Hydrogen Study: International H₂ Strategies

A study commissioned by and in cooperation with the World Energy Council – Germany

Dr. Carsten Rolle (WEC), Dr. Uwe Albrecht (LBST), Jens Geier, MdEP
Ludwig-Bölkow-Systemtechnik GmbH (LBST)
World Energy Council – Germany (WEC)
World Energy Council

- Largest international energy organization since 1923
- About 90 country committees
- Independent, no lobbying organisation
- Includes private and public sector, science and NGOs
- Includes all energy sources
- Represents over 90% of the world's energy production
- Develops important analysis and tools for leaders in the energy sphere
- Unique platform for exchange

Mission since 1923: „To promote the sustainable supply and use of energy for the greatest benefit of all people.“
Study objective: analyse and learn from H₂ strategies

What is the national governmental support for H₂ technologies and applications?
How can current experience benefit discussions of the European and German strategy?

- National goals
  - Which countries are supporting H₂ implementation?
  - What are the goals of national governments in supporting hydrogen technologies and applications?

- Target sectors and infrastructures
  - Which sectors, applications, and infrastructure developments are targeted primarily?

- Measures and H₂ requirements
  - Which support strategies or measures are discussed?
  - What are associated requirements (e.g. blue vs. green H₂)?

- Achievements and recommendations
  - What has been achieved and what can be learned from developments so far?
  - What are the conclusions for the EU and DE strategy?

- Understand international trends and developments
- Taxonomy of international H₂ strategies
- Put national activities into context
- Generate a solid basis for upcoming discussions
- Identify major topics for the political discussion
“Hot” strategic hydrogen summer 2020

2017

Japan
Dec 2017

South Korea
Jan 2019

2018

France
Jun 2018

(H₂ deployment plan)

2019

Netherlands
Apr 2020

Germany
Jun 2020

2020

Norway
May 2020

Portugal
Jul 2020

Norway
May 2020

Portugal
Jul 2020

Spain
Jul 2020

2021

EU Jul 2020

France Sep 2020

(Green H₂ strategy)

In preparation:

- Russia
- China
- Morocco

© World Energy Council – Germany | www.weltenergierat.de | 22 September 2020
Overview H₂-strategies and activities (Status: August 2020)

<table>
<thead>
<tr>
<th>Region</th>
<th>No. of countries analyzed</th>
<th>National hydrogen strategy available</th>
<th>National hydrogen strategy in preparation</th>
<th>Support for pilot and demonstration projects</th>
<th>Initial policy discussions</th>
<th>No relevant activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>31</td>
<td></td>
<td>9</td>
<td>11</td>
<td>13</td>
<td>18</td>
</tr>
<tr>
<td>South America &amp; the Caribbean</td>
<td>6</td>
<td></td>
<td></td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asia &amp; the Pacific</td>
<td>11</td>
<td></td>
<td></td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle East &amp; Africa</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>North America</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
</tbody>
</table>

56 countries analyzed in total.

August 2020, World Energy Council, LBST
Overview H₂ strategies and activities
(Status: August 2020)

National hydrogen strategy available
National hydrogen strategy in preparation
Support for pilot and demonstration projects
Initial policy discussions
No relevant activities
Not assessed
Overview H₂ strategies and activities
(Status: August 2020)

National H₂ strategies in place or in preparation in at least 20 countries

By 2025 H₂ strategies are expected to cover > 80% of global GDP
## Main goals of current H₂ strategies per country

<table>
<thead>
<tr>
<th>Strategic goals</th>
<th>EU</th>
<th>DE</th>
<th>NL</th>
<th>FR</th>
<th>ES</th>
<th>IT</th>
<th>UK</th>
<th>NO</th>
<th>CH</th>
<th>UA</th>
<th>RU</th>
<th>JP</th>
<th>KR</th>
<th>CN</th>
<th>AU</th>
<th>CA</th>
<th>MO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce emissions</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Diversify energy supply</td>
<td>✓</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>×</td>
</tr>
<tr>
<td>Foster economic growth</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Support national technology develop.</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Integration of renewables</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Develop hydrogen for export</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>×</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
</tr>
</tbody>
</table>

