amlam

Solid-State Hydrogen Storage Technology

Agenda

- Hydrogen Sector and State of Play
- Market Conditions
- amlam Potential
- Conclusions

HYDROGEN SECTOR
STATE OF PLAY

A short review of the hydrogen sector:

What it is

Hydrogen is a potential, principal energy carrier, which could, in the near future, lead to the implementation of a world-wide, clean, Hydrogen Economy, in which an efficient usage of fuel cells where hydrogen gas (H2) in contact with oxygen (O2) is converted into an electrical energy, would become a widespread reality.

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Why it works

Hydrogen energy, with environment amicable, renewable, efficiency, and cost-effective advantages, is the future mainstream substitution of fossil-based fuel. Hydrogen physically or chemically stored into nanomaterials in the solid-state is a desirable prospect for effective large-scale hydrogen storage, which has exhibited great potentials for applications in both reversible onboard storage and regenerable off-board storage applications.

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Solid-State superior to gaseous and liquid storage

The two most common methods commercially used to store hydrogen are in gaseous form at high pressure and in liquid form at cryogenic temperature. The pressurization of hydrogen allows for improving the volumetric energy density, which remains remarkably lower than those of the most common fossil fuels. This storage method is also affected by another drawback - due to the boil-off phenomenon, a hydrogen loss of about 1% per day is expected. However, due to the high hydrogen packing density, a significant enhancement of the volumetric energy density is obtained when hydrogen is chemically bonded to other elements in solid-state.

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Opportunities

Engineering systems that are based on solid hydrides, for supplying hydrogen to fuel cells in the future Hydrogen Economy, are the most attractive long-term solution.

- Benefits: Its attractive points include safe, compact, light, reversibility, and efficiently produce sufficient pure hydrogen fuel under the mild condition.

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Outlook

The European Commission describes hydrogen as an energy carrier with a “great potential for clean, efficient power in stationary, portable and transport applications.”

How solid-state hydrogen could be used in everyday life

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ELECTRIC CARS

Electric is maturing through a growing fleet of hydrogen fuel cell vehicles. Toyota, Honda, Mercedes-Benz and Hyundai have launched fuel cell vehicles equipped with the compressed H2 fuel tank.

RE-CHARGING SYSTEMS

high-capacity metal hydride fast recharging battery systems for trains and trams in France and in Japan. Hydrogen storage remains challenge in rolling out infrastructure to support hydrogen fueled transportation.

PUBLIC TRANSPORT

In addition, hydrogen fuel cell trains are operating commercially in Germany, France and the UK, and hydrogen driven ferries in Norway.

