GLOBAL
Insight

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Monthly focus

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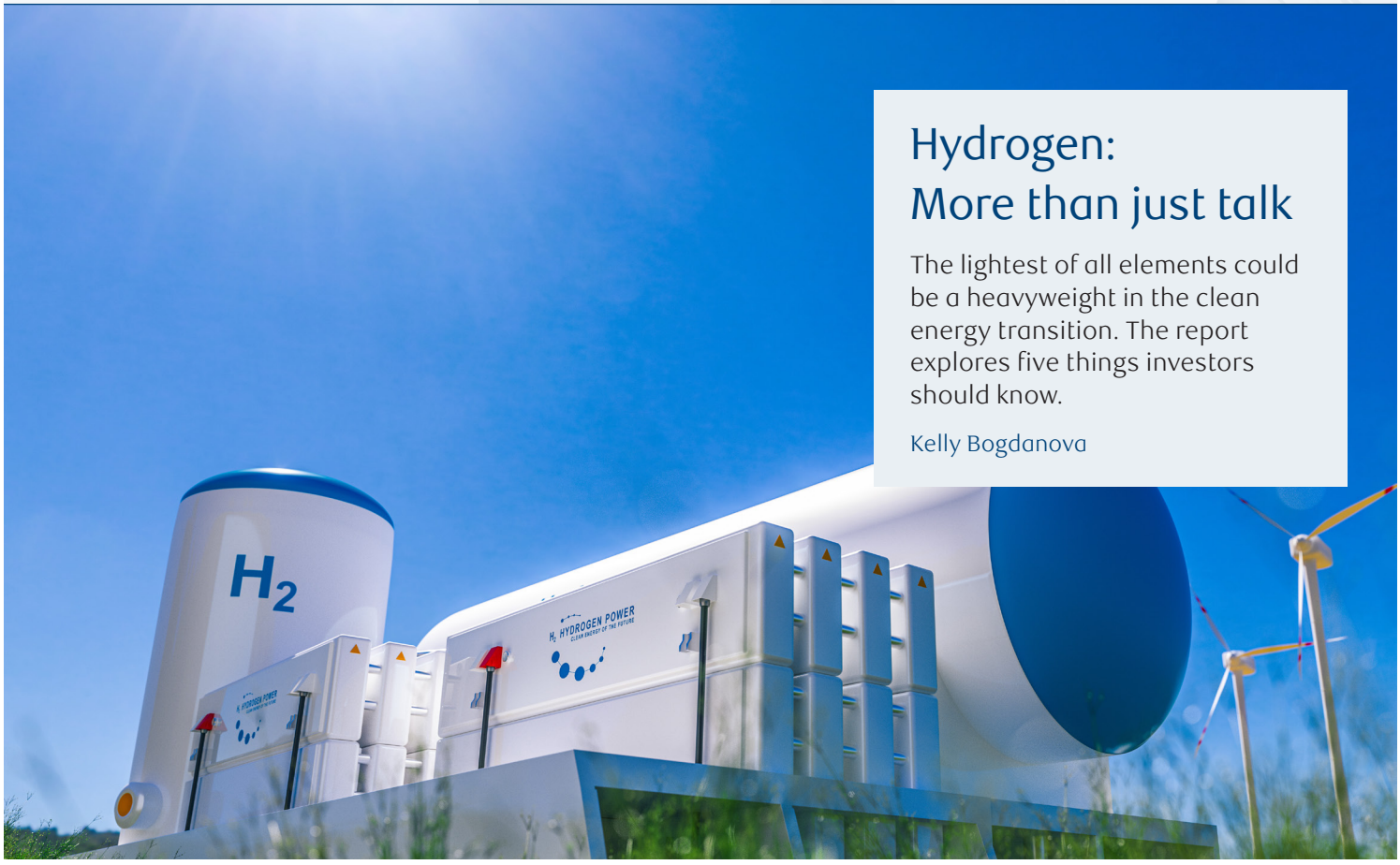

Hydrogen: More than just talk

The lightest of all elements could be a heavyweight in the clean energy transition. The report explores five things investors should know.

