Creating a viable hydrogen economy
A Future of Energy point of view
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01 Introduction
The global energy mix is shifting from fossil fuels to renewables in an effort to reduce CO₂ emissions.

**Global decarbonisation**

Global total primary energy by source

- Renewable energy
- Fossil

**Global net energy-related CO₂ emissions**

- Business as usual
- "Paris"

Net zero emissions in 2070

**Introduction**

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**Note:** EJ = Exajoule = 1^18 joule

Source: Deloitte Future of Energy Scenarios; Shell Sky 1.5 scenario
Deloitte's Future of Energy scenarios

But to what extent, and how fast depends for a large part on global dynamics and societal response to climate change, two critical uncertainties that span our Future of Energy scenarios space.

**In 2020 Deloitte published its Future of Energy scenarios.**

• These four plausible and divergent energy scenarios represent guideposts that can help leaders make decisions and take action in the short term.

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**Deloitte’s Future of Energy scenarios**

- **Ready, set, innovate**
  - The failure of governments to globally address climate change leads private industry to take it upon themselves to innovate to lower emissions. The build-out of renewables relies on businesses as there is limited coordination between nationalistic governments creating hurdles for the scale-up of these technologies.

- **One team, one dream**
  - Consumer behavior dramatically favours the long-term health, environmental, economic, and social benefit of the collective, triggering a globally collaborative atmosphere that successfully commercialises low-carbon technology and commits to drastic decarbonisation. Governments introduce a global carbon pricing mechanism.

- **Me and my resource**
  - Protectionist policies that create trade barriers and limit technology/knowledge transfer prevail. Governments compete for access to cheap and stable energy resources. Innovation focuses on development of local resources, whether renewable or hydrocarbon. Climate change responses are disparate, reactive, and focused on localised infrastructure projects versus abatement.

- **Rising tide**
  - Energy efficiency, affordability, and accessibility drives consumer behavior, resulting in the expansion of both renewables and hydrocarbons. Global powers share the priority of short-term economic growth, which leads to increases in wealth and quality of life for most. Advanced technologies create new options for adapting to climate change.

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**Societal response to climate change**

**Global dynamics**
What is clear is that after a decade of investments targeted at electrification of the energy system, solar and wind are cost-competitive and the share of electricity in the energy mix has increased.

**Electrification of energy mix**

**Cost of solar PV and wind electricity**

- **Solar PV electricity**
  - $1.3 trillion investment '10-'19
  - 88% cost decline forecasted '10-'30

- **Wind electricity**
  - $1.0 trillion investment '10-'19
  - 69% cost decline forecasted '10-'30

**Total energy consumption by source (EJ/year)**

- **2010**
  - Gas: 353
  - Coal: 82%
  - Solar PV: 18%
  - Electricity: 82%

- **2020**
  - Gas: 403
  - Coal: 79%
  - Solar PV: 21%
  - Electricity: 79%

- **2030F**
  - Gas: 444
  - Coal: 73%
  - Solar PV: 27%
  - Electricity: 73%

Note: LCOE = levelised cost of energy = average cost per MWh over the lifetime of the asset; Solar PV electricity refers to solar photovoltaic electricity; EJ = Exajoule = $1^{18}$ joule

Source: BloombergNEF; Shell sky scenario
However, there are limits to electrification, where hydrogen can be an alternative way to decarbonise energy use.

‘Path to Paris’ – Prioritisation of decarbonisation alternatives

<table>
<thead>
<tr>
<th>Decarbonisation alternative</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy reduction and efficiency (Use less energy)</td>
<td>Behavioural</td>
</tr>
<tr>
<td>Electrification (Use renewable electricity)</td>
<td>Physical</td>
</tr>
<tr>
<td>Sustainable fuels (Use green molecules as energy carrier)</td>
<td>Economic</td>
</tr>
<tr>
<td>Carbon capture and storage (Prevent CO₂ emissions to atmosphere)</td>
<td>Societal</td>
</tr>
<tr>
<td>Offset emissions (Save carbon emissions elsewhere)</td>
<td>Ecological</td>
</tr>
</tbody>
</table>

Physical limits to electrification when you need:
- Combustibility to reach high temperatures
- High energy density in mobile applications
- Flexibility in time and space through storage
- Feedstock for industrial processes

Note: ‘Path to Paris’ refers to the global agreement to keep a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels.
In energy, around 20-50% of demand cannot be physically or economically electrified.

**Energy electrification potential towards 2050 (% of 2018 consumption, EJ; DE, NL, BE)**

- **20-50% of energy will not be electrified**
  - High: ~80%
  - Low: ~50%

- **Will not be electrified**:
  - ~4.3 EJ
  - ~90%
  - ~60%
  - ~40%

- **Will likely be electrified**:
  - ~1.2 EJ
  - ~70%
  - ~60%

- **Already electrified**:
  - ~1.2 EJ
  - ~60%
  - ~70%

Electrification limitations:
- Poorly insulated buildings less suitable for electric heat pumps
- Central heat can be more economical in urban areas
- High temperature heating very difficult to electrify
- Costs of redesigning processes to new energy sources
- Energy density (range) per kg and m³ (shipping and aviation)
- Development time (aviation)

Source: Deloitte Energy System Model based on Eurostat Energy Balances June 2020 (DE, NL, BE); OECD; Shell Sky; IEA SDS; Zsiborács et al., Electronics 8, 2019; EEA
And although hydrogen has been talked about before, this time the fundamentals have changed...