HYDROGEN GENERATION / STORAGE SYSTEMS

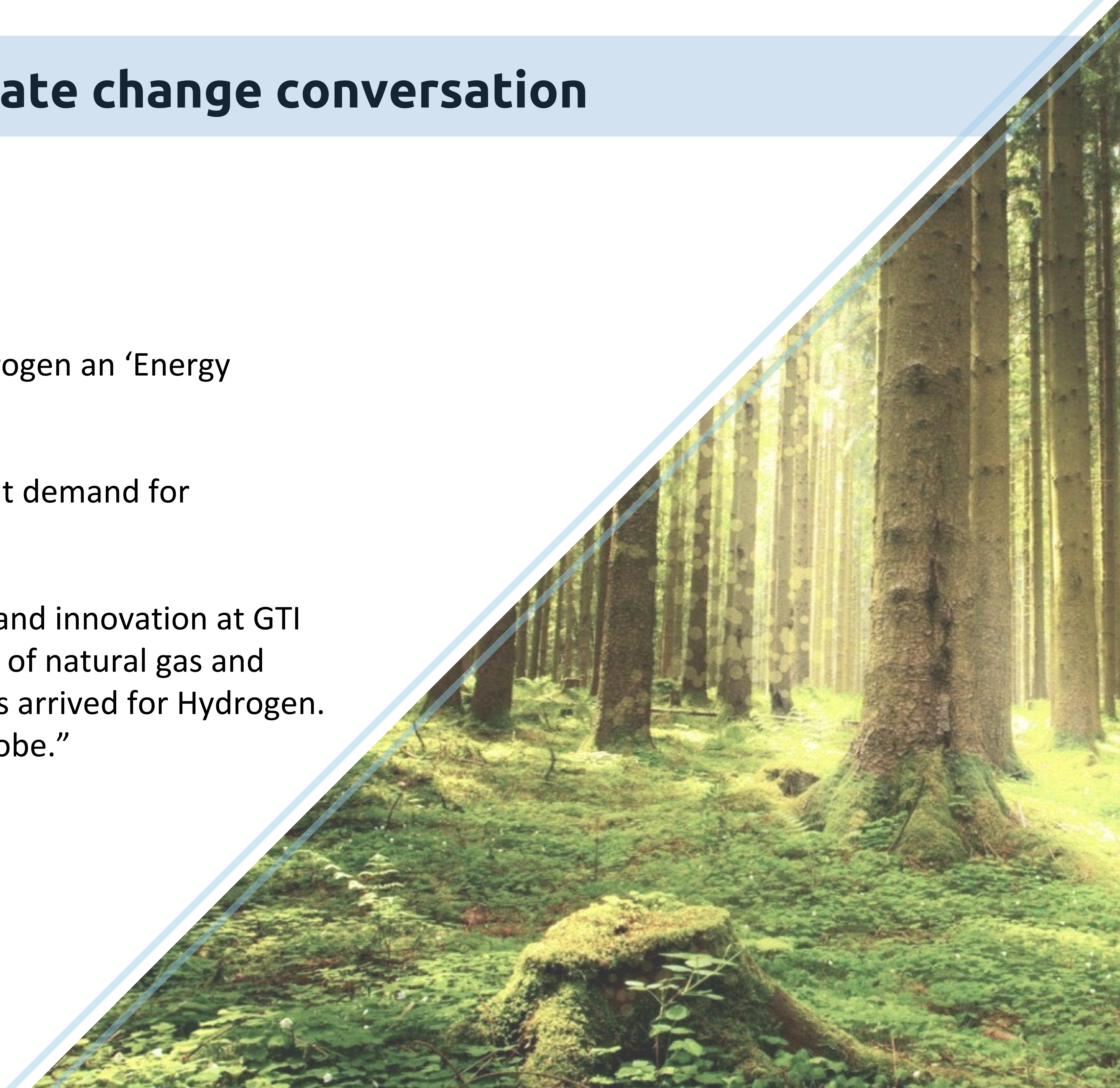
PORTABLE ELECTRONIC DEVICES

STATIONARY AUXILLARY POWER

LI-ION BATTERIES AND ELECTROCHEMICAL STORAGE

Hydrogen's position in the climate change conversation

- The Clean Hydrogen Future Coalition calls Hydrogen an 'Energy Superstar'
- The International Energy Agency calculated that demand for Hydrogen has more than tripled since 1975
- Paula Grant, senior vice president for strategy and innovation at GTI (an organisation aiming to unlock the potential of natural gas and other energy resources) said: "The moment has arrived for Hydrogen. There is tremendous excitement around the globe."



Hydrogen’s role in climate neutrality

- The Hydrogen economy is a priority for the EU’s post-COVID-19 economic recovery package, guided by the European Green Deal which commits Europe to become the world’s first climate neutral continent by 2050

- For climate experts, green or renewable Hydrogen is indispensible to climate neutrality. It features in all eight of the European Commission’s net zero emissions scenarios for 2050

- Energy efficiency, renewables and direct electrification are the bulk solutions to climate change

- Hydrogen is essential to get to net zero in certain sectors like industry, but we are talking about the last 20% of emission reductions

What this means for the gas industry

In theory, Hydrogen can do three things:

- Store surplus renewables power when the grid cannot absorb it
- Help decarbonize hard-to-electrify sectors such as long-distance transport and heavy industry
- Replace fossil fuels as a zero-carbon feedstock in chemicals and fuel production

Net-zero requires a full fossil fuel phase-out. It puts the spotlight on gas for the first time - the gas industry is turning to hydrogen for a new lease of life.

Hydrogen’s role in regulatory and government trends

- The number of countries with a hydrogen strategy doubled in 2021, from 13 to 26. This year, 22 more could follow. The strategies from the U.S., Brazil, India and China could redraw the world’s Hydrogen map.

