Carbon Sequestration leadership forum

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

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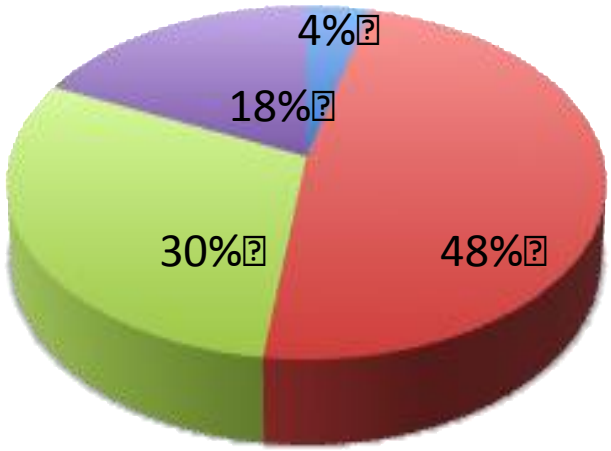
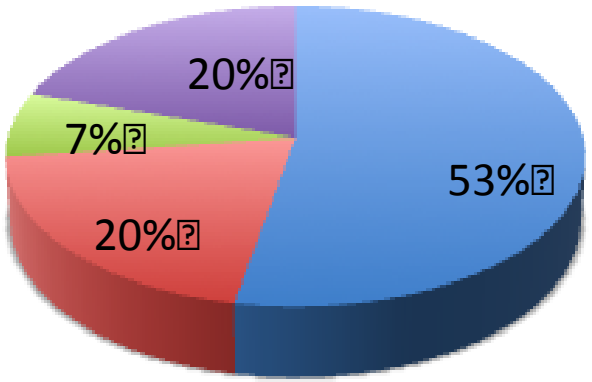
Hydrogen production and use around 2015



Total 55 Mt H_2/year



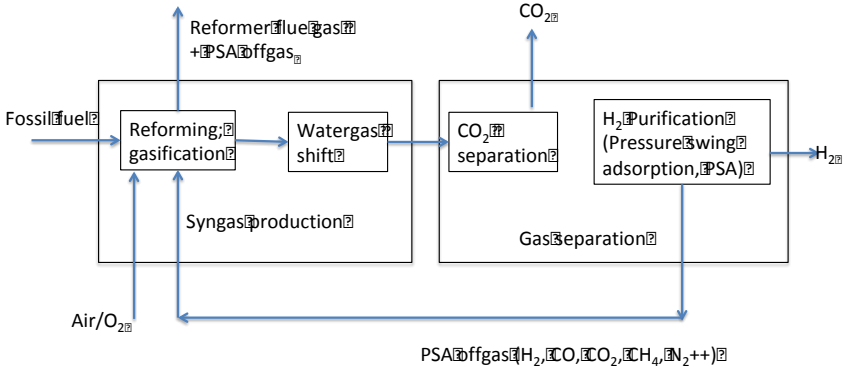
Total 55 Mt H_2/year

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

Main use: Industrial feedstock

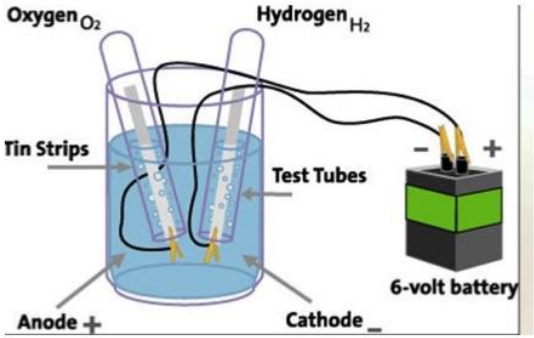
Hydrogen from fossil fuels (and biomass) feedstocks or water