**Technology enabled**

- Renewable power has become **commercial** enabling **green hydrogen production**
- Shares of renewable power have increased to the level that **supply exceeds demand** more often, therefore requiring energy storage
- Electrolysers have shown signs of **steep cost declines** similar to solar PV and wind turbines
- **Electricity grid congestions** in some parts of Europe (e.g. NL) are limiting further renewable power deployment, requiring alternative ways of **transport energy**

**Governments pushed**

- Policy focus has shifted from renewable electricity to **decarbonising the hard-to-abate sectors**
- Governments in Europe are making **large investments** in hydrogen infrastructure as part of COVID-19 recovery packages
- **National hydrogen strategies** are developed to create a strategic advantageous position
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... creating opportunities for hydrogen, particularly in industrial chemical feedstock, industrial process heating, the electricity system and freight mobility

Fossil fuel uses and hydrogen potential

- Industrial feedstock: Chemical feedstock (E.g. making fertiliser)
- Industrial heat: Process heating (E.g. steel melting)
- Electricity production: Buffering (E.g. steam turbines)
- Mobility: Passenger (E.g. personal car), Freight (E.g. trucking), Space heating (E.g. radiators), Cooking (E.g. gas stoves)

Substitution opportunities

- Oil, gas, coal
- Hydrogen
- Electrification (Hydrogen in niches)
Renewable energy value chain and hydrogen role

Introduction

Which will create new elements to the energy value chain

Note: $e$ = electricity

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Renewable electricity generation

Electrolysis $\rightarrow H_2$

Storage (optional) $\rightarrow H_2$

Transport $\rightarrow H_2$

Electricity production $\rightarrow e$

Synthetic hydrocarbons $\rightarrow C_x H_y$

Decentral electrolysis $\rightarrow H_2$

Consumption

Industrial feedstock

Industrial heat

Mobility

Built environment

Upstream

Midstream

Downstream

Note: $e$ = electricity
Hydrogen demand – Sector overview
In industrial feedstock, hydrogen is potentially more competitive because it substitutes converted hydrocarbons, however uptake will be slow owing to large existing assets.

**Renewable energy value chain and hydrogen role**

<table>
<thead>
<tr>
<th>Subsegment</th>
<th>Hydrogen adoption</th>
<th>Example projects</th>
</tr>
</thead>
</table>
| Industrial feedstock – Existing demand | • Hydrogen application units are already in place  
• Hydrogen is more competitive as feedstock because it competes with converted hydrocarbons (grey hydrogen instead of natural gas) instead of hydrocarbons directly | • E.g. 1 GW electrolyser to replace grey hydrogen from SMRs for i/a fertiliser (Yara) and refining (Lukoil-Total Refinery) in Zeeland (NL) |
| Industrial feedstock – New demand | • Hydrogen is more competitive as feedstock because it competes with converted hydrocarbons (e.g. coals instead of coal) instead of hydrocarbons directly  
• Production and application of hydrogen requires installing new assets  
• Difficult to obtain premium for using green energy because of distance to end consumer | • E.g. Hybrit, a joint venture between LKAB, Vattenfall and SSAB for a pilot to use hydrogen instead of cokes for direct reduction of iron ore |

In industrial heat, hydrogen has potential to replace fossil fuels for consumer goods companies that can capture a premium from using renewable energy.

**Hydrogen potential for industrial heat**

<table>
<thead>
<tr>
<th>Subsegment</th>
<th>Hydrogen adoption</th>
<th>Barriers</th>
<th>Example projects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Industrial heat – B2C</strong></td>
<td>• Consumer goods companies can directly benefit from switching to hydrogen by charging premiums to consumers based on green image</td>
<td>• Consumer-facing companies carefully balance benefits and risks as failures are directly linked to the company brand</td>
<td>• E.g. Unilever piloting the use of hydrogen in an industrial-scale boiler for manufacturing home and personal care products at its Port Sunlight facility</td>
</tr>
<tr>
<td></td>
<td>• Energy cost often accounts for minimal part of total operating cost</td>
<td></td>
<td>• Uses blue hydrogen supplied by Essar Oil via dedicated pipeline</td>
</tr>
<tr>
<td></td>
<td>• Technical barriers are low, e.g. burners and boilers can be switched to hydrogen relatively easily</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Industrial heat – B2B</strong></td>
<td>• Technical barriers are low, e.g. burners and boilers can be switched to hydrogen relatively easily</td>
<td>• Companies bear additional cost as B2B customers are not willing to pay a premium for renewable energy</td>
<td>• E.g. Nedmag developing a hybrid burner, capable of handling 0-100% natural gas/hydrogen mixtures</td>
</tr>
<tr>
<td></td>
<td>• Burners can also be converted to run on 0-100% natural gas-hydrogen content, limiting the risk of downtime due to limited hydrogen supply</td>
<td>• Energy cost often accounts for a larger share of total cost relative to B2C companies, therefore increasing the cost impact of switching to hydrogen</td>
<td>• Handling varying mixtures mitigates supply lock-in and smoothens transition to (green) hydrogen</td>
</tr>
</tbody>
</table>
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Consumer goods companies can switch from fossil fuels to hydrogen to appeal to consumers, at a cost increase that is minimal relative to marketing and operating expenses.

**Consumer goods companies energy cost**

- **Fossil**
  - Energy cost: 15%
  - Marketing: 64%
  - Other operating expenses: 21%
  - Operating margin: 0%
  - Revenue/ton: ~$1,950

- **Hydrogen**
  - Energy cost: 13%
  - Marketing: 64%
  - Other operating expenses: 21%
  - Operating margin: 0%
  - Revenue/ton: ~$3,250

Transitioning from fossil energy to hydrogen would only **marginally increase total cost** of consumer goods companies since energy costs account for a **relatively small share** of total cost.

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Note: Assumes fossil fuel usage of 100% natural gas at cost of $5/GJ and hydrogen at cost of $35/GJ.

Source: 2019 company annual reports; 2019 company environmental performance indicators.
In the electricity system, hydrogen could be used as storage medium for renewable electricity production and benefit from buffering, arbitrage and alternative transport compared to direct electricity usage.

**Hydrogen potential for electricity production**

### Power surplus

#### Electrolysis

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#### Storage alternatives

- **Tank storage**
  - High CAPEX makes storage not cost competitive with batteries
  - No location constraints

- **Underground storage**
  - Low CAPEX enables seasonal storage
  - Location constraint and technical complexities

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#### Electricity production

- **Hydrogen turbine peak power plant**

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#### Fuel cell

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Hydrogen offers the opportunity to decarbonise mobility, with high energy density that offers advantages of longer ranges and faster charging.

