Role of hydrogen from renewable (carbon) resources to decarbonize industry, transport and grids

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Created in October 1977

Over 40 R&D&D and analysis tasks

25 contracting parties and 6 sponsors

360 experts involved in tasks, 960 experts publications

930 presentations, 60 task meetings

**CONTRACTING PARTIES**

1. Austria
2. Australia
3. Belgium
4. Canada
5. China
6. Denmark
7. EC
8. Finland
9. France
10. Germany
11. Greece
12. Israel
13. Italy
14. Japan
15. Korea
16. Lithuania
17. Netherlands
18. New Zealand
19. Norway
20. Portugal
21. Spain
22. Sweden
23. Switzerland

**SPONSORS**

1. HyChico (Argentina)
2. Hydrogen Council (International)
3. NOW GmbH (Germany)
4. Reliance (Reliance Industry Limited, India)
5. Shell Global Solutions (International)
6. Southern Company (USA)

- Task 37: Hydrogen Safety
- Task 38: Power-to-Hydrogen and Hydrogen-to-X
- Task 39: Hydrogen in Marine Applications
- Task 40: Energy storage and conversion based on hydrogen
- Task 41: Data and Modelling

**For 2020-2025: ambitious objectives and targets**

• Market Deployment & Pathways to Scale
• Supply Chains
• Renewable H₂ production
• Conversion to energy and chemicals
• Applications In Primary Sectors
• Industrial Use of H₂ in Middle Income Developing countries
• Underground large storage
• Hydrogen from Nuclear
• Low Carbon Hydrogen from fossil fuels

*Secretariat Paris*
Energy mix in 2020

Energy mix (r)evolution takes decades...

<table>
<thead>
<tr>
<th>Source</th>
<th>Oil</th>
<th>Coal</th>
<th>Natural gas</th>
<th>Nuclear</th>
<th>Traditional biomass</th>
<th>Modern Bioenergies</th>
<th>Hydraulic</th>
<th>PV</th>
<th>Wind</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>32</td>
<td>26</td>
<td>22</td>
<td>5</td>
<td>4</td>
<td>6,4</td>
<td>2,5</td>
<td>0,7</td>
<td>0,9</td>
<td>0,5</td>
</tr>
</tbody>
</table>

- Despite an impressive growth, and dramatic cost fall, Wind+PV with a 1300 GW installed Power (+200GW/year), the energy share PV + Wind is only around 1,5%
- Variable Renewable represents more than 60% of new additional Power Plant capacity
- Total Biomass contribution represents 70% of Renewable Contribution to final energy consumption

**Main assumption:** IEA SDS Scenario: Final primary energy demand will remain stable:
- 15280 MToe 2070 for 14600 Mtoe in 2020)
- despite economic growth (3% /Y, GDPx2.5) and
- population growth (9.9 Md Inhabitants by 2050)

- Energy efficiency gain, electrification etc

- Ratio Energy/GDP unit: divide by 2.8 in 2070 (, 2.2% per year (-1.6 % between 1990 and 2020)

- Huge investment needed X4 to X 8 relative to today’s level)

- PV+WIND: x25-x50: 50-100 TW?

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**STEPS: Stated Policies scenarios**
SDS Net Zero Emissions by 2070
SDS 2050: Net Zero in 2050

Source: IEA ETP 2020
Energy mix in 2050-2070

Trajectory to a zero carbon world in 2070 or 2050?

Source: IEA ETP 2020
Assets mainly in Asia and early phase of life but Climate change can’t wait!

Who will finance desinvestment of stranded assets?

Can we retrofit, upgrade infrastructures and assets with Hydrogen or hydrogen-based fuels?