Kelly Bogdanova

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Focus

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Hydrogen: More than just talk

Hydrogen is the lightest of all elements, but it has the potential to be a heavyweight in the transition to clean energy. Startups and seasoned corporations in a variety of sectors are already committing to innovative hydrogen applications, and governments are setting ambitious goals. It won't be a one-size-fits-all transition. There will be—and should be—regional differences in the uses and export of hydrogen, especially in the early years. The report takes a closer look at hydrogen's global potential, including untapped opportunities for its use in a variety of industries.

Five things investors should know about hydrogen's potential in the clean energy transition:

#1 – Hydrogen has promise

This versatile, clean-burning element has a role to play in carbon reduction and the transition toward lower- and zero-carbon energy production. Hydrogen can help reduce emissions from fossil fuels and heavily polluting industries. Importantly it also has the potential to improve the reliability of renewable energy.

In the coming years, we think hydrogen will:

- **Flow through natural gas pipelines**. Some existing pipelines can safely carry a mixture of 5–15 percent hydrogen with natural gas without damaging the infrastructure, according to RBC Capital Markets;
- **Reduce emissions in heavy industries** such as chemicals, steel, iron, and cement production, as well as crude oil refining;
- **Become a key component of local industrial power supply chains** that incorporate wind, solar, and other green energy solutions; and
- **Help to power transportation systems** such as truck fleets, trains, industrial equipment (e.g., forklifts), ferries, tug boats, ships, and airplanes.

Hydrogen demand is currently modest, but appears set to rise as industries look to reduce their carbon footprint. Hydrogen's uses are already expanding into the applications cited above and perhaps will move into even more ambitious applications as the costs of low- and zero-carbon hydrogen production decline.

RBC Capital Markets estimates global demand for pure hydrogen is about 70 million metric tons, with about 95 percent consumed by the oil refining and chemicals industries.

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An additional 45 million metric tons of hydrogen demand comes from mixtures of hydrogen with other gases, mainly used for heat and electricity.

We believe demand for pure hydrogen is expected to increase meaningfully in coming decades, but the forecasts and scenarios vary widely, from a 267 percent increase to a 10-fold increase by 2050. There is even a "theoretical max" demand estimate that is much higher, as the chart below illustrates.

The degree to which hydrogen demand will grow depends on how weak or strong governments' clean energy and hydrogen policies are, and how coordinated. Importantly, demand will also depend on how much cost improvement occurs through hydrogen innovation relative to competing energy sources.

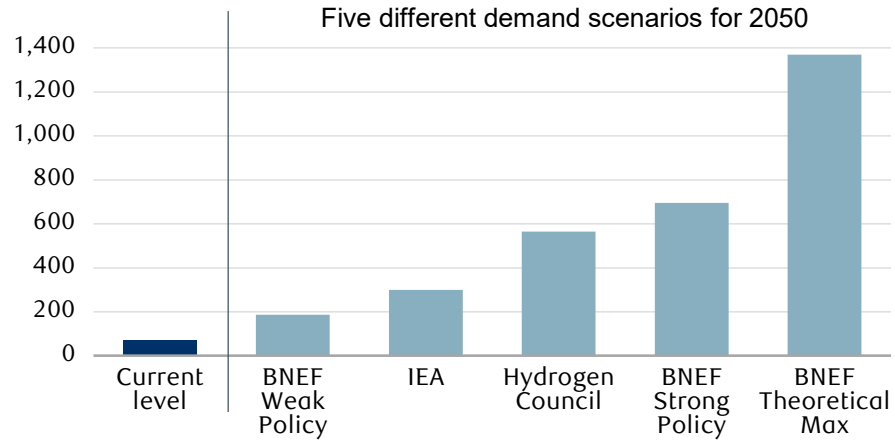
Existing national and multi-national carbon reduction agreements are key factors that could incentivize hydrogen demand growth. But we doubt the Paris Climate Agreement will be the last word on climate and sustainability goals.