### Hydrogen potential for mobility

<table>
<thead>
<tr>
<th>Subsegment</th>
<th>Hydrogen adoption</th>
<th>Example projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trucks &amp; buses</td>
<td>• Cost advantage for commercial fleets from longer range (1,200 vs 800 km) and faster charging (15 vs 60 minutes) of than batteries(^1)</td>
<td>• Nikola</td>
</tr>
<tr>
<td></td>
<td>• Requires new refuelling network</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Higher energy cost per km than electricity</td>
<td></td>
</tr>
<tr>
<td>Cars</td>
<td>• Increased convenience from longer range and faster charging than battery-electric vehicles</td>
<td>• Toyota</td>
</tr>
<tr>
<td></td>
<td>• However not required for typical private trip</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Requires new refuelling network</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Higher energy cost per km than electricity</td>
<td></td>
</tr>
<tr>
<td>Shipping</td>
<td>• Energy density of hydrogen is more suitable for global shipping than batteries</td>
<td>• KOMERI</td>
</tr>
<tr>
<td></td>
<td>• Can be used in fuel cells or combustion</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Industry has yet to settle on fuel and technology to replace fossil fuels, with ammonia also in the race</td>
<td></td>
</tr>
<tr>
<td>Trains</td>
<td>• Avoids high cost of electrifying train tracks</td>
<td>• Stadler</td>
</tr>
<tr>
<td></td>
<td>• Therefore suitable for long-distance, low-utilization tracks (e.g. rural or mining freight)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Higher energy cost per km than electricity</td>
<td></td>
</tr>
<tr>
<td>Aviation</td>
<td>• Energy density of is better than batteries</td>
<td>• Airbus</td>
</tr>
<tr>
<td></td>
<td>• Can both be combusted in turbines to boost take-off and in fuel cells to power cruise</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Requires substantial R&amp;D investments on propulsion technology and aircraft body design before ready to go to market</td>
<td></td>
</tr>
<tr>
<td>Specialist equipment</td>
<td>• Cost advantage of faster charging than batteries, e.g. for forklifts in 24-hr warehouse</td>
<td>• Toyota</td>
</tr>
<tr>
<td></td>
<td>• On-site usage needs little refuelling infra</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Higher energy cost per km than electricity</td>
<td></td>
</tr>
</tbody>
</table>

Notes: Charging time for full range
Source: Transport & Environment (2020) ‘Comparison of hydrogen and battery electric trucks’; Company websites
While hydrogen is a feasible alternative for specialist equipment today, additional applications can be found in the future for the freight mobility sector.

Hydrogen potential for future mobility

- **Trucks and buses**: ~2030, ✔2050
- **Cars**: ✗2030, ✗2050
- **Shipping**: ~2030, ~2050
- **Trains**: ✗2030, ~2050
- **Aviation**: ✗2030, ~2050
- **Specialist equipment**: ✔2030, ✔2050

- **Road freight represents ca. 9% of global CO₂ emissions**
- **Common view** that range and charging time will be prohibitive for use of battery electric vehicles (BEVs) in heavy-duty trucks and that hydrogen fuel cell electric vehicles (FCEV) will be the most likely solution.
- **However, our ongoing research on road freight decarbonisation shows that BEVs may take a foothold in some duty cycles for HDT**
- **If BEVs are adopted at scale in the next five years, hydrogen may be permanently locked out from the sector**
- **Shipping represents ca. 3% of global CO₂ emissions**
- **Our study shows that hydrogen is among the contenders as “fuel of the future”, but ammonia is also in the race**
- **Green ammonia, although using hydrogen ions, requires different infrastructure than hydrogen used as a fuel**

“With small changes to operations, most fleet owners could use battery electric vehicles for 80% of road freight duty cycles, at lower cost than hydrogen”

Vice President from a leading global truck OEM

“Ammonia could be a good option for shipping, and we know how to handle it”

CEO of a shipping technology provider

Source: IEA, CO₂ emissions by sector
In the built environment hydrogen can be blended in the gas network and used in households, but alternatives are likely more attractive.

**Hydrogen potential for built environment**

**Existing uses**
- In the building sector, hydrogen could already be used through blending in small fractions.
- A 5-10% hydrogen fraction would help to scale up hydrogen production, making it more affordable.

**Short term**
- Greater blending fractions could be achieved, more than 30%, after:
  - Improvement of some components of the gas network.
  - Adjustment of the existing regulation.

**Long term**
- When gas grids are completely transformed into hydrogen or new hydrogen infrastructure is ready:
  - Hydrogen boilers with zero carbon emissions.
  - Hydrogen cogeneration systems and fuel-cells that provide heat and power, enabling off-grid systems.
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Hydrogen in the built environment will be very limited in 2030, but pilots are being developed.

Hydrogen potential for built environment

<table>
<thead>
<tr>
<th>Leeds (UK)</th>
<th>Hoogeveen (NL)</th>
<th>Stad aan het Haringvliet (NL)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Examples</strong></td>
<td><strong>Examples</strong></td>
<td><strong>Examples</strong></td>
</tr>
<tr>
<td>• Conversion of the existing gas grid to carry 100% hydrogen</td>
<td>• Conversion of existing gas infrastructure in new and existing residential areas to 100% green hydrogen</td>
<td>• Conversion of existing gas network in residential areas to 100% hydrogen</td>
</tr>
<tr>
<td>• Total average yearly demand = 5.9 TWh</td>
<td>• Blue hydrogen production capacity of 0.15 million tonnes per annum</td>
<td>• All-electric heat pumps are no feasible alternative because of old and detached houses, where required level of isolation is unattainable</td>
</tr>
<tr>
<td>• Blue hydrogen production capacity of 0.15 million tonnes per annum</td>
<td>• Incremental conversion of major UK cities’ natural gas supply to 100% hydrogen</td>
<td>• (Local) availability of green hydrogen is prerequisite for further growth and application of hydrogen in the built environment</td>
</tr>
<tr>
<td>• Incremental conversion of major UK cities’ natural gas supply to 100% hydrogen</td>
<td>• Convert 3.7 million homes and businesses by 2035 and 15.7 million by 2050</td>
<td>• Connect to nearby wind turbines for green hydrogen production</td>
</tr>
<tr>
<td>• Convert 3.7 million homes and businesses by 2035 and 15.7 million by 2050</td>
<td></td>
<td>• Convert 600 existing homes, and potentially the whole city to reach climate neutrality by 2050</td>
</tr>
</tbody>
</table>

Source: H21.green; Leeds Climate Commission; Proefproject Hoogeveen Publiek Rapport 2020; Stedin.net
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The first sectors for hydrogen demand will be industrial heat and road freight for consumer goods companies, which can obtain premium from consumers.