- 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

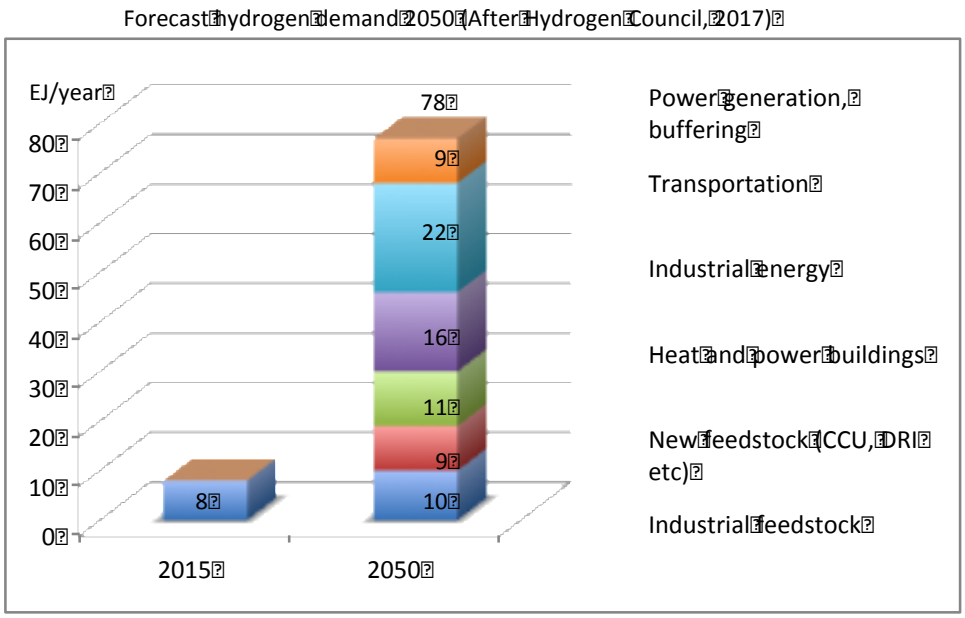


Hydrogen production – future perspectives

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



Note: 78 EJ equivalent to 550 Mt H_2

Large uncertainties: ”World Energy Outlook – H2” from 2006: 42 EJ or 300 Mt H_2 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_2/year captured from bitumen upgrader by use of chemical solvent and stored in saline acquifer
- Norhtwest Sturgeon project, Alberta, under construction.
  - 1.2 Mt CO_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, Xinjang:
  - 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

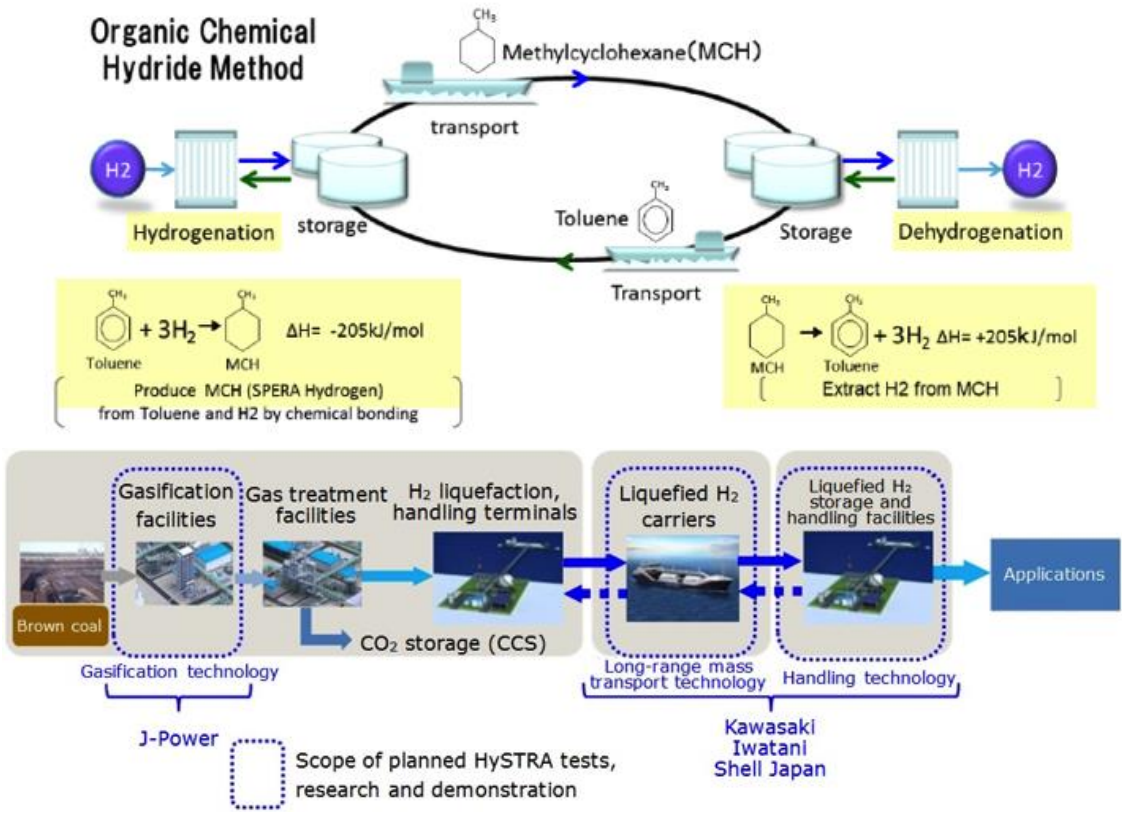
- ACT projcet Elegancy see separate presentation at this meeting)
- Zero Emission Platform (ZEP) report on hydrogen and CCS
- Magnum projects, see under Netherlands

