Hydrogen from Renewable Power
Technology outlook for the energy transition

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Context: the Global Energy Transformation

- **Paris Agreement**: Average global temperature to “well below 2 degrees”

- Presently, **no economically viable options** to decarbonize one third of energy-related emissions (mostly from the energy-intensive industry sectors and freight transport).

- **Hydrogen could be the “missing link”**: supply renewable energy to sectors for which electrification is otherwise difficult, such as transport, industry and processes that require high-grade heat
Hydrogen today

Hydrogen is used at scale as a feedstock in industry

- Global demand (2015): 8 exajoules (EJ)
  - Largest consumers: Ammonia and Oil Refineries
  - Lower share: iron and steel, glass, electronics, chemicals and bulk chemicals
- Current hydrogen production is almost entirely fossil-fuel based
- Around 4% by electrolysis
Decarbonising Transport:

- **Fuel cells**
  - FCEVs are complementary to BEVs in decarbonising road transport
  - Technical maturity within the next 5-15 years
  - Suitable for road, rail and maritime

- **Drop-in synthetic liquid fuels**
  - Complementary to biofuels
  - Mainly aviation

Decarbonising Industry:

- Replace fossil-fuel based feedstocks
- Applications in iron&steel, petrochemical, refining
- Potential in high-temperature processes

Decarbonising the gas grid:

- Capture low electricity prices on the market
- Provide seasonal storage for solar and wind
- Provide grid services from electrolysers
Hydrogen Pathways

• **Short-term:**
  o Electrolyser operators need sufficient guaranteed take-off of hydrogen production for mobility or industrial demand

• **Medium-term:**
  o Additional revenue streams from ancillary services market for PEM electrolysers
  o Injection into the gas grid
    + Run at high load factors
    - May not have enough hours in a year with low-enough prices in electricity markets

• **Long term**
  o Carrier for linking the best renewable resources from remote locations to the global energy market
  o On-site production for energy intensive industry from electricity grid with high shares of renewables
## Green hydrogen production pathways

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<th>Most established</th>
<th>Less mature</th>
<th>Photo-catalysis</th>
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<td>Water electrolysis</td>
<td>Biomass gasification and pyrolysis</td>
<td>Supercritical water gasification of biomass</td>
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<td>Steam reforming of biomethane/biogas with/without CCS and CCU</td>
<td>Thermochemical water splitting</td>
<td>Combined dark fermentation and anaerobic digestion</td>
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### Diagram:
- **Sun Irradiation**: Thermochemical water splitting, Photo-catalysis
- **Biomass and biogas**: Supercritical water gasification, Pyrolysis & gasification, Anaerobic digestion & dark fermentation, Steam reforming
- **Renewable Electricity**: SOEC electrolyzers, PEM electrolyzers, ALK electrolyzers
- **Feedstock used**: Applied research / Prototype / Demonstration / Commercial
Hydrogen production via electrolysis – grid connected

- **Alkaline**
  - Mature
  - Lower Capex
  - Lifetime is twice as PEM
  - Less flexible
  - Mostly active as buyer in **day-ahead market**

- **Proton Exchange Membrane (PEM)**
  - Approaching commercial stage
  - Higher Capex
  - Lifetime is shorter
  - Can provide ancillary services
  - Can **follow real time** prices in intra-day and balancing markets

Connected to the grid (ALK or PEM)
- Low load factors yield a high LCOH
- At higher load factors, electricity prices are the determining factor in the LCOH
Hydrogen production via electrolysis – off-grid solar and wind

- Requires **PEM** flexibility to be able to follow variations in VRE generation

- Possible to access lowest-cost electricity from best renewable resources, avoid grid cost

- **Low** capacity factor for electrolysers is a significant challenge

- Cost reductions in solar, wind and electrolysers will increase competitiveness over time

- Guaranteed to be 100% RE

- Requires supply chain to transport H2 to demand, or relocate demand/manufacturing (e.g. as happened in the past for aluminum)

- Production cost:
  - Current: 5–6 $/kg - Target: 1–3 $/kg

* Bubble size proportional to load factor of electrolyser, depending on full load hours of VRE
Hydrogen potential by 2050

Global Potential by 2050

• **Technical potential** is significant

• **Economic potential** will depend on cost reductions and competition with other options, with estimates in the order of 10-100 EJ

• Switching current feedstocks from fossil fuels to RE has a potential of 10 EJ today

*(chart excludes feedstocks)*
Decarbonizing the gas grid

**Short-term:** Injection could support early-stage hydrogen infrastructure development and economies of scale

- **Up to 10-20%** blend: minor Investments
- **Greater than 20%**: significant changes in Infrastructure and end-use applications

**In the long-term:** Store large amounts of renewables, while decarbonizing gas

- **Large capacity of gas network** EU natural gas grid stores around 1200 TWh of energy
- **Enable further deployment of solar and wind** into continental power grids where renewable resources are close to gas grid
- **Possible creation of a global market** tapping into best remote/off-grid renewable resources
Deploying the hydrogen supply chain

- Achieving economies of scale for hydrogen production is key
- Beyond a certain consumption threshold, on-site production is the only viable production option
- Investment in large-scale production capacities can only be justified today if a large portion of the production is sold through long term contracts

The historic deployment pattern could serve as a blueprint for future investments in the hydrogen supply chain

- Start with investments focused on multi-megawatt capacities for large consumers
- Second phase, new production facilities can be leveraged to become “semi-centralized” or “centralized” supplying smaller local consumers
- Regions with best renewable resources can export hydrogen globally (e.g. see current LNG market growth)
Recommendations for policy makers

- **Technology is ready, costs need to decrease significantly**
- **Initial efforts**
  - Large-scale applications with limited investment requirements to **trigger cost reductions through scale**
  - Large industry (refineries, chemicals facilities, etc) and heavy-duty transport, difficult to decarbonize without hydrogen from renewables
- **Necessary conditions for scale-up**
  - Stable and supportive policy framework to encourage investments
  - Instruments aimed at final consumers can **trigger demand and justify** investment in infrastructure
Thank you!