### Hydrogen potential per demand sector

<table>
<thead>
<tr>
<th>Sector</th>
<th>2030</th>
<th>2050</th>
<th>Assessment of hydrogen potential</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Industrial feedstock</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Existing</td>
<td>Low</td>
<td>High</td>
<td>• High potential because competing with (more costly) grey hydrogen instead of with fossil fuels directly</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Slow uptake due to existing grey hydrogen assets with low marginal cost and difficulty to obtain premium</td>
</tr>
<tr>
<td>New</td>
<td>Medium</td>
<td>High</td>
<td>• High potential because competing with (more costly) converted hydrocarbons instead of fossil fuels directly</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Barrier from requirement for new technology and assets and difficulty to obtain premium</td>
</tr>
<tr>
<td><strong>Industrial heat</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B2C</td>
<td>High</td>
<td>High</td>
<td>• High potential because consumer goods companies can obtain premium from customers for using green energy that covers higher energy cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Slow uptake because of technical barriers are low</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
<td>• High potential because of difficulty to obtain premium and large energy cost as share of total cost</td>
</tr>
<tr>
<td>B2B</td>
<td>Low</td>
<td>High</td>
<td>• Niche potential for flexibility services to store excess renewable electricity supply to use as peak capacity</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Niche potential for transport where cost advantage of pipelines over cables outweighs conversion loss</td>
</tr>
<tr>
<td><strong>Electricity production</strong></td>
<td></td>
<td>Medium</td>
<td>• High potential from cost advantage of longer range and faster charging time relative to electric vehicles</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Needs sufficient coverage of refuelling station infrastructure to take off</td>
</tr>
<tr>
<td><strong>Mobility</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trucks and buses</td>
<td>Medium</td>
<td>High</td>
<td>• Low potential as electric vehicles will likely remain cheaper and typical passenger car usage does not need long ranges and fast charging times</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Industry has yet to settle on fuel and technology to replace fossil fuels</td>
</tr>
<tr>
<td>Cars</td>
<td>Low</td>
<td>Low</td>
<td>• Hydrogen has potential for benefits of energy density, but ammonia is also in the race</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Low potential as most trains can be electrified at cheaper cost than using hydrogen</td>
</tr>
<tr>
<td>Shipping</td>
<td>Medium</td>
<td>Medium</td>
<td>• Some niche potential for long-distance, low utilization tracks where electrification has prohibitive infra cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Low potential because of extreme energy density needed for aviation which are better provided by biofuels or synthetic hydrocarbons</td>
</tr>
<tr>
<td>Trains</td>
<td>Low</td>
<td>Medium</td>
<td>• Industry has yet to settle on fuel and technology to replace fossil fuels</td>
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<td></td>
<td></td>
<td></td>
<td>• High potential from cost advantage of longer range and faster charging time relative to electric equipment</td>
</tr>
<tr>
<td>Specialist equipment</td>
<td>High</td>
<td>High</td>
<td>• Typically needs little refuelling infrastructure as usage is restricted to on-site</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• High potential from cost advantage of longer range and faster charging time relative to electric equipment</td>
</tr>
<tr>
<td>Built environment</td>
<td>Low</td>
<td>Medium</td>
<td>• Niche potential where electrification or alternatives of district heating or biomass are not attainable, typically for city-center old buildings with poor insulation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Niche potential where electrification or alternatives of district heating or biomass are not attainable, typically for city-center old buildings with poor insulation</td>
</tr>
</tbody>
</table>
Steam reforming of natural gas results in grey hydrogen, or, if carbon dioxide is captured and stored, blue hydrogen, while electrolysis with renewable electricity results in green hydrogen.

**Hydrogen production methods**

**Grey hydrogen**
- Current hydrogen production is almost exclusively grey hydrogen from natural gas.
- Grey hydrogen has high carbon emissions.

**Blue hydrogen**
- Blue hydrogen has same production method as grey hydrogen, but uses carbon capture and storage.
- Has controllable production capacity hence does not require storage.
- Could be the gateway towards green hydrogen.

**Green hydrogen**
- Green hydrogen is the only 100% renewable hydrogen production method.
- Requires storage to balance out fluctuating production from intermittent renewables with constant demand.
- Electrolysis technologies vary. Mature alkaline technology is best for stable electricity supply; newly developed PEM technology for intermittent supply.
Green hydrogen can become cost-competitive if renewable electricity prices fall, electrolyzer cost decrease and if carbon taxes make fossil fuels less competitive.

**Green hydrogen production process**

**Cost competitiveness** of green hydrogen is determined by:

1. **Renewable electricity cost**, the main variable cost, continue to fall
2. **Electrolysers cost**, the main fixed cost, decrease as a result of **technology improvements** and **production at scale** – similar to solar PV
3. **Carbon taxes** make carbon-free green hydrogen more competitive relative to fossil fuels

Large-scale, centralized electrolysis will likely supply the **majority of hydrogen** in the **end-state**.
Blue hydrogen, based on mature technology, may be used in the short term to kick-start supply without having to wait for green hydrogen cost to decrease.

**Blue hydrogen production process**

Blue hydrogen can kick-start the transition by supplying low-carbon hydrogen to companies that do not want to wait for green hydrogen cost to come down.

**Cost competitiveness** of blue hydrogen is determined by:

1. **Natural gas**, the main variable cost, is **cheap** and **abundantly available**

2. **Steam reformers**, the main fixed cost, have a cost advantage over electrolyzers as an **existing and mature technology**

3. **Carbon capture and storage/usage** can be done cost-efficiently (e.g. in depleted gas wells or reused in methanol) and yields a saving on **carbon taxes**

Note: (1) Can also be another hydrocarbon source, such as coal or refining fuel gases
Green hydrogen cost is forecasted to decrease significantly, but more expensive than blue hydrogen in the short term; both will require policy incentives to be competitive with fossil fuels.

**Hydrogen production cost forecast**

- **Green hydrogen**: $2.5-4.6 per kg hydrogen
- **Blue hydrogen**: $1.4-2.9 per kg hydrogen
- **Natural gas**: $0.7-1.7 per kg hydrogen

Cost range forecast: Green hydrogen | Blue hydrogen | Natural gas

Source: BloombergNEF (2020) ‘Hydrogen economy outlook’
Even though hydrogen system efficiency is reduced by energy losses during conversion, it has advantages over electrification in terms of system cost.