Source: IEA ETP 2020
WEO 2020
Hydrogen: Why Now?
Drivers

*The time is right to tap into hydrogen’s potential to play a key role in a clean, secure and affordable energy future.*

- **Emissions CO2 increasing despite unprecedented deployment of renewables**
  - Hydrogen can help tackle Hard to Abate sectors challenges like Transport and industry: sector couping

- **Electric Renewables like PV, On shore or Off shore Wind at very low costs** (cf Portugal Auction 15€/Mwh, Abu Dhabi 11,3€/kWh)) >> H2 affordable, at market price

- **H2 Technologies mature**
  - 18 000 vehicles, HRS, 24 000 Forklift, 355 000 stationnary system with fuel cells
  - 300 Demo projects Prod and Power to Gas 1-20 MW
  - 80 GW hydrogen production planned
  - 31 countries with national strategy/Action Plan; 262B US $ projects planned for 2030;
  - Fuel cells costs divided by 3 (2015), 10(2005) , lifetime 10 000h- 80 000h
  - Hydrogen gas turbine

- **Hydrogen can enable renewables to provide an even greater contribution.**

- **Hydrogen can be used much more widely, Hydrogen allows flexibility**

- **Hydrogen is versatile, addressing different goals: Climate, Air Quality, Energy Security, Economic growth, Energy access**

- **Hydrogen: optimise existing energy infrastructure assets**
Reminder: 4 main usages for Low Carbon Hydrogen

1. **Power to Power**
   - Electrolysis
   - Turbine
   - Fuel cells

2. **STORAGE**
   - Renewables integration

3. **INDUSTRY**
   - Heat or chemical properties
   - Refineries, ammonia, methanol, HMD etc

4. **MOBILITY**
   - Electric power train
   - Buildings, Cities Gas network

5. **New applications**
   - Biofuels, synfuels, NH₃, steel and metals, cement etc

6. **Existing applications**
   - Hydrogen injection in gas grid, turbine etc

7. **Combustion**
   - CHP Combined Heat and Power

8. **Turbine, ICE**
   - CH4/H₂ gas Fuel cell

- H₂ gas Fuel cells
- Storage on board
- Dedicated infrastructure

Embedded in lique fuel: ammonia, biofuels, synfuels
Gas: Methane Hydrogen...
“Hard to abate” sectors can be indirectly electrified through Hydrogen

High Renewable Power share of the Power System

- Need for seasonal energy storage
- Excess power vs demand at certain periods
- In some zones, not enough capacity with HV power lines

Strong decarbonization of the industry through electrification

- Not all industrial processes can be directly electrified

IEA Energy Technology Perspectives 2020

“Hydrogen extends electricity’s reach”.

- Steel, ex. H2 Directly Reduced Iron (DRI)
- Chemicals, ex. e-Methanol
- Heavy duty transport, ex. e-Fuels
- Aviation, ex e-Kerosene
Sector Coupling = Indirect Electrification through Hydrogen

Also called Energy Systems Integration

**Power-to-X**
1. Electrolysis for the production of hydrogen
2. Heat pumps for the production of heating or cooling networks

**X-to-Power**
3. Generation from biogas or synthetic methane
4. Generation from hydrogen
5. Electricity from cogeneration

Source: RTE
2050/2070 target: Role of Hydrogen in energy scenarios:
Between 10 and 20 % in final energy consumption

Scenario: Hydrogen Council (World)
- 18% of final energy demand
- 6 Gt annual CO₂ abatement
- $2.5 tr annual sales (hydrogen and equipment)
- 30 m jobs created

IRENA Forecast
(World Energy Transition Outlook 2021)
- Total Final Energy Consumption: 348 EJ
- Renewable share in hydrogen: 66%
- Renewable share in district heat: 90%

Scenario IEA ETP SEPTEMBER 2020
- 13 % Final energy demand

European Union Forecast: 14 %
What does Scale-up mean?

