reduce GHG emissions is growing, so companies are looking for flexible and cost-efficient solutions to reduce their carbon footprint. This complex process requires extensive research, detailed cost-benefit analyses, and careful consideration of available options.

Start by evaluating your process and infrastructure to determine the options that make the most sense for implementation from financial, operations, logistics and environmental standpoints.

- What are your emission reduction goals and respective timeline?
- What are the steps in your process that you can decarbonize?
- What is the source of emissions?
- Is there room for efficiency improvements that will lead to emissions reductions?
- How much capacity will you need and what is the consumption pattern?
- What is the economic life left in your process, if applicable?
- How much space do you have space to accommodate the new system?
- What are the competing economic factors (funding, incentives, penalties, etc.)?

"It's important to talk with an expert about the scope of what your company wants to achieve and to examine economic considerations, logistics, regulations and policies. Then work toward determining the best way of launching your project."

David Burns,
Linde's Vice President,
Clean Energy Development

For example, if already producing gray hydrogen, it might be financially feasible to include an electrolyzer system that produces green hydrogen in future project plans instead of retrofitting an entire plant already in operation. Or you might find that retrofitting a steam methane reforming (SMR) system with CCUS technology to produce blue hydrogen is an interim step that helps your business work toward meeting big picture goals.

When evaluating technologies, logistics considerations include your plant's proximity to viable geological storage facilities and transportation options. Are you located near an existing hydrogen pipeline network, or will you have to help front the infrastructure cost? Can you transport hydrogen by other means? If you are considering employing CCUS to produce blue hydrogen, is there already a carbon capture hub nearby?

The decision-making process warrants time, attention, and expertise. Consider working with experienced companies who are used to navigating through the complexities of the value chain and that can help you manage the permitting and funding landscape, and leverage industry partnerships.

The case for clean hydrogen

According to the Hydrogen Council, hydrogen is one of the key enablers in the transition to a more sustainable energy economy because of its versatility. The hydrogen market is predicted to grow tenfold by 2050, according to the global, CEO-led Hydrogen Council's Hydrogen Insights 2021: A Perspective on Hydrogen Investment, Deployment and Cost Competitiveness report.

A February 2021 report released by the global CEO-led Hydrogen Council developed in collaboration with McKinsey & Company reports that, as of 2021, more than 30 countries have created hydrogen roadmaps, and 228 large-scale hydrogen projects have been announced worldwide. If all projects come to fruition, total investments will reach more than $300 billion in spending through 2030. In addition, governments worldwide have committed more than $70 billion in public funding toward advancing clean hydrogen initiatives.

"We are seeing a new level of maturity for the hydrogen industry, and this is only set to accelerate. Hydrogen Council members collectively are planning a sixfold increase in total hydrogen investments through 2025 and a 16-fold increase through 2030. The plan is to direct most of this investment toward capital expenditures, while collaborations, consolidations and innovation will also be a key focus," said Daryl Wilson, Executive Director of the Hydrogen Council.

Consider the multifaceted benefits your company could realize by incorporating clean hydrogen into your business processes.

30
Plus

More than 30 countries have created hydrogen road maps projects

228
Projects

228 Large-scale hydrogen projects have been announced worldwide

300
Billion

Total investments of all projects will reach more than $300 billion in spending through 2030

Clean Hydrogen Helps Reduce Your Environmental Footprint

A new generation of investors, consumers, and employees expect companies to incorporate social and environmental goals and values into their mission, vision, and operations. Clean hydrogen applications offer a viable way for companies in the industrial and energy sectors to demonstrate significant financial and operational commitment to offsetting greenhouse gas emissions produced through their processes. Companies that adopt clean technologies are at the forefront of this emerging trend and will be considered leaders in their industries.

Clean hydrogen is attracting investors' attention

Environmental, Social, and Governance (ESG) investing is ramping up, coinciding with the growing interest in projects that use and promote clean energy. This brings possibilities for ESG investors to provide funding and public support for projects that help businesses transition to net-zero emissions.

The recent focus on decarbonization and accelerated growth of low-carbon technologies has sparked a new wave of interest in the scale-up of the hydrogen supply chain.

> "Policy support and economic considerations, with the acceleration of low-cost renewables and electrification infrastructure, seem to be converging to create unprecedented momentum in the use of hydrogen and paving the way for potentially more rapid deployment and investment in hydrogen technologies and the required infrastructure."

Goldman Sachs;
Carbonomics: The Rise of Clean Hydrogen
by various authors; July 8, 2020.

Clean hydrogen is benefitting from government investment and incentives

The Paris Agreement served as a catalyst for local, state, provincial, and federal governments across the world to consider policy-based incentives that demonstrate commitment to making carbon reduction goals a reality. As a pathway to lowering barriers to entry and enhancing the commercial viability of clean energy-driven projects, governments have – and will – develop financial incentives, such as tax credits and appropriate funding to encourage companies to invest in low-carbon technology, retrofits and new facility projects.

Several countries are creating the necessary frameworks to accelerate the hydrogen economy by creating programs, policies, and incentives that encourage widespread investment in clean hydrogen projects. These include:

- The U.S. Department of Energy's **(DOE) H_2@Scale** initiative seeks to advance affordable hydrogen production, transport, storage, and utilization to increase revenue opportunities in multiple energy sectors; and to fund projects and national laboratory- industry co-funded activities that accelerate the early-stage research, development, and demonstration of applicable hydrogen technologies An example of a Cooperative Research and Development Agreement (CRADA) project funded through this initiative is the Southern California Gas-NREL's fully integrated electrolyzer and bioreactor prototype. In addition, the U.S.'s 45Q tax credit enacted by the Energy Improvement and Extension Act of 2008 provides a credit of up to $50 per metric ton of carbon captured and placed in geological storage and up to $35 per metric ton of carbon injected into oil or natural gas wells for EOR.