**Hydrogen conversion efficiency and system cost**

- Power-to-hydrogen-to-power/heat conversion leads to energy losses relative to directly using electricity, with efficiency at only 25-50%.
- However, lower system efficiency is outweighed by lower system cost of hydrogen relative to electrification.
  - Hydrogen allows for decarbonising end-uses where electrification has physical limits.
  - Hydrogen pipeline transport can be 8-15x cheaper than electricity cable transport per unit of energy.
  - Hydrogen allows for energy storage and therefore 100% intermittent renewable electricity integration.

---

**Note:** Does not take into account inefficiencies in transport and storage; Efficiency in terms of calorific value

**Source:** Hydrogen Europe
Hydrogen demand – sector overview

Hydrogen supply – technology overview

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Hydrogen distribution

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Transporting energy in the form of hydrogen will be more costly than transporting fossil fuels because hydrogen has a lower energy density per cubic meter.

**Hydrogen energy density and transport implications**

- **Lower energy density** per m³ of hydrogen (~1/3rd of natural gas) means that **less energy** can be transported in the **same truck or pipeline**, therefore requiring:
  - Additional **compression or cooling**, hence **cost**
  - Additional **truck trips**, hence **cost**

- **Higher energy density** per kg of hydrogen means the transported **weight** will be **less**

- Hydrogen has higher **flow velocity** (~3x faster than natural gas), meaning:
  - lower energy density is **partially offset** when evaluating **pipeline transport**
  - **Pipeline transport** has increased **cost advantage** over **truck transport** in hydrogen relative to fossil fuels

Note: (1) At pressure of 3,000 psi

Still, hydrogen transportation alternatives are similar to what we know from fossil fuels, with trucks for small volumes, pipelines for large volumes and ships for long (intercontinental) distances.

<table>
<thead>
<tr>
<th>Most efficient hydrogen transport alternative by distance and volume</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Volume (tons/day)</strong></td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td><strong>Truck</strong></td>
</tr>
<tr>
<td><strong>Inter-city</strong></td>
</tr>
<tr>
<td><strong>Urban</strong></td>
</tr>
<tr>
<td><strong>Inter-continental</strong></td>
</tr>
<tr>
<td><strong>Distribution pipelines</strong></td>
</tr>
<tr>
<td><strong>Transmission pipelines</strong></td>
</tr>
<tr>
<td><strong>Ships</strong></td>
</tr>
<tr>
<td><strong>Not viable</strong></td>
</tr>
</tbody>
</table>

Source: BloombergNEF (2020) ‘Hydrogen economy outlook’
Hydrogen does offer the novel possibility of decentral electrolysis, with the advantage of eliminating the need for any transport infrastructure at all.

**Decentral electrolysis cost-efficiency**

Decentral electrolysis will be more cost-efficient than truck transport when:

- Decentral location has access to **cheap renewable electricity** (from grid or dedicated solar PV or wind)
- Volumes are large enough for **sufficient utilisation** of the electrolyzer, but small enough for pipelines not to be viable
- Distances to a central electrolyser are large hence **savings on transport** are high

Storage has a crucial role to play in enabling the hydrogen transition by stabilising supply and demand, as hydrogen production patterns will follow those from intermittent renewables.

**Hydrogen entry and exit in storage**

- Hydrogen demand, particularly for industry, will be constant.
- Green hydrogen production will fluctuate in line with intermittent renewable electricity generation.
- Therefore storage will be crucial, with a large share of hydrogen supply and demand will pass in and out of storage.
- This requires rapid response of transport destinations to production changes, which can only be done with pipelines.
- Storage is focus for government to enable hydrogen transition as well as an opportunity for business.

**Note:** Hydrogen production pattern follows European electricity generation from wind pattern. The data in the chart is for illustrative purposes only. Source: WindEurope; IEA; Monitor Deloitte analysis.

Storage entry (Production exceeds demand)

Storage exit (Demand exceeds production)
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Geographical conditions will determine hydrogen cost in the long term, resulting in imports from regions with the lowest renewable electricity costs, either via pipeline or ship.

**Hydrogen costs in the long term**

- **Portugal and the Netherlands strengthen bilateral cooperation on green hydrogen**
  
  “The two countries affirm their intentions to develop a strategic export-import value chain to ensure production and transport of green hydrogen from Portugal to the Netherlands and its hinterland.”

  Government of the Netherlands

- **A North Africa – Europe Hydrogen Manifesto**
  
  “A joint hydrogen strategy between Europe and North Africa can help build a European energy system based on 50% renewable electricity and 50% green hydrogen by 2050.”

  Hydrogen, the Bridge between Africa and Europe

- **Australia ‘hydrogen road’ to Japan set to cut emissions**
  
  “A consortium’s $500m project will produce hydrogen from brown coal in one of the world’s first zero-emission energy supply chains.”

  Financial Review

Source: IEA, The Future of Hydrogen
Synthetic hydrocarbon fuels can be produced from hydrogen with renewable electricity and CO2 from waste streams or directly from air, circumventing new hydrogen infrastructure at the demand side (e.g. aviation).

### Production process of synthetic hydrocarbon fuels

**Atmospheric CO₂**

- Solar PV
- Electricity 4.7 GJ

**CO₂ activation**

- CO₂ 472 kg

**Direct Air Capture**

- Electricity 4.7 GJ

**CO**

- CO 270 kg, 2.5 GJ

**Synthesis**

- H₂ 2.8 GJ

**Electrolysis**

- H₂ 4.9 GJ

**Synth HC Fuel**

- 5.5 GJ

- 200$/bbl

Source: O. Kraan – On the Emergence of the Energy Transition – Joule 2019

Synthetic hydrocarbon fuels can be used to circumvent the substitution to hydrogen technology at the user side and high infrastructure investment (e.g. fuel stations).
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Policy perspective
Creating a viable hydrogen economy | A Future of Energy point of view

Hydrogen cost declines will be stimulated by governments that are developing hydrogen ecosystems, in line with their overall energy and industrial policy agendas...

