Hydrogen Council
Update, ambition, latest reports

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HYDROGEN COUNCIL

A global CEO-led initiative

Founded at Davos 2017

Grown from 13 to 81 Companies

Representing 6 Million jobs

18 Countries

4 Continents

Representing €18.7 Trillion in revenues

ONE SHARED VISION
A STRONG & DIVERSE GROUP
ENGAGED AT THE HIGHEST LEVEL

“The new hydrogen economy is not just a dream – it’s quickly becoming a reality.”

TAKESHI UCHIYAMADA
Chairman of the Board of Directors, Toyota Motor Corporation

“We are responding to public demand for a clean future by raising the understanding of hydrogen’s key role across different sectors.”

BENOÎT POTIER
Co-Chair of the Hydrogen Council & Chairman and CEO of Air Liquide

“Our gas pipeline and storage system could be used to store excess power in the form of green hydrogen, serving as a long-term storage that a low-carbon energy system will need in addition to batteries and other technologies.”

MARYAM BROWN
President of SoCalGas

“We believe that a hydrogen-powered society is the most viable way to achieve a successful energy transition.”

EUISUN CHUNG
Co-Chair of the Hydrogen Council & Executive Vice Chairman of Hyundai Motor Group

More statements by Hydrogen Council CEOs & executives
WHY WE ARE HERE
Based on real industry data, the Council sees hydrogen as an enabler of the future energy system, growing its role over time and delivering tangible benefits:

**By 2030**

*H₂ scales up to achieve competitiveness*
- Cost falls sharply, making hydrogen a competitive low-carbon option across 22 applications – equivalent to 15% of annual global energy demand

**By 2050**

*H₂ reaches full potential*
- 6 GT of CO₂ abatement annually
- 30 million jobs
- $2.5 trillion market

Sources:
- "Hydrogen, Scaling Up" report, 2017
- "Path to Hydrogen Competitiveness" report, 2020
OUR RESULTS
The Hydrogen Council has accomplished the following:

- Built relationships with key governments
- Established partnerships with international organisations
- Launched Investor Group to engage financial community
- Created a roadmap to competitiveness based on scale & cost
- Quantified hydrogen’s potential contribution to deep decarbonisation

The Council is now working to provide a clear vision to governments on:

- Financing tools *(best practices & innovative ideas)*
- Flagship projects ready for large-scale investment
- Increasing awareness of hydrogen globally
- Policy tools *(best practices)*
The Council creates studies on the use, development and deployment of hydrogen across sectors and industries. These studies further our understanding of how to make the hydrogen economy a reality through concrete data provided by Council members and informed conversations with key stakeholders around the globe. All studies are available here.

- **How hydrogen empowers the energy transition**
  Explores the role of hydrogen in the energy transition and offers recommendations to help accelerate deployment

- **Hydrogen scaling up**
  Discusses the feasibility of our 2050 hydrogen vision and proposes tangible steps to get there

- **Hydrogen meets digital**
  Considers how digitization and hydrogen could complement each other in the energy transition

- **Path to hydrogen competitiveness**
  Presents a cost trajectory for hydrogen to become cost competitive to other low carbon and conventional alternatives by 2030
AN INTEGRATED APPROACH TO COMMUNICATIONS & ADVOCACY

• Boost awareness of and support for hydrogen in the energy transition by creating common messaging to demonstrate hydrogen’s benefits and impacts and show a clear commitment and pathways to scale

• Support advocacy efforts at the highest level through engagement of Hydrogen Council member CEOs and targeted global campaigns
TOOK STOCK OF POLICY AND FINANCING TOOLS

Delivered a comprehensive review of the hydrogen policy landscape and associated financial incentives in selected markets across the world.

This study is available exclusively for members

LAUNCHED COLLABORATION WITH KEY INVESTORS

Brought together financing experts from member companies and key investor organisations to advance development of innovative financing schemes.

The Investor Group is open exclusively to members
MOVING FORWARD
1. Bring together key stakeholders to enable investment & large scale projects
   - Build a business marketplace
   - Stimulate investment

2. Amplify the voice of hydrogen worldwide
   - Understand hydrogen perception & challenges
   - Address issues & leverage new/broader opportunities

3. Guide policymakers toward appropriate regulations
   - Identify key policies & technical recommendations
   - Influence through key organizations

4. Ensure transversal coverage of safety topics globally
   - Closing safety/standards gaps
   - Reputation management and crisis preparedness
Path to hydrogen competitiveness
A cost perspective
20 January 2020
Drivers of renewed interest in hydrogen

- **Stronger push to limit carbon emissions**
  - 10 Years remaining in the global carbon budget to achieve the 1.5°C goal