**Role of Hydrogen in energy scenarios:**
*Between 10 and 20 % in final energy consumption*

- Renewables PV and Wind: 1 300 GW deployed
- Climate change target: X by 30 to 60
  - From 1.3 TW to 50-100 TW (100 000 GW)
  - Investment from 380B $/year (2020) to 1 600B$/year 2030
- **Hydrogen in 2050 ou 2070**
  - 15 % final energy consumption
  - IEA: 420 Millions tons (**x6 today’s production**)  
  - Electrolyser capacity 4 000 GW (4 TW or **3,4 TW according to IEA**) full time equivalent
  - IRENA near 250 M tons, 5 TW electrolyser needed
  - BNEF between 180 and 700M tons
  - PV or wind park needed: between 12 and 30 TW
  - Nuclear needed: 5 TW

- **Hydrogen in 2030: objectives**
  - World 40 millions tons (equivalent 270 GW full time)
  - Europe: 40 GW ou 2x40 GW electrolysers near 7 millions tonnes
  - France 6 GW 1 M tons >> 20-40 GW Wind PV or 6-8 GW nuclear
Basic of Hydrogen costs
Production, transport, distribution & storage (1)

Hydrogen production costs, 2018

- Natural gas
- Natural gas w/CCUS
- Coal
- Renewables

CO2 100$/ton

Colors of Hydrogen
For pedagogic usage only

- Blue Hydrogen: Hydrogen from natural gas with CCS
- Turquoise Hydrogen: Hydrogen from natural gas cracking C+H2
- Yellow or red Hydrogen: Hydrogen from nuclear energy (electricity and/or heat)
- Green Hydrogen: Hydrogen from Renewables (PV, Wind, biomass, solar, hydraulic)
- By-product Hydrogen: Hydrogen as a by-product of a mainstream chemical process

Source IEA, 2019
The future of Hydrogen, Webinar

• Low carbon Hydrogen costs are country-dependent, costs of local energy, local electricity cost, existence of CCS possibilities, CO2 price, and also distance of an end-use application, industrial H-based process etc...
1€/Kg (from Renewables) is reachable at 2050 cheaper than blue hydrogen premisses of a new geopolitic of Energy/international trade

- Combining
  - Electricity at 10-15 us$/MWh
  - Electrolyser efficiency 76%
  - Load factor > 4000h/y
  - Electrolyser capex 100-150 US $/kW
  - Improvement of electrolyser technology (efficiency, size, etc.)
  - Hydrogen carrier...

- Limiting factors
  - Critical materials Pt Ir Sc Y La Ce Zr Gd)
  - Plus PV Wind critical material Cu ...
  - Land use: 1 TW= 10 000 km2
  - Long distance transport infrastructure

Hydrogen costs from hybrid solar PV and onshore wind systems in the long term

Source: Irena, Green Hydrogen costs 2020 report

Source IEA, 2019
The future of Hydrogen, Webinar

Source: Irena, Green Hydrogen costs 2020 report
A wide range for infrastructure, transport, distribution and storage costs

<table>
<thead>
<tr>
<th>Elements</th>
<th>New pipe line Long distance (5000t/d)</th>
<th>Adapting existing pipe lines Long distance (5000t/d)</th>
<th>Salt cavern storage</th>
<th>Liquid H2, NH3 LOHC Hydrogen carrier</th>
<th>Local pipe line (100t/d)</th>
<th>Regional distribution (50-300km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost/Kg H2* 2020-2030</td>
<td>0,2 $/1000km</td>
<td>0,1 $/1000 km</td>
<td>0,25-0,5 $/cycle month</td>
<td>3-7 $</td>
<td>0,1 $ (100km)</td>
<td>1-3,5 $</td>
</tr>
<tr>
<td>Cost/Kg H2* 2050</td>
<td>0,1 $/1000km</td>
<td>-</td>
<td>0,1 $/cycle month</td>
<td>1,5-2 $</td>
<td>0,06$</td>
<td>0,6-1,5 $</td>
</tr>
</tbody>
</table>

- What can we conclude from this table to date:
  - Long distance Pipe line option appears the less costly and less uncertain option when feasible No Regret Option
  - Pipe line option are between 2 to 3 times less costly than HV lines to carry energy (€/GWh) and more acceptable by citizens (footprint, landscape etc)
  - Pipe line+massive storage infrastructure provide guarantee of supply H24 for both H2 supplier and customer, allows H2 producer to optimize H2 costs
  - Huge R&D effort needed on LH2 and hydrogen carriers (overseas option) to increase efficiency and decrease costs
  - « Last mile » distribution (local 0-300km) is one of the most important item of expenditure

