CSLF Task Force on Hydrogen production and CCS
Results and recommendation from Phase 0

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Norway
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Hydrogen production and use around 2015

- Electrolysis: 48%
- Natural gas: 30%
- Oil: 18%
- Coal: 4%

Total 55 Mt H₂/year

- Ammonia production: 53%
- Refining: 20%
- Methanol production: 20%
- Other uses: 7%

Total 55 Mt H₂/year

“Other” includes reducing agency in industry and 500 – 1000 demonstration vehicles (cars and buses)

Main use: Industrial feedstock
Hydrogen from fossil fuels (and biomass) feedstocks or water

- Steam reforming (SMR, most common for natural gas)
- Partial oxidation (POX, most common for liquids like oil)
- Auto-thermal reforming (ATR, a combination of non-catalytic POX and SMR), and gasification (used for solid fuels like oil and biomass)

Hydrogen from water splitting: Electrolysis
Several organisations and individuals have tried to make predictions of new future uses and applications of hydrogen. The applications include (e.g. Hydrogen Council, 2017; IEA, 2015; IEA hydrogen, 2017):

- Enabling large-scale renewable energy integration and power generation
- Acting as a buffer to increase energy system resilience
- Decarbonizing transportation
- Decarbonizing industrial energy use
- Helping to decarbonize building heat and power
- Providing clean feedstock for industry.
Hydrogen production – future perspectives
Envisioned use 2050

Forecasts hydrogen demand 2050 (After Hydrogen Council, 2017)

<table>
<thead>
<tr>
<th>EJ/year</th>
<th>2015</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power generation, buffering</td>
<td>8</td>
<td>78</td>
</tr>
<tr>
<td>Transportation</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Industrial energy</td>
<td></td>
<td>22</td>
</tr>
<tr>
<td>Heat and power buildings</td>
<td></td>
<td>16</td>
</tr>
<tr>
<td>New feedstock (CCU, DRI etc)</td>
<td></td>
<td>11</td>
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<tr>
<td>Industrial feedstock</td>
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<td>9</td>
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<td>10</td>
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Note: 78 EJ equivalent to 550 Mt H₂

Large uncertainties: ”World Energy Outlook – H₂” from 2006: 42 EJ or 300 Mt H₂ per year
Some numbers

- 5-10-fold increase in hydrogen demand by 2050
- Producing 550 Mt H$_2$ (78 EJ) by electrolysis requires 27 500 TWh (100 EJ) electricity
- World electricity production (envisioned in IEA ETP 2017)
  - 2014 (all sources) ≈ 24 000 TWh
  - 2050 (renewables) ≈ 36 000 TWH (2DS)
  - 2050 (all sources) ≈ 42 000 TWh (2DS)
- CO$_2$ emissions from reforming
  - 8-9 t CO$_2$/t H$_2$ for natural gas
  - 10-11 t CO$_2$/t H$_2$ for coal gasification
  - 300 – 550 Mt H$_2$/year → CO$_2$ emissions in range 2.5 – 5.0 Gt/year from reforming
- Numbers uncertain but indicate no single silver bullet to get carbon free hydrogen
- By 2050 other technologies may be available (too late?)
Hydrogen and CCS Canada

- Hydrogen production and CCS implemented
  - Quest project, Alberta: 1.08 Mt CO\textsubscript{2}/year captured from bitumen upgrader by use of chemical solvent and stored in saline aquifer
- Northwest Sturgeon project, Alberta, under construction.
  - 1.2 Mt CO\textsubscript{2}/year from bitumen refinery. Physical solvent system.
  - To be transported by Alberta Trunk Line for EOR
- RD&D
  - Capture technologies
Hydrogen Canada
Other aspects

• Hydrogen activities strongly linked to fuel cell development and applications
• Hydrogen and renewables projects include
  – TUGLIQ Energy, Hydrogenics. Lambton Energy Research Powertec Labs
• Hydrogen value chain, including life cycle costs and carbon footprint
Hydrogen and CCS
China

• Coal indirect liquefaction plant in Erdos, Xinjiang:
  – 100 000 tons CO$_2$/year captured and injected in saline formation

• Refinery: Sinopec Maoming Petrochemical Company:
  – 100 000 tons CO$_2$/year captured and used in food industry

• Lihuayi Group Co, Ltd. Heavy oil and hydrogenation project
  – CO2 partially used for polycarbonate synthesis
Hydrogen and CCS
European Commission