- ✓ main goal
- (✓) less relevant
- × not addressed

1) Hydrogen imports transit to other counties (e.g. Germany) considered.
2) For Norway, hydrogen is not targeted for direct export, but indirectly through the export of NG with local CCS.
### Main goals of current H₂ strategies per country

<table>
<thead>
<tr>
<th>Strategic goals</th>
<th>Main goals</th>
<th>Less relevant</th>
<th>Not addressed</th>
<th>All strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce emissions</td>
<td>EU, DE, NL, FR, ES, UK, NO, CH, JP, CN, CA, MO</td>
<td>IT, UA, RU, KR, AU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diversify energy supply</td>
<td>EU, DE, ES, UA, JP, CN</td>
<td>FR, IT, NO, RU, KR, AU, CA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foster economic growth</td>
<td>EU, DE, NL, FR, NO, JP, KR, CH, AU, CA, MO</td>
<td>ES, UK, CH, UA, RU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Support national technology develop.</td>
<td>EU, DE, NL, FR, UK, NO, RU, JP, KR, CN, AU, CA, MO</td>
<td>ES, CH, UA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integration of renewables</td>
<td>EU, DE, NL, FR, ES, UK, UA, RU, JP, CN, CA, MO</td>
<td>IT, NO, CH, KR, AU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop hydrogen for export</td>
<td>ES, UA, RU, AU, MO</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Main goal**: Addressed by EU, DE, ES, UA, JP, CN, CA, MO, IT, UA, RU, KR, AU.
- **Less relevant**: Addressed by EU, DE, ES, UA, JP, CN, FR, IT, NO, RU, KR, AU, CA.
- **Not addressed**: Addressed by EU, DE, NL, FR, NO, JP, KR, CH, AU, CA, MO, ES, UK, CH, UA, RU, ES, CH, UA, AU, CA, MO, IT, NO, CH, KR, AU, ES, UA, RU, AU, MO.
## Main goals of current H₂ strategies per country

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce emissions</td>
<td></td>
<td>FR, IT, NO, RU, KR, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
</tr>
<tr>
<td>Diversify energy supply</td>
<td></td>
<td>FR, IT, NO, RU, KR, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
</tr>
<tr>
<td>Foster economic growth</td>
<td></td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
</tr>
<tr>
<td>Support national technology develop.</td>
<td></td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
</tr>
<tr>
<td>Integration of renewables</td>
<td></td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
</tr>
<tr>
<td>Develop hydrogen for export</td>
<td></td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
<td>ES, UK, CH, IT, JP, AU, CA</td>
</tr>
</tbody>
</table>

H₂ is clearly recognised as an essential element of a decarbonised energy system.
Expected hydrogen consumption

Scaling upper $H_2$ demand expected for 2050 in national strategies to global level indicates a potential of up to 9000 TWh (an amount almost as large as half the primary energy consumption of the EU-28)
Hydrogen as an energy vector: International cooperation
In several countries with high energy needs, a substantial share of demand will be served by imports, initially on the basis of bilateral agreements.
### Main target sectors of current H$_2$ strategies per country

| Hydrogen use sectors | EU | DE | NL | FR | ES | IT | UK | NO | CH | UA | RU | JP | KR | CN | AU | CA | MO |
|----------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Industry             | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  |
| Power                | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  |
| Transport            | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  |
| Buildings            | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  |
| Export               | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  |

| ✓ | main sector | ✓ | less relevant | ✓ | not addressed |

1) Hydrogen imports transit to other counties (e.g. Germany) considered.
2) For Norway, hydrogen is not targeted for direct export, but indirectly through the export of NG with local CCS.
## Main target sectors of current H₂ strategies per country

### Hydrogen use sectors

<table>
<thead>
<tr>
<th>Sector</th>
<th>Main Target Countries</th>
<th>Less Relevant Countries</th>
<th>Not Addressed Countries</th>
<th>All Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry</td>
<td>EU, DE, NL, FR, ES, UK, NO, RU, AU, MO</td>
<td>IT, JP, CA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>FR, UK, UA, RU, JP, KR, CN, AU</td>
<td>EU, DE, NL, ES, CA, MO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transport</td>
<td>EU, DE, NL, FR, ES, UK, NO, CH, UA, JP, KR, CN, AU, CA</td>
<td>IT, RU, MO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buildings</td>
<td>JP, KR</td>
<td>EU, DE, NL, FR, UK, UA, RU, AU, CA, MO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Export</td>
<td>ES, UA, RU, AU, MO</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Main target sectors of current H₂ strategies per country