- Public sector support encouraged the proliferation of investment in green hydrogen startups and projects, and boosted the price of green hydrogen stocks. India’s two richest men are competing to be kings of green hydro; Europe’s private investment house built an investment platform to support clean hydrogen infrastructure stocks; and seven of America’s leading businesses formed Breakthrough Energy Catalyst, with the goal of advancing climate-smart technologies like green hydrogen

- Public sector funding for green hydrogen amounts to at least $37 billion, and private sector investment is at least $300 billion

Hydrogen's role in regulatory and government trends

There are a number of green energy projects in the U.S. and around the world attempting promote hydrogen adoption. Overall, there are more than 90 industrial green hydrogen projects under development worldwide:

California will invest $230 million on hydrogen projects before 2023; and the world's largest green hydrogen project is being built in Lancaster, CA by energy company SGH2. This innovative plant will use waste gasification, combusting 42,000 tons of recycled paper waste annually to produce green hydrogen. Because it does not use electrolysis and renewable energy, its hydrogen will be cost-competitive with gray hydrogen.

A new Western States Hydrogen Alliance, made up of leaders in the heavy-duty hydrogen and fuel cell industry, are pushing to develop and deploy fuel cell technology and infrastructure in 13 western states.

Hydrogen Europe Industry, a leading association promoting hydrogen, is developing a process to produce pure hydrogen from the gasification of biomass from crop and forest residue. Because biomass absorbs carbon dioxide from the atmosphere as it grows, the association maintains that it produces relatively few net carbon emissions.

Breakthrough Energy, co-founded by Bill Gates, is investing in a new green hydrogen research and development venture called the European Green Hydrogen Acceleration Center. It aims to close the price gap between current fossil fuel technologies and green hydrogen. Breakthrough Energy has also invested in ZeroAvia, a company developing hydrogen-fueled aviation.

In December, the U.N. launched the Green Hydrogen Catapult Initiative, bringing together seven of the biggest global green hydrogen project developers with the goal of cutting the cost of green hydrogen to below $2 per kilogram and increasing the production of green hydrogen 50-fold by 2027.

HYDROGEN SECTOR

CASE STUDY

California: A Case Study

Hydrogen investment: Since 2008, the California Energy Commission has invested $242 million to support hydrogen research, development, and deployment projects. In comparison, in the same time period, the Clean Transportation Program in California invested $217.5 million in electric vehicle infrastructure, meaning that hydrogen infrastructure investments have outpaced electric vehicle investments in California.

Hydrogen fuel infrastructure investment: As part of the 'Clean Transportation Program' Investments, California has invested a quarter million dollars into publicly available hydrogen refuelling infrastructure with 50 stations in place today and a goal of of 179 stations by 2026. In addition, the state is working to develop medium and heavy-duty hydrogen refuelling infrastructure, standards, and equipment certification.

Hydrogen storage challenge: 28% of the $18M invested into active and completed hydrogen research focused on finding storage solutions and applications for grid support. This investment was more than 5x higher than the investment in hydrogen production research and more than 20x higher than the budget for industrial applications and building use research.

Potential: The revised state budget proposal for the next several years builds on the CEC's existing research with a proposed investment of $350M toward research into long-term hydrogen storage solutions.

MARKET CONDITIONS

How Hydrogen is being used today

In the U.S.: Almost all the hydrogen produced in the United States each year is used for refining petroleum, treating metals, producing fertilizer, and processing foods.

Electricity
Hydrogen can also be used with fuel cells to power anything that uses electricity, such as electric vehicles and electronic devices.

Better than Batteries
Unlike batteries, hydrogen fuel cells don't need to be recharged and won't run down, so long as they have hydrogen fuel.

More Bang
Pound for pound, hydrogen contains almost three times as much energy as fossil fuels, so less of it is needed to do any work.

Efficiency
Hydrogen is used most often used to power hydrogen fuel cells, namely in the transportation industry. Because of its energy efficiency, a hydrogen fuel cell is two to three times more efficient than an internal combustion engine fueled by gas. And a fuel cell electric vehicle's refueling time averages less than four minutes.

Less Reliant
Because hydrogen fuel cells can function independently from the grid, fuel cells can be used in the military field or in disaster zones and work as independent generators of electricity or heat. When fixed in place they can be connected to the grid to generate consistent reliable power.