- **Falling costs of renewables and hydrogen technologies**
  - 80% Decrease in global average renewable energy prices since 2010

- **Strategic push in national roadmaps**
  - 70% Share of global GDP linked to hydrogen country roadmaps to date

- **Industry alliances and momentum growing**
  - 60 Members of the Hydrogen Council today, up from 13 members in 2017

Indicators of hydrogen’s growing momentum

- **10 m** 2030 target deployment of FCEVs announced at the Energy Ministerial in Japan

- **30+** Major investments announced globally since 2017, in new segments, e.g. heavy duty and rail

- **66** Countries that have announced net-zero emissions as a target by 2050

- **55x** Growth in electrolysis capacity by 2025 vs. 2015

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1. Based on 18 country roadmaps announced as of publication
2. Not exhaustive
Leveraging the members’ expertise

Analytical support
McKinsey & Company
For selected technical areas:

E4tech
25,000 Data points

Aggregated and analysed clean team data from 30 companies across 4 regions (EU, US, Japan/Korea, China) on the cost/performance trajectory for hydrogen

40+ Technologies

Built cost trajectories for hydrogen supply chain from production to end use, compared them with cost targets relative to competing technologies, and identified gaps to close them

35 Applications

Modelled all end uses based on detailed total costs of ownership (TCO) across mobility, heating, power, and industrial feedstock applications
In addition, hydrogen can also be used in, e.g.

- **Mobility**: Container ships, tankers, tractors, container ships, motorbikes, tractors, off-road applications, fuel cell airplanes
- **Other**: Auxiliary power units, large scale CHP for industry, mining equipment, metals processing (non-DRI steel), etc.
Depending on the availability of CCS

Hydrogen is most competitive low-carbon solution

Hydrogen is less competitive low-carbon solution

1. Hydrogen is the only alternative and low-carbon/renewable hydrogen competing with grey (optimal renewable or low-carbon shown)
### New hydrogen applications

- Regional train
- Heavy-duty trucks
- Medium-duty trucks
- Vans for urban delivery
- Coach
- Urban bus (long distance)
- Urban bus (short distance)
- Small ferry
- RoPax (large ferry)
- Taxi fleet
- Large passenger vehicle
- SUV
- Mid-size short range vehicle
- Mid-size long range vehicle
- Compact urban car
- Synfuel for aviation
- Forklifts

### Existing hydrogen applications

- Existing network
- New network
- Blending
- CHPs
- Simple cycle turbine
- Combined cycle turbine
- Backup generation
- Remote generation
- Mid-grade generation
- High-grade generation

### Segment

#### Low-carbon competition

<table>
<thead>
<tr>
<th>Segment</th>
<th>Competition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transportation</strong></td>
<td>Battery vehicles, Biofuel (for aviation and large ferry), Electric catenary (trains)</td>
</tr>
<tr>
<td><strong>Heat and power for buildings</strong></td>
<td>Biogas, Natural gas/coal with CCS</td>
</tr>
<tr>
<td><strong>Heat and power for industry</strong></td>
<td>Heat pumps</td>
</tr>
<tr>
<td><strong>Industry feedstock</strong></td>
<td>Natural gas, Coal</td>
</tr>
</tbody>
</table>

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1. In some cases hydrogen may be the only realistic alternative, e.g. for long-range heavy-duty transport and industrial zones without access to CCS
### Cost breakdown of hydrogen applications

<table>
<thead>
<tr>
<th>Application</th>
<th>Percentage of total cost 2020</th>
<th>Cost drop 2020-30, Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy-duty trucks</td>
<td>-45%</td>
<td>-50%</td>
</tr>
<tr>
<td>Large passenger vehicle</td>
<td>-45%</td>
<td>-45%</td>
</tr>
<tr>
<td>Boiler</td>
<td>-45%</td>
<td>-45%</td>
</tr>
<tr>
<td>Gas turbine</td>
<td>-35%</td>
<td>-45%</td>
</tr>
<tr>
<td>Ammonia production</td>
<td>-45%</td>
<td>-45%</td>
</tr>
</tbody>
</table>

### Cost reduction levers to reach target

- **Scale-up of full supply chain Industrialisation of fuel cell and hydrogen tank manufacturing**
- **Industrialisation of fuel cell and hydrogen tank manufacturing Scale-up and utilisation of HRS**
- **Lower-cost hydrogen from renewables Higher pipeline network utilisation due to scale-up of demand**
- **Scale-up of system size and manufacturing of electrolysers for green hydrogen production**

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1. Assumes 50/50 blend of low-carbon and average renewable hydrogen

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**Cost breakdown of hydrogen applications**

**Cost drop 2020-30, Percent**

**Cost reduction levers to reach target**
Capex development of selected technologies over total cumulative production
Indexed to 2020 values (2010 for comparative technologies)\(^1\)

1. Installed base: assuming 50/50 split of electrolysers volume with 50-75% utilisation; assuming 115 kW for PV, 250 kW for buses and 300 kW for trucks; LCOE used for solar cost; batteries in MWh.