- ACT project Elegancy see separate presentation at this meeting
- Zero Emission Platform (ZEP) report on hydrogen and CCS
- Magnum projects, see under Netherlands
Hydrogen Japan

• Already a sizeable hydrogen economy
  – 200 000 “Ene-farms”, 1 800 FCVs, 100 hydrogen refuelling station
  – Most hydrogen from natural gas or LPG, not CO₂-free

• Hydrogen and fuel cells roadmap, three phases
  1. Expansion of hydrogen for Ener-farms
  2. Expansion of hydrogen for power and establishment of hydrogen supply systems
  3. Establishment of CO₂-free hydrogen supply systems

• Phase 3 includes hydrogen and CO₂ (power-to-gas)

• METI CO₂-free hydrogen report looks at
  – Options of power-to-gas technologies, i.e. hydrogen by water electrolysis with renewable power
  – Low-carbon hydrogen transportation options;
  – Methodologies for evaluating a degree of carbon-free use of hydrogen in a life cycle and mechanisms to enhance the use of carbon-free or low-carbon hydrogen.
Hydrogen and CCS
Japan

- Two NEDI projects
  - Hydrogen from steam reforming of natural gas in Brunei, with future capture of CO$_2$ from SMR
  - Hydrogen from Australian ignite, with future capture of CO$_2$

- Tomokomai: Amine scrubbing of PSA off-gas in hydrogen plant, CO$_2$ to offshore geologic storage
Hydrogen and CCS in the Netherlands

- Statoil, Vattenfall and Gasunie have a Memorandum of Understanding (MoU)
  - Evaluate the possibilities of converting Vattenfall’s gas power plant Magnum in the Netherlands into a hydrogen-powered plant.
  - Explore the possibility of combining hydrogen production with Carbon Capture and Storage (CCS), which can open up new business opportunities.
- h-Vision Rotterdam;
  - Coal fired power plant with a gas turbine for firing hydrogen.
  - Natural converted to hydrogen
  - CO₂ will be transported to the North Sea; all is taking advantage from the work done at the ROAD project.
- Berenschot study; this is merely still a study on conversion of NG to hydrogen and the opportunities to use it.
Hydrogen and CCS Norway

- Statoil: Large Scale Hydrogen Solutions
  - Power generation, heat; maritime
- Institute for Energy Technology (IFE)
  - Emerging technolgies for reforming
    - sorption-enhanced reforming
  - Modelling aspects of hydrogen infrastructure
  - Hydrogen and heavy duty transport
Hydrogen and CCS Norway

- Sintef
  - Elegancy
  - Hyper - Large-scale hydrogen co-production and liquefaction from renewable and fossil energy sources in Norway
  - Membrane-enhanced H$_2$ production with CCS
Hydrogen
Saudi Arabia

- SABIC: Main focus on hydrogen from water
- SABIC started hydrogen production from renewables in 2013.
Hydrogen and CCS
United Kingdom

• Leeds H21 (Northern Gas Networks)
  – Convert local gas grid in the city of Leeds to hydrogen
  – Hydrogen production planned to be with SMR+CCUS in Teesside
  – Alternative low carbon hydrogen production system utilising ATR/Ammonia and CCS

• Liverpool-Manchester Hydrogen cluster (Cadent Gas)
  – Low-carbon hydrogen through reformation of methane in the Ellesmere Port area
  – Supply low-carbon hydrogen to 10-15 energy intensive industrial users in the Liverpool-Manchester area
  – Blend hydrogen in to the local gas distribution network up to 10-15%
High hydrogen (ETI)
- Advancement of the safe design and operation of gas turbines using hydrogen-based fuels
- Identifying the bounds of safe design and operation
- Aim to increase the range of fuels that can be safely used in power and heat generating plant

Flexible hydrogen power generation (ETI)
- Increase the understanding of the economics and potential use of energy systems involving low carbon hydrogen production, storage and flexible turbine technology. Supply low-carbon hydrogen to 10-15 energy intensive industrial users in the Liverpool-Manchester area

Salt cavern
- Examine the potential for storing
Hydrogen and CCS
United States

• Not investigating hydrogen production with CCS specifically
  – Several of DoE R&D program activities can support its development as an option.
  – E.g. Port Arthur is hydrogen production with CCS
    • Demonstrating a state-of-the-art system to concentrate CO₂ from steam methane reforming (SMR) hydrogen production plants
    • CO₂ is used for EOR
• Co-producing H₂ in IGCC with carbon capture
• Pre-combustion capture with novel technologies for the separation of hydrogen from CO₂ in synthesis gas streams
• Significant activities on hydrogen and fuel cells (Hydrogen and Fuel Cells Program)
Hydrogen and CCS
IEAGHG