In 2020, the EU developed more aggressive goals to decarbonize its economy and, importantly, incorporated hydrogen in its plans. Within the EU, the German government has among the most ambitious hydrogen goals, which is notable because that country is home to the largest industrial firms in the EU.

We think carbon reduction targets in other major economies are likely to be ratcheted up and will serve to expand the uses and demand for hydrogen.

Demand forecasts vary widely

Potential global demand for hydrogen in 2050 in different scenarios (in millions of metric tons per year)



Note: BNEF "Weak Policy" and "Strong Policy" scenarios depend on how strong and coordinated government decarbonization and hydrogen policies are. The BNEF "Theoretical Max" estimate depends on strong policy plus the adoption of hydrogen by unlikely-to-electrify sectors of the economy. The IEA forecast represents its Sustainable Development Scenario, which it estimates based on goals in the Paris Climate Agreement. The Hydrogen Council is an industry group of more than 100 companies that seeks to accelerate the deployment of hydrogen in order to foster the clean energy transition.

Source - RBC Wealth Management, RBC Capital Markets, BloombergNEF (BNEF), International Energy Agency (IEA), Hydrogen Council

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#2 – There are hurdles

With every promising or revolutionary aspect of hydrogen's future role in cleaner energy output, hurdles exist. We think many of them can be overcome, but others seem more daunting. The degree to which such challenges are met will determine just how ubiquitous hydrogen becomes.

The International Energy Agency (IEA) estimates that about 75 percent of hydrogen currently comes from natural gas and 23 percent from coal, the latter with a high carbon footprint. In the future, other means of hydrogen production using electricity derived from wind, solar, hydro, and nuclear energy, will come to represent a greater share of the total.

As hydrogen production becomes less carbon-intensive, its uses expand, and more production processes become viable, the following challenges will inevitably arise:

Storage: Hydrogen is more difficult to store than fossil fuels because it is less dense (only 15 percent as dense as gasoline), more diffusible (i.e., can spread), and can penetrate and leak through some types of steel and iron and cause them to become brittle.

Back to school: What is H_2?

Hydrogen ...

Is the most abundant element in the universe

Is clean-burning, colorless, and odorless

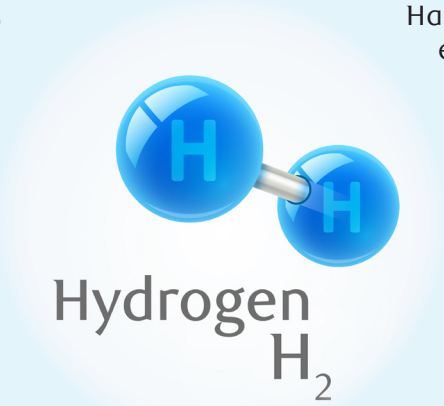
Has a flame that is invisible to the naked eye

On earth, exists only bonded with other elements (i.e., water H_2O)

Is the lightest element, so it has low density or mass by volume (only 15% as dense as gasoline)

But it has high energy density (almost 3 times more than diesel or gasoline)–meaning a greater amount of energy stored in its mass

Is an energy carrier, not an energy source



Can store energy, which allows it to function as a battery to complement renewable energy and smooth out intermittent supply and demand mismatches of solar and wind power

Has diffusibility (i.e., it can spread more easily than natural gas)

Can penetrate through porous metals, including some types of steel and iron pipes

Can be stored and transported within certain limitations

Has a combustion potential (auto-ignition temperature) similar to natural gas and much higher than gasoline vapor

Generates no carbon emissions on its own. The amount of carbon emissions involved in hydrogen production depends on the source used to extract it (hydrogen from coal has high emissions; hydrogen from wind power has very low to zero emissions)

Source - RBC Wealth Management, RBC Capital Markets, U.S. Department of Energy

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There are four primary methods of storing hydrogen: underground salt caverns, depleted oil and natural gas fields, rock caverns (aquifers), and pressurized containers. Salt caverns are the best-suited of the geological options, according to RBC Capital Markets. But salt caverns are limited geographically. Containers are better-suited for small-scale storage. Companies and the scientific community are working to develop storage tanks for liquefied and solid-state hydrogen using innovative metals.