Review of the potential current and future uses of hydrogen

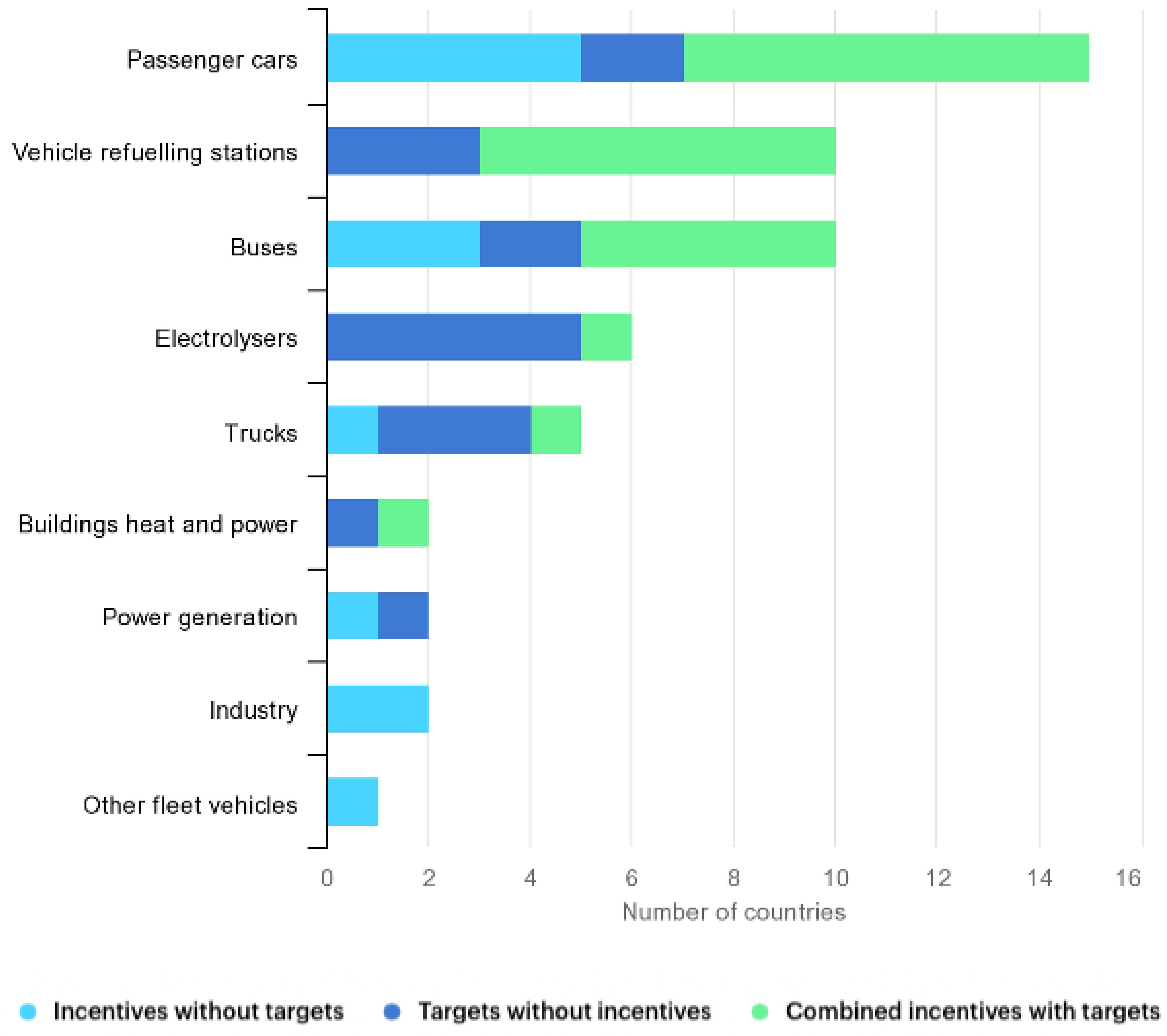
For reducing emissions, Hydrogen can help tackle various critical energy challenges.

It offers ways to decarbonize a range of sectors where it is proving difficult to meaningfully reduce emissions, such as long-haul transport, chemicals, iron and steel.

Hydrogen use today is dominated by industry, namely: oil refining, ammonia production, methanol production and steel production. Virtually all of this hydrogen is supplied using fossil fuels, so there is significant potential for emissions reductions from clean hydrogen.

Current policy support for hydrogen deployment, 2018

Source: [IEA.org](IEA.org)



Transport

In transport, the competitiveness of hydrogen fuel cell cars depends on fuel cell costs and refueling stations.