**Hydrogen policy goals across the globe**

**EU: All**
- Energy importer
- Wants decarbonisation and energy independency
- Green energy, technology subsidies and demand stimulation
- Leverage chemical and pipeline infrastructure

**Saudi Arabia: Supply push**
- Energy exporter
- Wants to create employment not dependent on fossil fuels
- Green hydrogen from solar and wind farms as feedstock for fertiliser
- Part of Vision 2030 program

**Australia: Supply push**
- Energy exporter
- Focus on blue hydrogen to export to Japan

**China: Technology push**
- Energy importer
- Most cost competitive technology (electrolysers and fuel cells)
- Target of 1m FCEVs by 2030
- R&D grants, usage incentives

**Japan: Demand pull**
- Energy importer
- Wants to innovate in the transportation sector
- Focus on mobility and electricity production

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Next to country-specific hydrogen strategies, the EU’s hydrogen and energy system integration strategies will set a new clean investment agenda.

EU hydrogen strategy

**Scope**
- Boost renewable hydrogen production in Europe
- Focuses on hydrogen as feedstock, a fuel or an energy carrier and storage agent for applications across industry, transport, power and buildings sectors

**Investment outlook**
- Now – 2030: investments in electrolysers €24 and €42 billion
- Required: €220-340 billion to scale up and directly connect 80-120 GW of solar and wind energy production capacity to the electrolysers to provide the necessary electricity
- Retrofitting with CCS: half of the existing plants ~€11 billion
- Transport and infrastructure: investments of €65 billion
- Now- 2050: investments in production capacities would amount to €180-470 billion in the EU
- Adapting end-use sectors to hydrogen consumption and hydrogen-based fuels will also require significant investments

**Demand creation**
- Gradually create new lead markets; industrial applications and mobility.
- **Industrial:** 1) Reduce and replace the use of carbon-intensive hydrogen in refineries (production of ammonia, and for new forms of methanol production) 2) Zero-carbon steel making processes
- **Mobility:** 1) Captive uses, such as local city buses, commercial fleets (e.g. taxis) or specific parts of the rail network, where electrification is not feasible. 2) Heavy-duty road vehicles, Hydrogen fuel-cell trains, inland waterways and short-sea shipping, aviation and maritime sectors

**Policy perspective**
- Next Generation EU (Commission’s economic recovery plan) highlights hydrogen as an investment priority to boost economic growth and resilience, create local jobs and consolidate the EU’s global leadership
The funds earmarked for hydrogen in the European fiscal stimulus packages for COVID-19 recovery illustrate the governmental commitment.

### European hydrogen investment announcements 2020

<table>
<thead>
<tr>
<th>EU</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>June: outlines COVID-19 recovery package including €9 billion for the expansion of hydrogen capacity</td>
</tr>
<tr>
<td>France</td>
<td>September: plans hydrogen investment of €7 billion, including €2 billion as part of the €100 billion COVID-19 recovery plan</td>
</tr>
<tr>
<td>Spain</td>
<td>October: approves hydrogen strategy including 4 GW electrolysis, which needs €8.9 billion public-private investment</td>
</tr>
<tr>
<td>Portugal</td>
<td>May: announces national hydrogen strategy which foresees investments of €7 billion by 2030</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>March: minister for Economics Affairs and Climate publishes “Kamerbrief Kabinetsvisie waterstof”</td>
</tr>
</tbody>
</table>

Public investment will predominantly be directed at subsidising **market-enabling infrastructure** (e.g. fuel stations, pipelines) and **first movers in production** (e.g. first electrolysers).

Source: Public announcements
In line with the investment announcements, governments have various options to stimulate the hydrogen market such as blending obligations, innovation budgets and market instruments.

### Instruments for market development

<table>
<thead>
<tr>
<th>Description</th>
<th>Blending obligations</th>
<th>Innovation budgets</th>
<th>Market-instruments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong>&lt;br&gt;• Government can easily mandate the blending obligation&lt;br&gt;• Significant effect on the market&lt;br&gt;• Minor investments required, e.g. compression units and valves as well as application units only to be replaced with increased hydrogen percentage</td>
<td><strong>Blending obligations</strong>&lt;br&gt;• Obligation for suppliers to deliver a certain share of hydrogen in natural gas (~5-15%)&lt;br&gt;• Create additional demand for hydrogen with the aim to kick-start the hydrogen market</td>
<td><strong>Innovation budgets</strong>&lt;br&gt;• Funding programs for demonstration projects (e.g. Innovation fund, growth fund)&lt;br&gt;• Boost economic growth towards climate announcements</td>
<td><strong>Market-instruments</strong>&lt;br&gt;• Subsidies for certain products (e.g. SDE++)&lt;br&gt;• Increased taxes on certain products (e.g. carbon tax)</td>
</tr>
<tr>
<td><strong>Disadvantages</strong>&lt;br&gt;• Small share will only kick-start the market, but not create a big market&lt;br&gt;• Blending of a high premium product with a commodity product could devalue hydrogen</td>
<td><strong>Innovation budgets</strong>&lt;br&gt;• Financing limited to one-offs&lt;br&gt;• Commercial parties are stimulated to fulfill funding requirements even if not strategically relevant for the project</td>
<td><strong>Market-instruments</strong>&lt;br&gt;• Hydrogen not yet commercial for market funding&lt;br&gt;• Market instruments not designed for energy carriers and limited comparability with solar and wind</td>
<td></td>
</tr>
</tbody>
</table>
The promise of hydrogen has led to several companies to invest in pilot projects, predominantly around the use of hydrogen as industrial feedstock.

**Hydrogen pilot projects**

**Steel – Feedstock**
- SSAB, LKAB, Vattenfall

  - Joint venture named HYBRITT
  - Steel production via direct reduction technology, using hydrogen as feedstock
  - LKAB pelletises iron with bio-fuel heat; Vattenfall supplies green energy for hydrogen production
  - Pilot phase until 2024, plant to be built ≥ 2025

**Steel – Heat**
- Ovako, Linde

  - Conducted a trial to use hydrogen to heat steel before rolling at an Ovako plant in Sweden
  - Hydrogen replaced LPG as fuel for combustion

**Chemicals – Feedstock**
- Haldor Topsoe

  - Developed a new technology, SOEC, for production of "green" ammonia
  - With renewable energy, SOEC produces hydrogen and nitrogen, both feedstock for ammonia
  - SOEC enables future ammonia plants to be as energy efficient as current state-of-the-art facilities
  - SOEC demonstration plant planned in 2025, expected to be commercially available in 2030