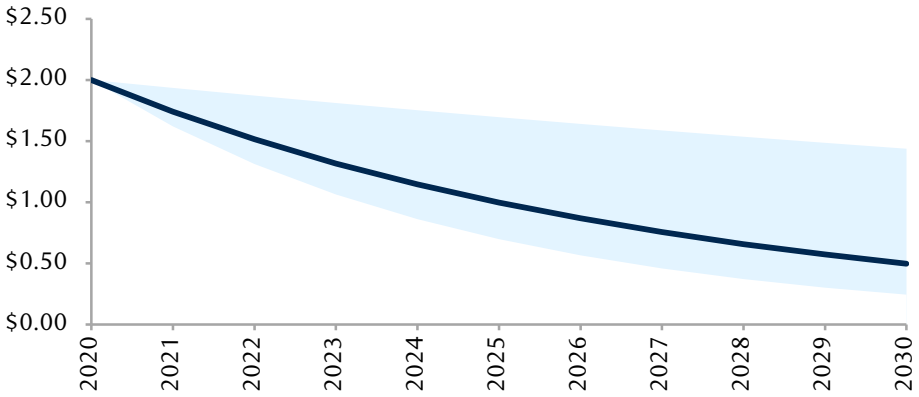
Transport: Without modifications, many natural gas pipelines can carry a 5–15 percent blend of hydrogen, RBC Capital Markets estimates, depending on the pipeline's type of steel. Over time, existing pipelines could be converted to pure hydrogen pipelines, and new hydrogen pipelines could be built, albeit both at a significant cost. Hydrogen's low density makes it costly to transport by road, rail, or ship. But innovation and carbon reduction incentives should make this more feasible over time.

Cost: Large-scale local supply chains will likely be the most cost-effective means to deliver hydrogen to industrial users, according to BloombergNEF (BNEF). Its analysts estimate the cost of "green hydrogen" (i.e., hydrogen produced with renewable power sources having almost zero carbon emissions) could decline by 85 percent to under $1 per kilogram in many parts of the world by 2050, an accelerated pace compared to its own estimate just one year ago. This is among the most aggressive forecasts.

Regardless of the pace of green energy efficiencies, we think electrolyser equipment will play a key role in the cost equation. That equipment uses electricity from wind, solar, hydro, or nuclear power to separate hydrogen from oxygen in water, enabling the hydrogen to generate power via fuel cells, internal combustion engines, turbines, and other processes. RBC Capital Markets expects the capital cost of hydrogen electrolysers to fall dramatically through 2030, as the chart below illustrates. The drawback is that the electrolysis process is highly water-intensive. Not all countries or locales have the necessary water supplies; those that do are best equipped to incorporate electrolysis processes.

Potential capital cost declines of electrolysers (per kilogram of H_2)

Electrolysers are the equipment used to produce hydrogen from wind, solar, hydro, and nuclear power. The lower the cost of this equipment, the more likely hydrogen will be in demand.



Bear scenario: The upper part of the light blue shaded area, where the costs are highest

Base scenario: The dark blue line

Bull scenario: The lower part of the light blue shaded area, where the costs are lowest

The "Bear scenario" assumes 22.5 gigawatt total capacity installed, 13% learning rate. The "Base scenario" assumes 90 gigawatt total capacity installed, 13% learning rate. The "Bull scenario" assumes 90 gigawatt capacity installed, 19% learning rate. Data assumes a 50% load factor.