For trucks, the priority is to reduce the delivered price of hydrogen.

Shipping and aviation have limited low-carbon fuel options available and represent an opportunity for hydrogen-based fuels.

Buildings

In buildings, hydrogen could be blended into existing natural gas networks, with the highest potential in multifamily and commercial buildings, particularly in dense cities.

Longer-term prospects could include the direct use of hydrogen in hydrogen boilers or fuel cells.

Power generation

In power generation, hydrogen is one of the leading options for storing renewable energy, and hydrogen and ammonia can be used in gas turbines to increase power system flexibility.

Ammonia could also be used in coal-fired power plants to reduce emissions.

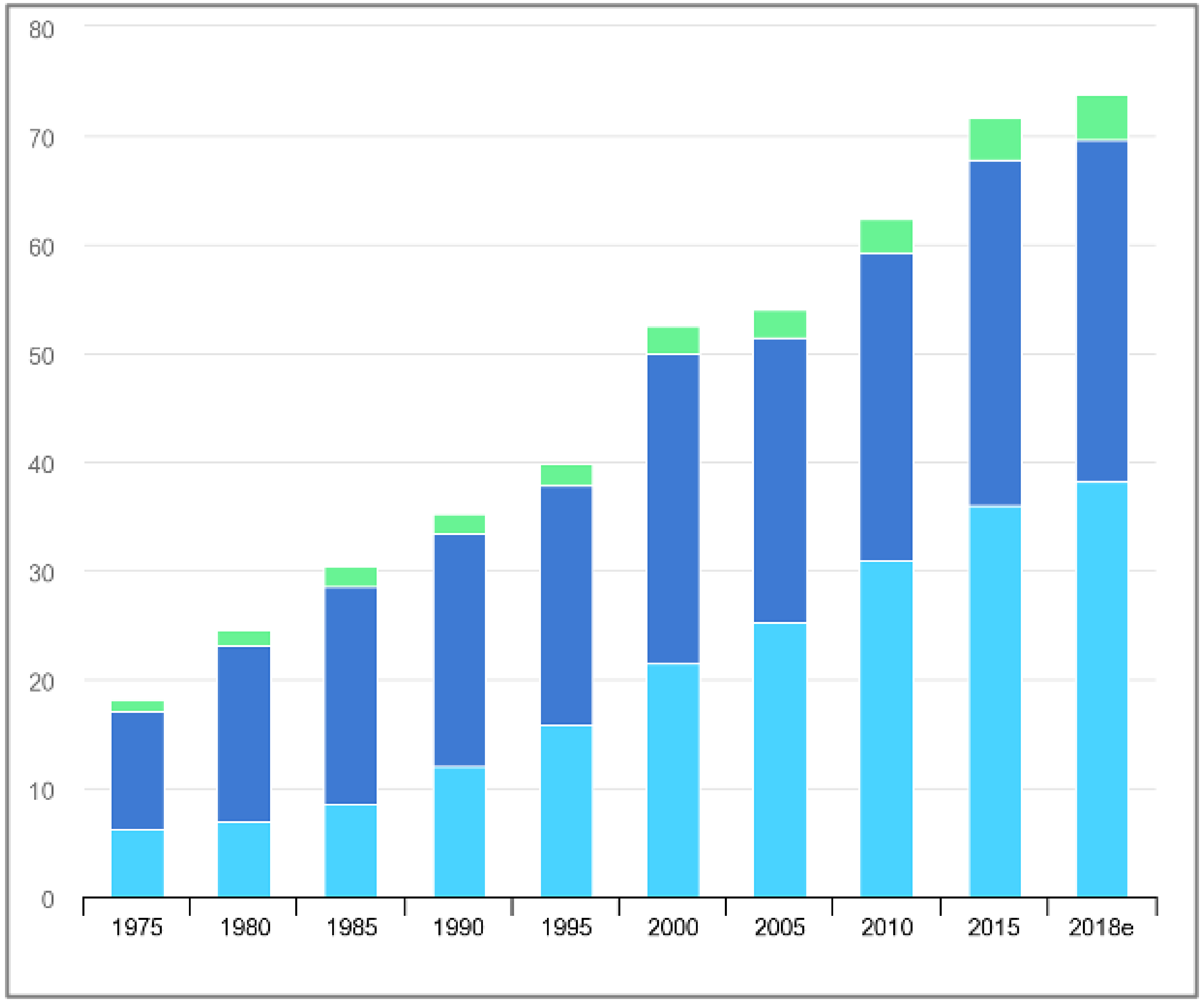
Review of the potential current and future uses of hydrogen cont.