**Chemicals – Feedstock**
- Liquid Wind

  - Cooperating with a consortium of a.o. Haldor Topsoe, Axpo, and Siemens Energy
  - Combining hydrogen with waste CO2 into "eMethanol, to be used as fuel or feedstock
  - Planned to be operational in 2023

**Magnesium – Heat**
- Nedmag

  - Developing a hybrid heating solution, capable of handling varying natural gas/hydrogen mixtures (0 – 100% hydrogen)
  - Handling varying mixtures mitigates supply lock-in and smoothens the change to (green) hydrogen
  - To be tested in 2020 at a Nedmag location

Source: company websites, amoniaindustry.com
Hydrogen supply projects at scale are in the making

**NorthH2 – Green hydrogen**

- **Consortium** of energy suppliers, grid and port operators
- Aims to build integrated chain from offshore wind to green hydrogen production, transmission, storage and supply
- Targets production capacity of 3-4 GW in 2030 to supply to industrial users in the Netherlands and rest of North-western Europe
- Hydrogen is transported via planned Dutch hydrogen grid of repurposed natural gas pipelines and stored in salt caverns
- Pre-FID phase

**Zero Carbon Humber – Blue hydrogen**

- **Consortium** of energy suppliers and users, grid and port operators
- Aims to transform the Humber industrial cluster into the UK’s first net-zero carbon cluster by 2040
- Demand for first Equinor production plant (600MW) is secured by blending hydrogen into Triton gas-fired power plant
- Subsequently production capacity can be expanded to supply industrial heat to steel and chemicals industry via local pipeline grid
- Pre-FID phase

Source: Project websites
Collaboration through consortia and ecosystems becomes critical to connect expertise and accelerate developments.

Large-scale hydrogen projects by company and region

Top 10 hydrogen electrolyser projects by company

- **Asian Renewable Energy Hub**: 12,000 MW
- **North2 Hydrogen Electrolyser**: 8,000 MW
- **Silver Frog**: 1,600 MW
- **Murchinson Renewable**: 4,000 MW
- **Beijing Jingneng Inner Mongolia**: 8,000 MW
- **Neom (Green Hydrogen Project)**: 12,000 MW
- **Pacific Solar Hydrogen**: 12,000 MW
- **H2 Hub Gladstone**: 8,000 MW
- **Greater Copenhagen Area**: 4,000 MW
- **Geraldton Hybrid Project**: 16,000 MW

Large-scale hydrogen projects by region

- **Middle East**: 3
- **N. America**: 7
- **Europe**: 16
- **Asia**: 15
- **Australia**: 9

Source: Rystad Energy RenewableCube (2020); Companies, IEEFA estimates
The hydrogen economy faces a vicious circle, with uncertainty around where to begin.

**Decarbonisation uncertainties**

- What if there is **insufficient production infrastructure** or the cost is prohibitive?
- What if there is **insufficient production infrastructure** or the cost is prohibitive?
- What if **fuelling infrastructure is not available next to my location or different standards**?
- What if there is **insufficient production infrastructure** or the cost is prohibitive?
- What if provinces/ states, countries, and international bodies adopt **contradicting regulations**?
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- What if provinces/ states, countries, and international bodies adopt **contradicting regulations**?
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We see analogies with similar infrastructure and technology developments, where a breakthrough was enabled on the backbone of other technologies or systematic investments in R&D.

**Analyses with similar developments**

**Internet**

**First public connection through telephone network**
- In the early 1990s, the world wide web could be accessed through dial-up connections.
- Dial-up connections established a connection with other computers through the telephone network, which would not allow for the parallel usage of the telephone and the internet.

**Introduction of commercial broadband**
- In the late 1990s, broadband connections via cable, digital subscriber line, satellite and FTTX replaced dial-up access as standard technology.

**Solar PV**

**First application in satellites supported by government funds**
- In 1964, NASA launched the Nimbus spacecraft, a satellite powered by a 470w PV array.
- Massive governmental investments in space programs pushed development to win the space race, alongside investments from electronics and oil companies.

**More applications for solar PV followed once technology was developed**
- In 1980, the University of Delaware developed the first thin film solar cell exceeding 10% efficiency with potential application for houses.
- Research exploded in 1990s and 2000s, and with it application possibilities.

Open infrastructure standards enable developments of new technologies

Governmental support is key to kick-start research and development

Source: U.S. Department of Energy
Creating a viable hydrogen economy | A Future of Energy point of view

The key to a successful hydrogen strategy is overcoming four key challenges

**Key challenges**

- **Government and policy support is required** to create an environment for low-carbon hydrogen application to become competitive with other technologies and energy sources.

- **Currently in its infancy as regulations and standards around the world and in Europe and Middle East do not yet fully support hydrogen uptake or new uses of hydrogen.**

- **By 2035, total levelised cost of hydrogen is more cost effective than diesel.**

- **Ecosystem is complex creating a need for investments and policies to be synchronised in scale and time.**

- **However, it remains behind natural gas which is a prolific resource even out to 2050. Europe and Middle East is abundant with cheap electricity resulting in headwinds for hydrogen to directly compete with incumbents.**

- **Europe and Middle east currently lacks a cohesive integrated hydrogen strategy.**
Making strategic bets and building an eco-system while learning and pro-actively connecting with policy makers to create the rules are the lessons learned from the development of the hydrogen market so far.