Learning rates are highest for emerging technologies (PEM) and high volume FC for passenger vehicles. Learning rates for tanks are ~10-13%, somewhat lower than for fuel cells due to higher materials share of cost.

**Learning rate**

- **2020-30**
  - 13% - PEM electrolysers
  - 9% - Alkaline electrolysers
  - 17% - Fuel cell stack for passenger vehicles
  - 11% - Fuel cell stack for commercial vehicles

**Comparative technologies (2010-20)**

- 35% - Solar
- 39% - Battery
- 19% - Wind onshore

Learning rates are highest for emerging technologies (PEM) and high volume FC for passenger vehicles. Learning rates for tanks are ~10-13%, somewhat lower than for fuel cells due to higher materials share of cost.

SOURCE: McKinsey; IRENA; BNEF; Ruffini & Wei (2018) (learning rates); DoE
**Total cost of ownership (USD cents/km)**

<table>
<thead>
<tr>
<th>Event</th>
<th>Cost Reduction</th>
<th>Production Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scale-up of manufacturing step 1</td>
<td>-18%</td>
<td>200,000 vehicles</td>
</tr>
<tr>
<td>Scale-up of manufacturing step 2</td>
<td>-10%</td>
<td>700,000 vehicles</td>
</tr>
<tr>
<td>Scale-up of hydrogen distribution and retail</td>
<td>-11%</td>
<td>Transition to 2.5x larger HRS and +40% trucking capacity</td>
</tr>
<tr>
<td>Green hydrogen production</td>
<td>-5%</td>
<td>~50 GW electrolysis deployed and transition to ~100 MW production systems</td>
</tr>
</tbody>
</table>

**Insight** | Majority of cost reduction in vehicle capex comes from scaling up to 200k annual production; to reach fully parity with full battery vehicles 600k annual production volumes are required
Breakeven hydrogen costs at which hydrogen application becomes competitive against low-carbon alternative in a given segment (USD/kg)

- Hydrogen is the only alternative for industry feedstock for existing applications.
- Hydrogen is a competitive low-carbon option for space heating where it is competing with heat pumps, e.g., Europe or the US.
- Commercial mobility applications become viable around $3/kg.
- On average, passenger vehicles become viable around $2/kg.
- Hydrogen-based steel production in China breaks even at low-carbon hydrogen costs of $1.9/kg.

1. Regions assessed are the US, China, Japan/Korea, and Europe.
2. Transportation segments breakeven calculated as weighted average.

SOURCE: McKinsey; IHS; expert interviews; DoE; IEA
Breakeven hydrogen costs at which hydrogen mobility applications becomes competitive against low-carbon alternative in a given segment in focus regions\(^1\) (USD/kg at nozzle)

1. Regions assessed are the US, China, Japan/Korea, and Europe
2. No distribution costs for aviation as it can be distributed as liquid fuel

SOURCE: McKinsey; IHS; expert interviews; DoE
Best source of low-carbon hydrogen in different regions

- **Optimal renewable and low-carbon resources**
- **Optimal low-carbon resources**
- **Average low-carbon resources**
- **Optimal renewable resources**
- **Average renewable resources**

**EU**
- Likely to be a high-demand location
- Renewables-constrained due to varying load curves and limited space availability

**Middle East**
- High PV/wind hybrid potential due to good local resources

**Japan/Korea**
- Strategy to scale up hydrogen consumption
- Space and resource constraints; may import hydrogen

**China**
- Large investments in hydrogen economy
- Potential to be self-sufficient

**US**
- Favorable PV and wind conditions

**Chile**
- Favourable PV/wind hybrid conditions

**Australia**
- Potential for large-scale PV farms with favourable load profiles

Demand centres, e.g. EU, North-east Asia, are often constrained for resources, and may not be able to self-supply hydrogen. Countries with complementary load profiles of wind and PV can produce renewable hydrogen at very low prices. Regions like China and the US are both demand centres and have favourable RES.
Cost reduction lever for hydrogen for electrolysis connected to dedicated offshore wind in Europe (average case) (USD/kg hydrogen)

1. Assume 4,000 Nm³/h (~20 MW) PEM electrolysers connected to offshore wind, excludes compression and storage
2. Germany assumed