Source - RBC Capital Markets estimates, Hydrogen Council

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#3 – It's not one size fits all

There will be—and should be—regional differences in the uses and export of hydrogen, especially over the next 5–10 years. While many governments' long-term goals will be to derive the bulk of hydrogen production from clean energy sources—aka green hydrogen—the main "colors" or types of hydrogen that dominate in one country or region likely won't be the best fit for others in the early years of this transition.

Leaders in natural gas supplies, such as the U.S., Russia, Qatar, and Canada, may initially tilt toward producing a greater share of blue and turquoise hydrogen—both of which can be derived from natural gas—than countries without such abundant resources.

This is not green hydrogen *per se*, but it can reduce carbon emissions nonetheless. According to RBC Capital Markets, blue hydrogen is four times less carbon-intensive than gray hydrogen, which is predominantly produced today. Turquoise hydrogen is even less carbon-intensive. RBC Capital Markets energy analysts wrote, "We believe natural gas may become a bridge fuel that helps green hydrogen become a reality."

The hydrogen rainbow

The major types of hydrogen classified by colors

Types of H_2	Production source (feedstock) and select production processes
Brown	From coal; traditionally has not involved carbon capture and storage (CCS) but can through coal gasification
Gray	From natural gas through thermochemical conversion
Blue	From natural gas via steam reforming; uses carbon capture and storage (CCS) to minimize CO_2 emissions
Turquoise	From natural gas via methane pyrolysis; H_2 and solid carbon are the outputs, both of which have uses
Yellow	From nuclear power via electrolysis and other methods
Green	From renewable electricity (solar, wind, and hydro) via electrolysis of water; breaks down water into hydrogen and oxygen

Source - RBC Wealth Management, RBC Capital Markets, U.S. Department of Energy, EWE AG, World Nuclear Association

Countries that already have a relatively higher proportion of renewable power supplies, such as the UK, Sweden, Denmark, and Spain, may be able to capitalize on green hydrogen production more quickly than countries still in the early stages of such a buildout.

China could, indirectly or directly, eventually become a leader in green hydrogen production. In addition to building out significant renewable power resources, China is already a leader in electrolysis equipment manufacturing which is essential for green hydrogen production. While Europe currently leads on electrolyser innovation, China produces the cheapest electrolysers in the world.

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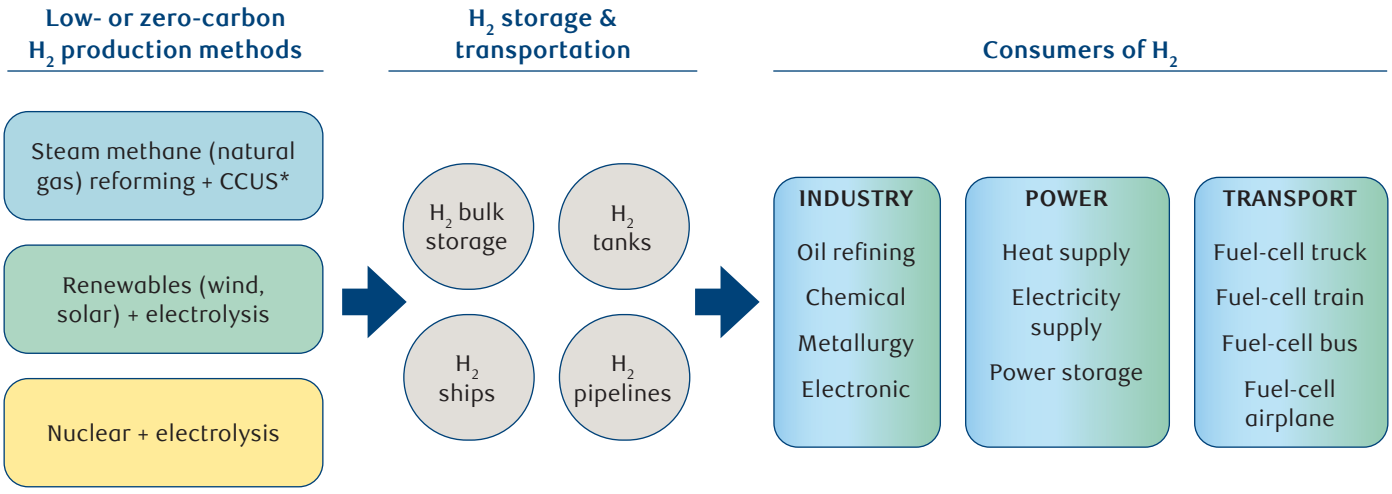
Even within countries, there will be geographic differences. For example, the Canadian provinces of British Columbia (BC) and Alberta have relatively robust wind and solar resources alongside abundant natural gas supplies and infrastructure. This makes BC and Alberta uniquely positioned to provide green hydrogen to local industries and export it to other parts of Canada and the U.S., and to develop blue and turquoise natural gas-based hydrogen for regional use and export.