• Key recent activities include:
  – Techno-Economic Evaluation of HyCO Plant Integrated to Amonia/Urea or Mathanol Production with with CCS
  – Reference data and supporting literature reviews for SMR based hydrogen production with CCS
  – Currently completing a report on the 4 years of operational experience of operation of the Air Products, Port Arthur CCS demonstration project
  – Flexible operation of CCS power plants; one key option is the use of integrated gasification combined cycle with physical absorption of CO₂ producing a hydrogen rich steam that can either be fired through the turbine or stored
Hydrogen and CCS
IEAGHG

• Key recent activities include:
  – Flexible operation of CCS power plants; IGCC with physical absorption of CO$_2$ producing a hydrogen rich steam that can either be fired through the turbine or stored
  – Co-operating with the Norwegian ACT Project Elegancy led by SINTEF
  – Contributed several studies, including
    • SMR based H2 production
    • business cases models for a CCS infrastructure network, a component of the H2/CCS value chain
    • blending hydrogen into natural gas pipelines for use in domestic use
Regional and international hydrogen initiatives

<table>
<thead>
<tr>
<th>Initiative</th>
<th>Objective</th>
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<tbody>
<tr>
<td>Hydrogen Council</td>
<td>Foster high level support for hydrogen technology and see that hydrogen technologies play an essential role in global energy transitions</td>
</tr>
<tr>
<td>IEA Hydrogen Technology Collaboration Program (TCP)</td>
<td>Accelerate hydrogen implementation and widespread utilization to optimize environmental protection, improve energy security and promote economic development internationally</td>
</tr>
<tr>
<td>International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE)</td>
<td>Facilitate and accelerate the transition to clean and efficient energy and mobility systems using fuel cells and hydrogen (FCH) technologies</td>
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<tr>
<td>European Hydrogen and Fuel Cell Association (EHA)</td>
<td>Promote the role of hydrogen in the energy system in Europe</td>
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Regional and international hydrogen initiatives

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<td>Certifhy</td>
<td>Create the path forward for a concrete and actionable guarantee of origin (OG) scheme with pilot demonstration of the hydrogen OG scheme</td>
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<tr>
<td>Fuel Cells and Hydrogen Joint Undertaking (FCHJU)</td>
<td>To develop by 2020 to the point of market readiness a portfolio of clean, efficient and affordable solutions that fully demonstrate the potential of H2 as an energy carrier and fuel cell as energy convertor</td>
</tr>
<tr>
<td>Mission Innovation</td>
<td>New Challenge on hydrogen??</td>
</tr>
<tr>
<td>Numerous other regional</td>
<td>Many related to hydrogen, fuel cells and transport</td>
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TRM and hydrogen

• There are few, if any, technical barriers to CO$_2$ capture associated with large-scale hydrogen production.

• However, continued research, development, and innovation for improved and emerging technologies for clean hydrogen production should be encouraged, including the following:
  – Process intensification: more compact, efficient, and economic solutions, such as membranes and technologies for catalytic reforming of the fuel and separation of H$_2$ and CO$_2$.
  – Process integration in the co-production of H$_2$
    • Electricity and heat production.
    • In industrial processes where H$_2$ or H$_2$-enriched natural gas can replace fossil fuel-based feedstock.
Findings (include findings from open literature)

- Hydrogen production with CCS already implemented
- Much activity on role of hydrogen, hydrogen demand, and hydrogen and fuel cells, particularly in the transport sector
- Some activities on improving efficiency of electrolyzers and on alternative ways of water splitting
- Much activity on technologies for CO$_2$ capture based on adsorption, absorption and membranes
- Important but less activities on applications to H$_2$ production with CCS
Summary

• TRM recommendations related to CO$_2$ capture technologies may need some follow-up
• Value of task force limited, given efforts in
  – Projects like Elegancy
  – Hydrogen in task force on industrial CCS
• Workshop on hydrogen production with CCS would be useful.
  – Join forces, IEAGHG, IEA HIA and GOTCP, others?
  – Could be held with Task Force on industrial CCS where hydrogen and hydrogen use in industry receive attention