In supply and demand, supplying hydrogen to industrial users is now a major business around the world.

Demand for hydrogen, which has grown more than threefold since 1975, continues to rise.

Global demand for pure hydrogen, 1975-2018

Source: IEA.org



Politics

In politics, the International Energy Agency (IEA) found that clean hydrogen is currently enjoying unprecedented political and business momentum, with the number of policies and projects around the world expanding rapidly.

It concludes that now is the time to scale up technologies and bring down costs to allow hydrogen to become widely used.

Fuel

In fuel, clean hydrogen is touted as the future fuel of the EU, promising to deliver an abundance of carbon-neutral energy by 2030.

It will power long haul freight vehicles, airplanes, steel production and domestic heating, proponents say.

Challenging areas

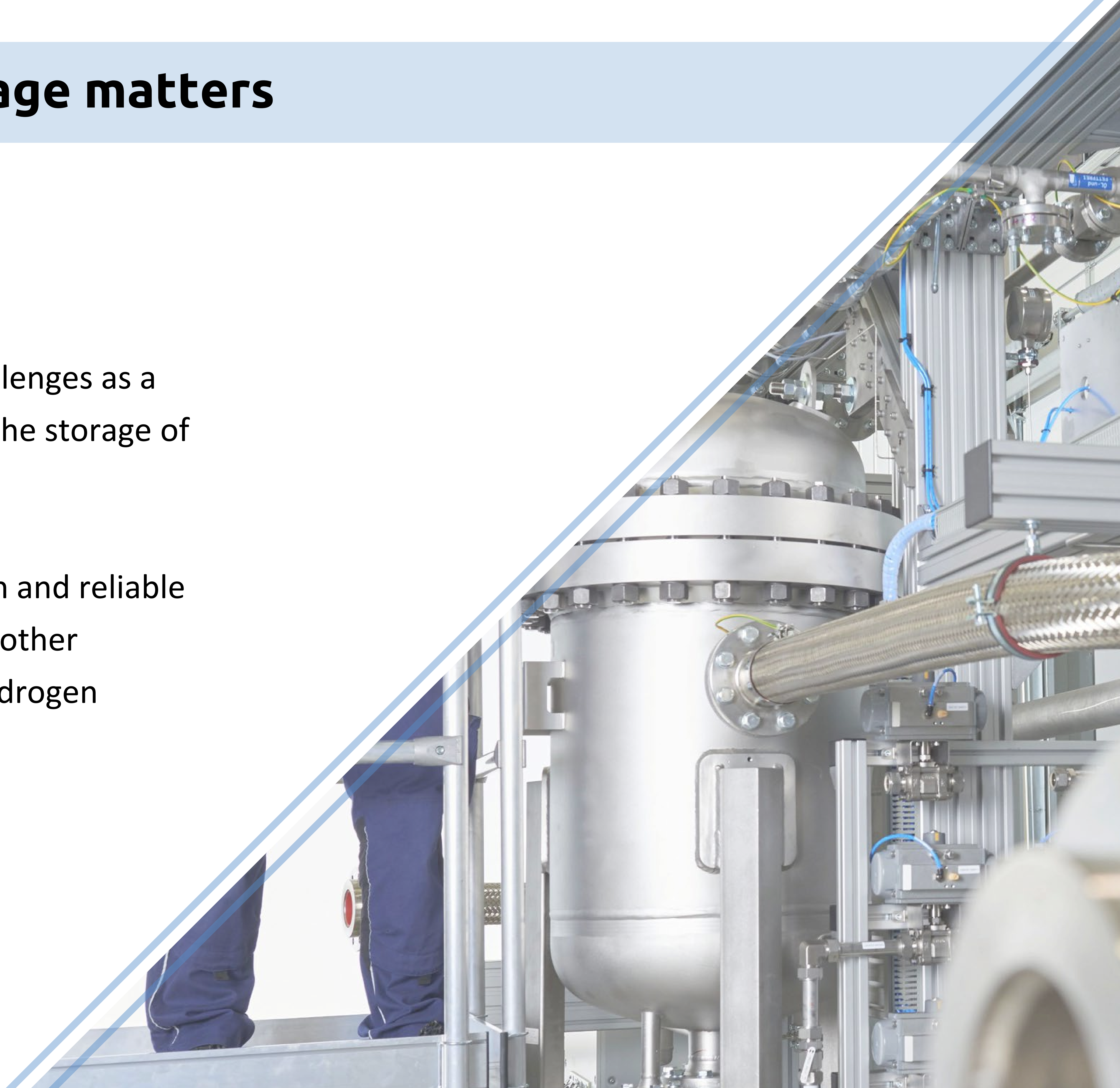
In challenging areas - aviation, shipping, long-distance trucking and concrete and steel (comprising 15% or so of the economy) has been historically difficult to decarbonize because these sectors require high energy density fuel or intense heat.