- The European Union's **Hydrogen Strategy** was introduced in 2020 to explore how producing and using renewable hydrogen can help cost-effectively decarbonize the E.U. economy in concert with the European Green Deal, which is driving the E.U. to no net GHG emissions by 2050. Hydrogen strategy initiatives will support installing at least six GW of renewable hydrogen electrolyzers in the E.U. and producing up to 1 million tons of renewable hydrogen by 2024.

- Australia's **National Hydrogen Strategy** details how the nation will explore its clean hydrogen potential, identify future scenarios with growth possibilities, and pursue nationally coordinated actions involving governments, industry, and communities. A key focus will be to create hydrogen hubs – at ports, in cities, or in regional or remote areas – that will make the development of infrastructure more cost-effective, promote efficiencies from economies of scale, foster innovation, and promote synergies from sector coupling.

- Japan's **Basic Hydrogen Strategy** strives to achieve cost parity with competing fuels through government investment in research and development, facilitation, and expansion of the hydrogen infrastructure for import and transport within Japan, and increased use of hydrogen in various areas such as mobility, cogeneration of power and heat, and power generation.

McKinsey & Co. recommends the following actions to stimulate the global hydrogen economy:

- **Create public incentives** – such as tax credits or tax deductions – to introduce low-carbon and renewable hydrogen to the public and encourage customer adoption.
- **Support** hydrogen infrastructure development.
- **Expand the use of hydrogen across sectors** – including aviation, shipping, power, data centers, steel and gas distribution – and achieve economies of scale.
- **Include hydrogen-based options in government procurement.**
- **Support research, development, demonstration and deployment, as well as workforce development.**

"We now have the opportunity to kick-start the next important phase of global CO_2 emissions reduction through the support of the developing CCUS and Clean Hydrogen Economy. Many of these clean technologies have been proven at industrial scale, and implementation has started. Still, commercial projects will continue to need financial incentives for broad deployment that will enable accelerated technology maturation and reductions in project risk and cost."

Lars-Erik Gärtner
Associate Director Sales & Business Development, Linde

Partner with a leader

Think Hydrogen. Think Linde.

Tackling climate change is a shared and global responsibility. Linde has the technologies, resources and capability to contribute across all aspects of managing climate change and reducing GHG emissions. With our technologies, we want to contribute to eliminating CO_2 emissions and supporting the transition toward a more sustainable economy.

Linde produces gray, blue and green hydrogen from a range of feedstocks and natural resources. Once produced, our processes include the removal of impurities, the separation of carbon dioxide (CO_2), compression and/or cryogenic liquefaction. We have the technologies and equipment to efficiently transport both gaseous and liquid hydrogen to its destination or to store it until needed.

"For decades, Linde has been innovating technologies for carbon management, and we will need even more solutions as we transition towards a more sustainable future. By 2028, our company will invest more than one billion dollars in decarbonization initiatives. Furthermore, we will dedicate at least 30 percent of our R&D budget to sustainability innovations."

Juergen Nowicki
Executive Vice President Linde plc
and CEO Linde Engineering

Count on our expertise

Building on decades of research and countless real-world projects, Linde's hydrogen capabilities demonstrate our innovative power and proven expertise in delivering workable, economically viable hydrogen solutions suited to mass deployment.

Services include

- Consulting
- Project development
- Economical and technical feasibility studies
- Support and documentation for authority engineering organizations
- Engineering and design
- Procurement
- Construction
- Commissioning and start-up
- Training of operational and maintenance personnel
- Project management
- Licensing arrangements
- Financing
- After-sales support
- Global sourcing
- Plant operations
- Gas Supply Solutions (On-Site, Bulk)

For more information, please visit Linde Engineering at linde-engineering.com

Get started with Linde

With our technologies and extensive experience and expertise, we will help you achieve your project goals in a fair, transparent, environmentally sustainable, and cost-conscious manner. Let's start with a discussion about your project. Contact us to set up a consultation.

About Linde

Linde is a leading global industrial gases and engineering company. We live our mission of making our world more productive every day by providing high-quality solutions, technologies and services which are making our customers more successful and helping to sustain and protect our planet.

The company serves a variety of end markets including chemicals and refining, food and beverage, electronics, healthcare, manufacturing and primary metals. Linde's industrial gases are used in countless applications, from life-saving oxygen for hospitals to high-purity and specialty gases for electronics manufacturing, hydrogen for clean fuels and much more. Linde also delivers state-of-the-art gas processing solutions to support customer expansion, efficiency improvements and emissions reductions.

Having received several accolades for its work in sustainability, Linde is in the business of resource transformation in a world that is dealing with climate change. We believe that issues over long-term energy availability and climate change will only continue to intensify. At Linde, sustainable development is rooted in our mission, values and policies and extends into all areas of our business.

Linde helps customers worldwide improve their environmental performance and reduce their carbon footprint. At the same time, we are committed to minimizing our own environmental resource intensity, including for energy, water and waste.

To learn more about sustainability at Linde, please visit linde.com/sustainable-development

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