Hydrogen Japan

- Already a sizeable hydrogen economy
  - 200 000 ”Ene-farms”, 1 800FCVs, 100 hydrogen refuelling station
  - Most hydrogen fro natural gas or LPG, not CO_2-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 CO_2-free hydrogen supply systems
- Phase 3 includes hydrogen and CO_2 (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

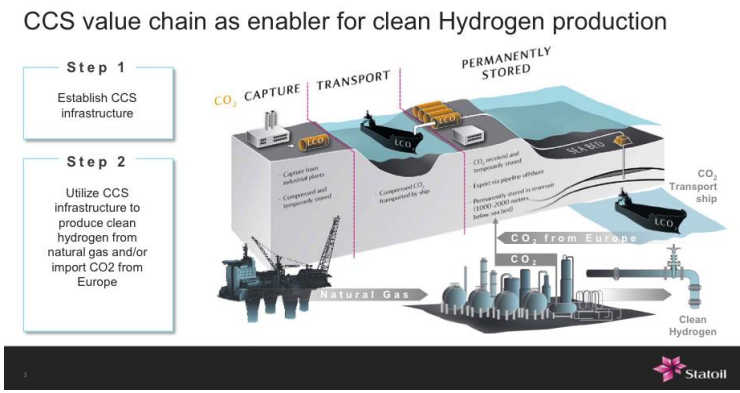


Hydrogen and CCS Netherlands

- 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
  - CO_2 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 opportunies to use it.

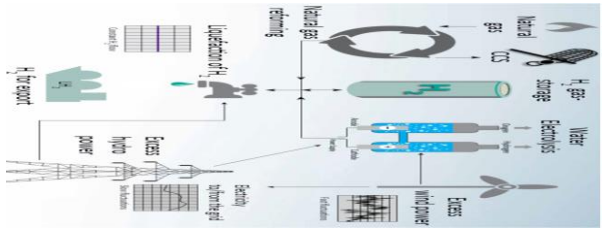
Hydrogen and CCS Norway

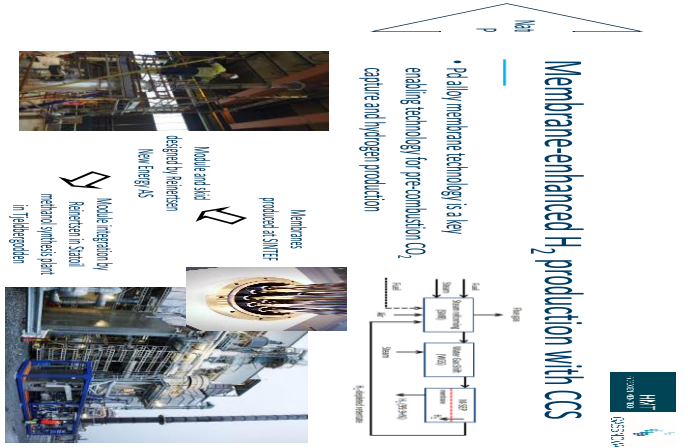
- Statoil: Large Scale Hydrogen Solutions
  - Power generation, heat; maritime
- Institute for Energy Technology (IFE
  - Emerging technolgies for reforming – sorption-enhanced reforming
  - Modelling aspects of hydrogen infrastructure
  - Hydrogen and heavy duty transport