**Hydrogen use sectors**

<table>
<thead>
<tr>
<th>Sector</th>
<th>Main Targets</th>
<th>Less Relevant</th>
<th>Not Addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry</td>
<td>EU, DE, NL, FR, ES, UK, NO, RU, AU, MO</td>
<td>IT, JP, CA</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>FR, UK, UA, RU, JP, KR, CN, AU</td>
<td>EU, DE, NL, ES, CA, MO</td>
<td></td>
</tr>
<tr>
<td>Transport</td>
<td>EU, DE, NL, FR, ES, UK, NO, CH, UA, JP, KR, CN, AU, CA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buildings</td>
<td>JP, KR</td>
<td>EU, DE, NL, FR, UK, UA, RU, AU, CA, MO</td>
<td></td>
</tr>
<tr>
<td>Export</td>
<td>ES, UA, RU, AU, MO</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Initial applications focus on the transport and industry sectors, details depending on national industry basis and GHG reduction targets.
H₂-related requirements: the color of hydrogen

- Renewable and fossil-based hydrogen (with and without CCS) are generally considered viable medium-term sources.
- Methane pyrolysis for hydrogen production is mainly discussed as option in the German and Russian strategies.

• Renewable hydrogen is the most favorable hydrogen quality in the long-term. Various countries considering it the only viable long-term option.
• Fossil based hydrogen with CCS is regarded a feasible hydrogen source in the long-term in a range of countries.

Main hydrogen sources

| EU | DE | NL | FR | ES | IT | UK | NO | CH | UA | RU | JP | KR | CN | AU | CA | MO |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|

Around 2030

Towards 2050

Renewable
Fossil based with CCS
Methane pyrolysis
Fossil*

* In Russia in 2050 mainly based on nuclear power
**H₂-related requirements: the color of hydrogen**

- **Around 2030**
  - Renewable and fossil-based hydrogen (with and without CCS) are generally considered viable medium-term sources.
  - Methane pyrolysis for hydrogen production is mainly discussed as option in the German and Russian strategies.

- **Towards 2050**
  - Various countries considering it the only viable long-term option.
  - Fossil based hydrogen with CCS is regarded a feasible hydrogen source in the long-term in a range of countries.

| Main hydrogen sources | EU | DE | NL | FR | ES | IT | UK | NO | CH | UA | RU | JP | KR | CN | AU | CA | MO |
|-----------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| **Around 2030**       |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| **Towards 2050**      |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |

- Renewable
- Fossil based with CCS
- Methane pyrolysis
- Fossil*  

* In Russia in 2050 mainly based on nuclear power
H₂ market development in 3 major phases (examples from selected countries)

- **Phase I: Market activation**
  - Market ramp-up start (2023) and development (2030)
  - H₂ technology development, demonstration and scale-up
  - Expand H₂ use and supply; Develop & demonstrate tech.
  - Foundation & demo (2025) Large market activation (2030)

- **Phase II: Constant market growth**
  - 10 GW electrolysis until 2035-2040
  - At least one low-carbon industrial cluster
  - Commercialisation of H₂ (e.g. imports, domestic PtG)
  - Commercial mass production (high competitiveness)

- **Phase III: Mature market development**
  - First net-zero carbon industrial cluster
  - CO₂-free hydrogen (renewable and CCS)
  - Economic growth through technological leadership
  - Major global player in hydrogen market

- **Established hydrogen market**
  - GHG neutrality
  - Hydrogen society
  - Hydrogen economy
  - Global exporter

Today | 2030 | 2040 | 2050
---|---|---|---
2023-2030 | 2035-2040 | First net-zero carbon industrial cluster | GHG neutrality
2023-2030 | 2035-2040 | CO₂-free hydrogen (renewable and CCS) | Hydrogen society
2023-2030 | 2035-2040 | Economic growth through technological leadership | Hydrogen economy
2023-2030 | 2035-2040 | Major global player in hydrogen market | Global exporter