There is a debate among experts about just how fast the various types of hydrogen will evolve and which will lead. Estimates are in flux, with some seeing a predominant role for blue and turquoise hydrogen for many years, but others such as BNEF seeing green hydrogen moving to the fore more quickly. An important determinant will be how rapidly the two major platforms for future hydrogen development are adopted. In some respects, there are competing interests between the two.

- **Large-scale transportation networks:** Hydrogen would be shipped by pipeline from production centers to industrial consumers, including over great distances. This model would be akin to today's oil and natural gas distribution channels.
- **Localized distribution networks:** Hydrogen production and consumption would occur within regions and countries—the closer to end-user demand the better.

The large-scale hydrogen transportation platform is a long-range and much more expensive approach in terms of infrastructure buildout, whereas the localized hydrogen networks could have near-term cost advantages and potential, but lack scale. We see advantages for the latter.

Hydrogen supply chain from production to consumers



*CCUS stands for "Carbon capture, utilization, and storage"
Source - RBC Wealth Management, Rosatom Global

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#4 – Government policies and innovation will play outsized roles

BNEF estimates that building on existing piecemeal regulatory approaches with support from governments will enable hydrogen to meet seven percent of global energy needs by 2050 compared to the low-single digits today—not an insignificant proportion.

For hydrogen to take off over the longer term and become a much greater component of total energy supply, significantly more will have to be done. Strong and coordinated government regulations and incentives, and significant government and private sector funding would be necessary to build scale and advance technologies. Corporations will need to be proactive and seize the opportunity. The price tag is high, and we are already starting to see mismatches between decarbonization goals and incremental realized outcomes.

BNEF analysts estimate expenditures of $11 trillion in hydrogen production, storage, and transport infrastructure would be necessary to push hydrogen's role up to 24 percent of global energy needs by 2050. This scenario would also require a significant, separate investment in renewable wind and solar energy, which hydrogen production would leverage.

Without substantial government support and coordinated regulation—and corporate enthusiasm—it's doubtful the private sector hydrogen research and development, innovation, and investment will take place on a grand scale. But ubiquitous hydrogen deployment is not required to push incremental hydrogen demand higher and derive decarbonization benefits.

#5 – Key industries are innovating

Investment opportunities in hydrogen are not yet "clear" so to speak—it's still early. But they are forming in four broad categories:

- **Heavy industry applications**, particularly in the chemicals, steel, other heavy metals, and cement industries where carbon emission reduction will be essential to achieve global goals;
- **Oil refining and natural gas industry uses**, including pipeline companies;
- **Hydrogen for local industrial supply chains and power generation** based on electrolysis from wind, solar, hydro, and nuclear power sources; and
- **Transportation industry innovations**.

Efforts in the transportation industry are garnering a relatively large share of media attention. Companies, startups, and research institutes are looking into and testing hydrogen-based fuel cells and internal combustion engines to power medium- and long-haul heavy-payload truck fleets, commuter and freight trains, industrial equipment (e.g., forklifts), ferries, tug boats, ships, and airplanes.