**Lessons learned**

- Make strategic bets
  - Be clever with your investments by investing with a strategic mindset
  - Make your bets consistent with your strategy
  - Fail fast, learn fast

- Build an eco-system
  - Create eco-systems to understand the needs of your stakeholders
  - Create partnerships to spread the risk of non-commercial projects

- Keep learning
  - Be part of project consortia to understand real project difficulties
  - Invest in start-ups to understand their business models
  - Support research consortia to realise where technology developments are going

- Create the rules
  - Be pro-active towards policy makers
  - Ensure favourable market rules
  - Understand where subsidies will be going too

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Creating a viable hydrogen economy | A Future of Energy point of view

The opportunities in a developing hydrogen market differ by sector

**Opportunities for different sectors**

**Oil, Gas & Chemicals**
- Handling of hydrogen molecules fits well with current core capabilities
- Opportunity to decarbonise chemical production by using hydrogen for industrial feedstock and industrial heat

**Power & Utilities**
- Potential to exploit the arbitrage opportunity on electricity production
- Increased flexibility to electricity systems and enablement of additional services
- Development of new business opportunities for utility companies

**Mining & Metals**
- Opportunity to decarbonise operations through hydrogen trucks
- Development of new business opportunities for raw materials used for hydrogen production (e.g. materials used in electrolysers)
- Development of new business opportunities for utility companies

**Industrial Products & Construction**
- Development of new business opportunities for assets used for hydrogen production, storage and distribution (e.g. electrolysers, burners, fuel cells)
- Opportunity to decarbonise operations through replacement of on-site diesel generators

**Company perspective**
### Next steps for archetype companies

<table>
<thead>
<tr>
<th>Archetype company</th>
<th>Next steps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel manufacturer</td>
<td>• Connect with potential customers to see whether there is enough demand for green steel and analyse market demand dynamics in scenario study</td>
</tr>
<tr>
<td></td>
<td>• Pilot green steel production and fulfil all technical and HSSE requirements</td>
</tr>
<tr>
<td>Integrated Power &amp; Utility provider</td>
<td>• Analyse the opportunity for power-to-hydrogen-to-power in scenario project</td>
</tr>
<tr>
<td></td>
<td>• Create understanding of applicability of hydrogen in built environment and industry</td>
</tr>
<tr>
<td>Integrated Oil &amp; Gas company</td>
<td>• Analyse the opportunity for power-to-hydrogen-to-power in scenario project</td>
</tr>
<tr>
<td></td>
<td>• Create understanding of applicability of hydrogen in mobility and industry</td>
</tr>
<tr>
<td></td>
<td>• Monitor technology developments of electrolysers and fuel cells</td>
</tr>
<tr>
<td>Natural Gas Transmissions System Operator</td>
<td>• Create understanding of supply and demand developments by connecting to customers and hydrogen providers</td>
</tr>
<tr>
<td></td>
<td>• Pro-actively connect with regulators to ensure the preferred role in hydrogen market</td>
</tr>
<tr>
<td>Industrial B2C company</td>
<td>• Connect with hydrogen suppliers and hydrogen technology providers to understand possibilities to transition to hydrogen</td>
</tr>
<tr>
<td></td>
<td>• Analyse pro's and con's of technology options, electricity, biomass and hydrogen</td>
</tr>
</tbody>
</table>
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Point of view summary
Hydrogen will play an essential role in decarbonising hard-to-abate sectors where electrification has physical limits. It will also play an important role in integrating intermittent renewable electricity, as transport medium and as storage medium.

**Hydrogen demand**
In the short term, hydrogen will be applied first in those sectors that are under societal pressure to decarbonise - likely those closest to the customer. Interest from the market is coming from consumer goods companies in Europe which can obtain a premium from consumers substituting their energy needs in production and distribution. Think about a car from green steel (produced with the use of hydrogen) and hydrogen trucks to distribute consumer products.

In the medium to long term, industrial feedstock and electricity buffering are also likely to be decarbonised by hydrogen, as well as potentially some niches in other mobility applications and the built environment.

In the longer term, the production of ammonia and synthetic hydrocarbon fuels produced from hydrogen will enable the decarbonisation of the hardest to abate sectors such as shipping and aviation.

As long as costs are high in the short run, blue hydrogen will be used to kick-start supply.

**Hydrogen distribution**
 Pipelines, trucks and ships will all play a role in transporting hydrogen. The ability to connect large-scale hydrogen storage for close-to-sea locations makes a pipeline infrastructure favourable, while for other inshore locations its role is to connect supply and demand. Hydrogen distribution via trucks will stay relevant as a dedicated hydrogen network will not be as dispersed as the current natural gas network; import (especially via pipelines and potentially in the future via ships) will be essential as hydrogen demand will likely exceed European domestic hydrogen production.

However, domestically produced hydrogen, especially from low-cost renewable electricity will likely remain competitive against imported hydrogen given the transport (and potential conversion) costs. When the hydrogen demand is really scaled-up, centralised production connected via a pipeline structure to large scale storage becomes favourable over decentralised production, given its ability to provide security of supply.

**Policy perspective**
Given the pressure to decarbonise, Europe will drive the hydrogen industry on the back of COVID-19 recovery packages which will create opportunities across regions such as the manufacturing industry in Asia (e.g. electrolysers, fuel cells, Solar PV, cars, trucks); export of renewable resources in North Africa and the Middle East; and capitalisation of cheap fossil resources (blue hydrogen) in Australia, Canada and Russia.

Blending can be used as a policy instrument to give security of demand to hydrogen suppliers and eliminate the risk of supply shortfalls to hydrogen users. However, now that there is increasing certainty that hydrogen demand will emerge, blending becomes less of a priority.

To enable the cost decrease of electrolysers (and fuel cells) governmental support in the short term is necessary, but in the longer term, hydrogen will likely always be more expensive than fossil fuels and therefore will need policy incentives to be competitive (e.g. carbon taxes or subsidies).

**Company perspective**
To be able to take advantage of the opportunities, companies will need to make strategic bets, build an eco-system, keep learning and pro-actively engage with policy makers.

On the demand side, eyes will be focused on the world’s big brands that are looking for renewable alternatives for their non-electrifiable energy use driven by their green ambitions. This is likely to trigger a hydrogen equivalent of a PPA market which emerged in the electricity market.

On the supply side, consortia of the world’s largest energy companies will drive the development of the hydrogen market given their scale (and subsequent ability to deliver these projects) and their interest in hydrogen as a lifeline for their relevance in a low-carbon world. They will increasingly put pressure on government to enable a hydrogen market to scale.
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As part of its thought leadership on the Future of Energy, Deloitte regularly publishes views on sectors impacted by hydrogen technology, offering clients the latest market insights and cutting-edge perspectives.

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  An exploration of hydrogen fuel cell applications providing in-depth perspectives on fuel cells and compares technologies on:
  - Total cost of ownership (TCO)
  - Energy efficiency
  - Environmental impact

- **Making hydrogen happen**
  Interview with René Schutte, Hydrogen Programme Manager at Gasunie, on the future of hydrogen market in the Netherlands

- **Investing in hydrogen**
  An overview of the developments in value chain, and the business considerations related to it
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