© World Energy Council – Germany | www.weltenergierat.de | 22 September 2020
H₂ market development in 3 major phases (examples from selected countries)

- **Phase I: Market activation**
  - Today
  - Market ramp-up start (2023) and development (2030)
  - H₂ technology development, demonstration and scale-up
  - Expand H₂ use and supply; Develop & demonstrate tech.
  - Foundation & demo (2025), Large market activation (2030)

- **Phase II: Constant market growth**
  - 2030
  - 10 GW electrolysis until 2035-2040
  - At least one low-carbon industrial cluster
  - Commercialisation of H₂ (e.g. imports, domestic PtG)
  - Commercial mass production (high competitiveness)

- **Phase III: Mature market development**
  - 2040
  - First net-zero carbon industrial cluster
  - Commercialisation of H₂ (e.g. imports, domestic PtG)
  - Economic growth through technological leadership
  - Major global player in hydrogen market

- **Established hydrogen market**
  - 2050
  - GHG neutrality
  - Hydrogen society
  - Economic growth through technological leadership
  - Global exporter

**Market ramp-up in 3 phases:**
- **Activation** (<2030)
- **Growth** (>2030)
- **Established** (2050)
A dynamically growing market for hydrogen

National H₂ strategies in place or in preparation in at least 20 countries

By 2025 H₂ strategies are expected in countries representing > 80% of global GDP

• Scaling upper H₂ demand expected for 2050 in national strategies to global level indicates a potential of up to 9000 TWh

• In several countries with high energy needs, a substantial share of this demand will be served by imports, initially on the basis of bilateral agreements

• Initial applications focus on the transport and industry sectors

• Green H₂ central to all strategies; blue H₂ mainly plays a role in a transition period before 2050

• Market ramp-up in 3 phases: activation (<2030) ⇒ growth (>2030) ⇒ established (2050)
Emerging opportunities for commercial actors

- Large industrial partnerships will be formed for production and export/import
- Refineries and chemical industry to become the first important large-scale green H₂ markets in the mid-term
- Road transport market (vehicles and trucks) currently stronger in Asia than in Europe
- Green synthetic liquid e-fuels (PtL) can grow into an interesting opportunity with large potential quantities particularly in the aviation and/or maritime sector

Large H₂ production capacities required

A > 40 B€ market alone in the EU until 2030
New policies needed to achieve strategic aims

Most strategies focus on targets rather than measures
Policy development is lagging behind strategic aims
Current measures insufficient to catalyse envisaged strong growth

• Building on earlier successes, policies should focus on commercialisation:
  – **Sectoral quota** stimulate large scale demand
  – Targeted support for establishing comprehensive value chains, providing nuclei for sustainable business
  – Move from CAPEX to **OPEX support**
  – Globally high CO₂ prices help further reduce cost gap
  – Provide long-term perspective and security of investment

• A broadly agreed **green or low carbon hydrogen certification** mechanism is crucial

• **Infrastructure development** requires public financing and central coordination for planning and harmonisation

• Complement all activities with measures supporting **public acceptance**
Danke!
Thank you!
Contacts

Dr. Uwe Albrecht
Managing Director
T: +49 (0)89 608110-31
E: uwe.albrecht@lbst.de

Dr. Jan Michalski
Project Manager
T: +49 (0)89 608110-18
E: jan.michalski@lbst.de

Jan Zerhusen
Senior Project Manager
T: +49 (0)89 608110-23
E: jan.zerhusen@lbst.de

Dr. Carsten Rolle
Executive Director
T: +49 (0)30-2061 6750
E: rolle@weltenergierat.de

Nicole Kaim-Albers
Head of Office
T: +49 (0)30-2061 6750
E: kaim@weltenergierat.de

Maira Kusch
Senior Manager
T: +49 (0)30-2028 1626
E: kusch@weltenergierat.de

LBST · Ludwig-Bölkow-Systemtechnik GmbH
Daimlerstr. 15 · 85521 München/Ottobrunn
Germany
www.lbst.de

World Energy Council – Germany
Gertraudenstraße 20 · 10178 Berlin
Germany
www.weltenergierat.de