For example, Canadian Pacific Railway plans to develop North America's first locomotive based on battery power and hydrogen fuel cells. In

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Europe, Austria recently placed Alstom's hydrogen-powered passenger train into regular service. Startup ZeroAvia, a UK-based firm, is developing a single-propeller airplane that can operate on an electric motor driven by hydrogen fuel cells. Europe's Airbus is testing hydrogen-based power applications as well. Kawasaki Heavy Industries conducted the world's first successful trial of transporting liquefied hydrogen by ship in October 2020. This effort is part of a long-term, landmark agreement between Japan and Australia to deliver liquid hydrogen produced from Australian coal via ship to Japan. Norway-based Nel, the world's largest producer of hydrogen electrolysers, was recently awarded a contract to build hydrogen fueling stations for light-duty fuel cell vehicles in Quebec, Canada. Nel also supplies fueling equipment and electrolysers for hydrogen-based truck and bus fleet infrastructure in the U.S., China, and Europe.

Transportation industry sizzle aside, we think the potentially more consequential innovations and uses of hydrogen in the next 5–10 years will take place in carbon-intensive heavy industries—steel, chemicals, natural gas, and power generation.

Linde, a UK-based multinational formed from a merger with U.S.-based Praxair, has already built more than 80 hydrogen electrolysis plants mainly used by traditionally carbon-heavy industries.

Some of the most ground-breaking innovations are coming in the steel industry. Linde, in partnership with Sweden-based steel maker Ovako, successfully replaced liquefied natural gas with hydrogen as feedstock in the production process—a first for the industry. This reduced carbon emissions without any negative impact on the steel's quality. German steelmaker ThyssenKrupp and Japan's Nippon Steel are attempting to make "zero-carbon steel" using green hydrogen derived from solar and wind electricity through the electrolysis process, instead of the heavy-carbon-intensive steel manufacturing process of burning "met" coal at high temperatures.

BASF, the world's largest chemicals company, has built a test plant that will be used to determine if low-carbon hydrogen using methane pyrolysis can succeed at an industrial scale. This process splits biomethane (natural gas) into two components: hydrogen and solid carbon. The hydrogen could be used to generate power for a variety of uses, while the solid carbon could be used in heavy metals production such as aluminum and steel, or for battery materials. Other firms are working on methane pyrolysis as well. We think this technology has promise.

There are a number of hydrogen initiatives in the power industry. The H21 project, a UK government partnership with Norwegian energy firm Equinor and UK gas distributor Cadent, would bring a 12.5 gigawatt hydrogen-based power plant to Northern England. In the U.S., NextEra Energy Inc. seeks to build its first green hydrogen power plant in Florida, which will use a 20 megawatt electrolyser based on solar power. Entergy is partnering with Mitsubishi Power to bring hybrid hydrogen- and natural gas-based power to Texas and other states in the region. In Ohio, the Long Ridge Energy Terminal is slated to become a carbon-free hydrogen production facility. It will initially run on a blend of hydrogen and methane (natural gas) based

on General Electric turbines, and then would ultimately transition to 100 percent hydrogen.

Opportunity

Hydrogen has rapidly become more than just talk. Many businesses ranging from startups to major industrials have committed to an accelerated increase in production and to innovative applications. Governments are committing to even more stringent and challenging emission reduction targets for 2050. The significant drop in renewable electricity costs and dramatic increase in renewable power production is facilitating and opening the door to hydrogen as a valuable complementary clean technology, in our opinion. While the costs for building out the related industrial infrastructure may be high, we think the potential for job and wealth creation is compelling.

For hydrogen-related investments, we would focus on opportunities that are likely to find their way to market in the next 5–10 years and are not as dependent on substantial, coordinated long-term government subsidies that have yet to be designated or allocated.

Research resources

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Buy [Outperform]	762	55.46	299	39.24
Hold [Sector Perform]	559	40.68	179	32.02
Sell [Underperform]	53	3.86	4	7.55

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