SOURCE: H21; McKinsey; Expert interview

1.6

90 GW electrolysis deployed

0.2

0.4

0.2

1.3

2.6

2020 Capex Efficiency Other Energy costs 2030

Significant contribution from offshore wind LCOE reduction

Capex decreases ~60% for the full system driven by scale in production, learning rate, and technological improvements
Increasing system size from ~2 MW to ~90 MW
Efficiency improves from ~65% to ~70% in 2030
Other O&M costs go down following reduction in parts cost and learning to operate systems
Additionally, storage may become cheaper (not included)
Energy costs offshore wind LCOE decreases from 57 to 33 USD/MWh, and is assumed to be dedicated to hydrogen production
Grid fees decrease from ~15 to 10 USD/MWh
Load factor of 50%, i.e. ~4,400 full load hours equivalent
Cost of shipping liquid hydrogen across regions, 2030 (USD/kg)

的成本可能因地区而异。这张图展示了液氢运输成本的预期水平

- **Chile to US**: 2.7 USD/kg
- **Australia to Japan**: 3.3 USD/kg
- **Saudi Arabia to Germany**: 3.7 USD/kg
- **Saudi Arabia to Japan**: 3.7 USD/kg

1. Includes liquefaction, terminals, and shipping.

**Cost of shipping**

- LNG: ~USD 12/MWh
- LH2: ~USD 60/MWh

**Source and expected cost level of low-carbon hydrogen in different regions**

- **Distribution**
- **Production**

**SOURCE**: McKinsey Energy Insights
FCEVs are generally better than BEV in use cases that require long tank range due to:

- Lower cost of vehicle due to smaller battery
- Short refueling times made possible by Hydrogen

Longer charging time may imply fleets need to purchase a higher number of vehicles to provide same service.

For fleets developing infrastructure, FC offers additional economies of scale vs. BEV, which scale more linearly.

Ratio of <1 implies FCEV outcompetes BEV on TCO.

**TCO ratio between FCEV/BEV vehicles**

No. average of 5 car segments ranging from small and low usage to large and high usage.

2020 2025 2030 2035 2040 2045 2050

### Year

- **Urban car (A/B) – 200 km**
- **Urban bus – 150 km**
- **Family usage (C/D) – 400 km**
- **Heavy duty truck (long-distance) – 600 km**
- **Taxi fleet (E+) – 650 km**

**SOURCE:** McKinsey Center for Future Mobility
## Cost of refuelling/recharging infrastructure investment and operations over lifetime (Germany use case) (USD/vehicle, thousands)

<table>
<thead>
<tr>
<th></th>
<th>FCEV</th>
<th>BEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower HRS investment due to larger stations</td>
<td>-60%</td>
<td></td>
</tr>
<tr>
<td>Larger stations can serve more vehicles at lower cost</td>
<td>-4x</td>
<td></td>
</tr>
<tr>
<td>Scale-up of compression centres and hydrogen trucking</td>
<td>-50%</td>
<td></td>
</tr>
<tr>
<td>Higher super-charger cost per vehicle</td>
<td></td>
<td>+200%</td>
</tr>
<tr>
<td>Higher utilisation of existing chargers</td>
<td></td>
<td>-2x</td>
</tr>
<tr>
<td>Investment into electricity grid to meet demand</td>
<td></td>
<td>+700%</td>
</tr>
</tbody>
</table>

- **FCEV**
  - Cost: 16.0 (USD/vehicle, thousands)
  - Lower HRS investment due to larger stations: -60%
  - Larger stations can serve more vehicles at lower cost: -4x
  - Scale-up of compression centres and hydrogen trucking: -50%

- **BEV**
  - Cost: 4.7 (USD/vehicle, thousands)
  - Higher super-charger cost per vehicle: +200%
  - Higher utilisation of existing chargers: -2x
  - Investment into electricity grid to meet demand: +700%

**SOURCE:** McKinsey Center for Future Mobility
Household heating (USD/year per household in 2030$^1$ (consumption 10 MWh/year))

1. One household is assumed to consume 10 MWh of heat per year
2. Range due to different state of insulation in building (new vs. old)/grid infrastructure requirements from high heat pump penetration/cost and utilisation of hydrogen network
3. Fuel cost varies by resources available; can be lower or higher than shown here

Hydrogen heating cost depends heavily on the utilisation of existing natural gas pipelines, at a rate of 90%