Hydrogen and CCS Norway

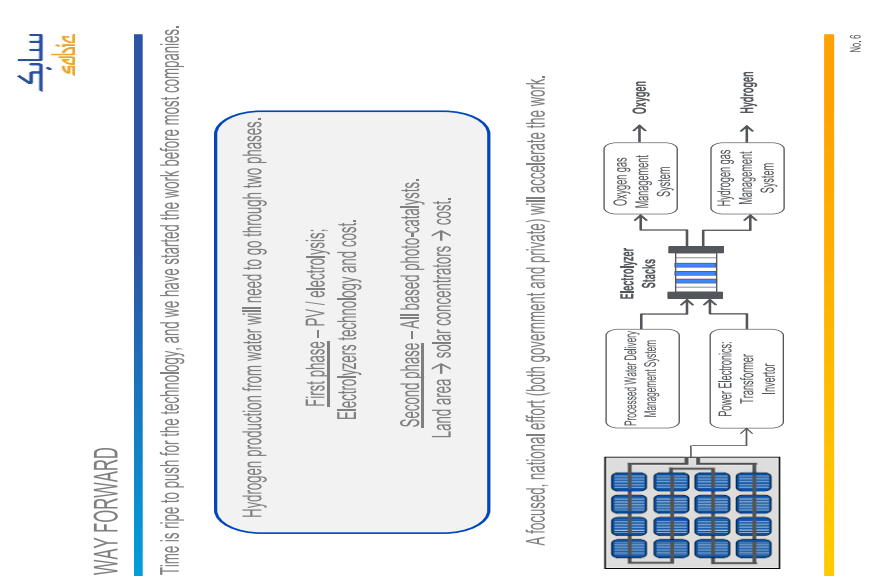
- Sintef
  - Elegancy
  - Hyper - Large-scale hydrogen co-production and liquefaction from renewable and fossil energy sources in Norway
  - Membrane-enhanced H_2 production with CCS





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%

Hydrogen and CCS United Kingdom

- 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 are
- 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 CO_2 from steam methane reforming (SMR) hydrogen production plants
    - CO_2 is used for EOR

- Co-producing H_2 in IGCC with carbon capture
- Pre-combustion capture with novel technologies for the separation of hydrogen from CO_2 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 Deploying CCS in Standalone (Merchant) SMR Based Hydrogen Plant using Natural Gas as Feedstock/Fuel.
  - 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 CO_2 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

Inititiative	Objective
Hydrogen Council	Foster High level support for hydrogen technology and see that hydrogen technologies play an essentiao role in global energy transitions
IEA Hydrogen Technology Collaboration Program (TCP)	Accelerate hydrogen implementation and widespread utilization to optimize environmental protection, improve energy security and promote economic development internationally
Internatiol Partnership for Hydrogen anf Fuels Cells in the Economy (IPHE)	facilitate and accelerate the transition to clean and efficient energy and mobility systems using fuel cells and hydrogen (FCH) technologies
European Hydrogen and Fuel Cell Association (EHA)	Promote the role of hydrogen in the energy system in Europe

Regional and international hydrogen initiatives

Inititiative	Objective
Certifhy	Create the path forward for a concrete and actionable guarantee of origin (OG) scheme with pilot demonstration of the hydrogen OG scheme
Fuel Cells and Hydrogen Joint Undertaking (FCHJU)	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
Mission Innovation	New Challenge on hydrogen??
Numerous other regional	Many related to hydrogen, fuel cells and transport

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 effiency 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