Hydrogen could meet these needs.

Why solid-state hydrogen storage matters

- Solid-state hydrogen solves hydrogen energy challenges as a cost-effective, compact and practical solution to the storage of hydrogen onboard vehicles.

- Solid-state hydrogen fulfills the promise of a clean and reliable energy supply in the transportation sector and in other applications previously limited within the new Hydrogen Economy.



The challenge

Storing enough hydrogen on-board a vehicle to achieve a driving range of greater than 300 miles is a significant challenge. On a weight basis, hydrogen has nearly three times the energy content of gasoline. However, on a volume basis the situation is reversed. Although hydrogen-powered vehicles are on the road today, they require large, heavy, cylindrical tanks of compressed gas. These cylindrical tanks are needed to keep pressure and stress from building up, but they take up significant space. Also, the energy penalty to compress gas into the tanks is high. Solid-based storage would also enable development of gas tank designs that are better fitted to an automotive interior than a cylinder.

The solution

Unlike compressed hydrogen and liquefied hydrogen, storing hydrogen in solid-state hydrides can realize a more compact and much safer approach that does not require high hydrogen pressure and cryogenic temperature. Hydrogen storage in solids may make it possible to store larger quantities of hydrogen in smaller volumes at low pressure and at temperatures close to room temperature. It is also possible to achieve volumetric storage densities greater than liquid hydrogen because the hydrogen molecule is dissociated into atomic hydrogen within the metal hydride lattice structure.

Why solid-state hydrogen storage matters

In the following decades, humankind will face enormous challenges related to climate change and energy supply. A swift transition to a more sustainable energy system is necessary, and hydrogen is the key element of this transition.

In this work, it was displayed that metal hydride-based systems provide a suitable solution to store large quantities of hydrogen for mobile and stationary applications, owing to their large variety of physicochemical properties. For these reasons, in the near future, metal hydride-based materials are expected to play an important role in realizing a fully decarbonized hydrogen-based economy.

However, a rethinking of the way metal hydrides are produced is necessary for avoiding issues connected to their environmental sustainability and high costs. A possible solution is the application of circular economy strategies involving the use of industrial metal scraps to be used as metal sources for the synthesis of high-quality metal hydride systems.

AMLAM POTENTIAL

Landscape of competition in the category

GKN Hydrogen, the only direct competitor, stores green hydrogen from renewable sources for various applications. The metal hydride storage has been developed and refined over the last 8+ years to become the ”most reliable and secure hydrogen storage solution on the market.”

They have three HY2 modular energy systems: the HY2MINI, the HY2MEDI, and the HY2MEGA, the largest metal hydride storage on the market with an up to 50% smaller carbon footprint than Li-ion batteries. The systems are 100% recyclable, low-pressure, have no capacity loss for decades, and save about 150 tons of CO2 over their lifetime.

The company has 16 pilot systems installed globally from California to Canada, but also in Australia, China and Central Europe in the following applications:

- Seasonal storage of hydrogen
- Micro-grids and buildings
- Off-grid standalone power supply
- Power back-up for IT servers
- Plug-in e-car charging systems
- Maritime Transport

amlam competitive advantage

In the hydrogen space where the greatest barrier to adoption is the ability to store hydrogen efficiently and compactly, amlam potentially has an advantage over its sole competitor, as it targets five times more hydrogen storage per unit size (6wt% vs. 1.2wt%).

Thank you