In contrast, the cost of heat pumps is strongly impacted by the refurbishment cost: low- to no-cost for new builds but substantial for old apartments
<table>
<thead>
<tr>
<th>Alternative</th>
<th>Grid upgrade</th>
<th>Infrastructure cost and charging time</th>
<th>Electricity costs</th>
<th>CO₂ cost</th>
<th>Fuel cost</th>
<th>Low carbon heating alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gas and grid electricity</td>
<td>1.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural gas CHP</td>
<td>1.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat pump and grid electricity</td>
<td>3.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen boiler and grid electricity</td>
<td>2.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen CHP²</td>
<td>2.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. We system (30% electrical efficiency; 80% overall efficiency)
2. Assumes new build house with 18 MWh heat and 7.5 MWh electricity consumption – Note that fuel and electricity costs will vary due to specific local conditions

SOURCE: H21; DoE; Element Energy; SGC Rapport 2014; Eurostat; IEA; Battelle Memorial Institute
Combined cycle turbine 2030 hydrogen vs. natural gas (USD/MWh)

- Hydrogen
- NG US [USD 50/t CO₂]
- NG EU [USD 50/t CO₂]
- NG EU [USD 100/t CO₂]

Flexible capacity (simple-cycle) 2030 hydrogen vs. natural gas (USD/MWh)

- Efficiency of ~60%
- Utilisation of ~75% or 6,500 full load hours annually

- Efficiency of ~40%
- Utilisation of ~25% or 2,100 full load hours annually

1. Assumed hydrogen cost from ATR with CCS in 2030 in the US at USD 1.1/kg, EU/Germany USD 1.7kg, Japan/Korea USD 1.8/kg
2. NG cost of USD 0.12/kg
3. NG cost of USD 0.31/kg
## Hydrogen Supply

### Segment

<table>
<thead>
<tr>
<th>Segment</th>
<th>What needs to be achieved</th>
<th>Required premium to 2030, USD bn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Renewable hydrogen</td>
<td>Renewable production scale up to cost parity with grey in countries with favourable renewables</td>
<td>20</td>
</tr>
<tr>
<td>Low-carbon hydrogen</td>
<td>Low-carbon production at scale until cost parity with grey in 2030</td>
<td>6</td>
</tr>
<tr>
<td>Transportation</td>
<td>Distribution and refuelling station network scale up</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Manufacturing scale-up</td>
<td>20</td>
</tr>
<tr>
<td>Heat and power for buildings</td>
<td>Network and gas boilers upgrades, fuel cost gap bridged</td>
<td>10</td>
</tr>
<tr>
<td>Heat and power for industry</td>
<td>Fuel cost gap bridged</td>
<td>7</td>
</tr>
</tbody>
</table>

### Segment

- **Renewable hydrogen**: Renewable production scale up to cost parity with grey in countries with favourable renewables.
- **Low-carbon hydrogen**: Low-carbon production at scale until cost parity with grey in 2030.
- **Transportation**: Distribution and refuelling station network scale up.
- **Manufacturing**: Manufacturing scale-up.
- **Heat and power for buildings**: Network and gas boilers upgrades, fuel cost gap bridged.
- **Heat and power for industry**: Fuel cost gap bridged.

### Required premium to 2030, USD bn

- Renewable hydrogen: 20 USD bn
- Low-carbon hydrogen: 6 USD bn
- Transportation: 10 USD bn
- Manufacturing: 20 USD bn
- Heat and power for buildings: 10 USD bn
- Heat and power for industry: 7 USD bn

Supporting regulation to embed USD 50/t CO₂ by 2030.
Economic gap with different volume ramp-up scenarios (Large passenger vehicle)

Conservative scenario with slow adoption

Ambitious scenario with faster adoption

Deployment, cumulative sales ‘000 large passenger vehicles:

Differential between FC and BEV fleet fuel cost
TCO of large fuel cell passenger vehicle
TCO of large battery electric passenger vehicle

Economic gap: $70 mn
Economic gap: $45 mn

Deployment, cumulative sales ‘000 large passenger vehicles:
How to accelerate Hydrogen’s competitiveness

Reduce demand uncertainty
Reduce uncertainty, e.g. with long-term offtake agreements, feed-in tariffs, ZEV targets, captive demand

Complementarity
Deploy applications that start ‘virtuous cycles’ and positive spillover effects, e.g. hydrogen infrastructure on airports for refuelling, heating and power

Low-cost production
Push scale-up of hydrogen production, e.g. with ~40 GW of electrolysers, renewable hydrogen can out-compete grey in select areas

Scale
Focus on solutions with biggest ‘improvement-for-investment’, e.g. fuel cells and tanks

Utilisation
Focus on increasing utilisation of assets, e.g. through aggregation of demand and synchronisation of deployment
Path to hydrogen competitiveness
A cost perspective

20 January 2020

Thank you