* Sources: Hydrogen council, IEA, « European Hydrogen Backbone, june 2020 », BNEF-IGU-Snam Global Gas report 2020, DOE targets, private source,
Hydrogen from biomass is not seen as a major source of hydrogen

- Near 80 GW of electrolyser from renewable (and nuclear in some case) in the pipe to date in Australia, Chile, Europe, Russia
- Only a few projects on biomass (Haffner Energy in France with gasification)
- A lot of Local project (wastes, biomass) with fermentation and reforming (example VaBhyoGas in Albi)
Low Carbon Hydrogen from carbon

Hydrogen from carbon
- Fossils
  - reforming + CCS
  - Methane pyrolysis: example Monolith
- Hydrogen from fermentation and biomethane reforming
- Hydrogen from biomass: pyro-gasification
  - example: Haffner
- 3rd generation biofuels
  - Micro-algae, bio-inspired

• Pros:
  - Attractive Costs
  - High efficiencies and high load factor
  - Address wastes + biomass
  - Integration in Bio-economy or Circular carbon economy

• Cons or Challenges:
  - Low availability or competition with other (energetic) usage of biomass
  - Low TRL for some processes
Hydrogen for/with carbon
Hydrogen carrier or final fuel?

- Hydrogen for/with carbon
  - E-fuels: CCU CO2 from fossil or biomass
    - Methanol
    - All hydrocarbons
    - Synthetic methane
  - Biofuels +
    - 2nd generation biofuels enriched with H2

- Pro
  - Flexibility and energy density of liquid fuels (for aeronautics...)
  - Compatibility with existing infrastructure
  - More suited for existing assets
  - Specifically industry-oriented or power oriented

- Cons/challenges
  - Additional step
  - Competition with pure hydrogen (Fuel cells or turbine
  - Competition with ammonia
  - Internal combustion engine banned
  - Air quality issues
What could be the limiting factors or other factors for hydrogen from Renewables?
A opportunity for hydrogen from biomass?

• Critical or current material, circular economy

• Security of supply and geopolitics

• Land use and social acceptance

• Technological breakthroughs

Initiate a new task for international collaboration in the frame of IEA Hydrogen + Bioenergy TCPs to explore the advantages of hydrogen from biomass?

Cumulative demand 2050 compared to proved reserve in 2010

<table>
<thead>
<tr>
<th>Material</th>
<th>Scénario 4°C</th>
<th>Scénario 2°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobalt</td>
<td>62.2 %</td>
<td>93.6 %</td>
</tr>
<tr>
<td>Cuivre</td>
<td>82.7 %</td>
<td>96.1 %</td>
</tr>
<tr>
<td>Lithium</td>
<td>17.1 %</td>
<td>26 %</td>
</tr>
<tr>
<td>Nickel</td>
<td>48.5 %</td>
<td>56.6 %</td>
</tr>
<tr>
<td>Terres rares</td>
<td>1.6 %</td>
<td>3.8 %</td>
</tr>
</tbody>
</table>

Land usage: Nuclear 4-10 ha/TWh, PV 500-800 ha/TWh
Concrete and steel: A nuclear plant need 8 to 10 times less concrete and 10 to 20 times less steel per TWh
Thank you for your attention

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New Hydrogen roads and International Trade of low carbon Hydrogen

- **Main Bottlenecks**
  - Cost and efficiency of hydrogen carrier for overseas transport
  - Hydrogen carrier must be more energy intensive at Export port than in Import Port
  - International regulation and framework
  - Renewables projects at scale will take decades

- **Producing and exporting hydrogen-based products used as such (avoiding one transformation step)**
  - Ammonia for direct combustion
  - E-fuels for ICE and turbines

- **What will be the trade off between pure H2 usage and indirect usage?**

*Source Hydrogen Council, Hydrogen Insights 2021*