Carbon Sequestration Leadership Forum
www.cslforum.org

CARBON SEQUESTRATION LEADERSHIP FORUM

TECHNICAL GROUP

Task Force on Hydrogen Production and CCS

Results and Recommendations from "Phase 0"

June 2018

EXECUTIVE SUMMARY

This note summarises the work of Phase 0 of a Task Force under the Technical Group (TG) of the Carbon Sequestration Leadership Forum (CSLF). The objective of Phase 0 has been to map international activities regarding hydrogen production with CCS (HCCS). The Task Force should give recommendations to the CSLF TG on whether or not to continue with a full task force report at the TG meeting, in April 2018.

Phase 0 concluded that the value of a task force may be limited, given efforts and activities within and outside CSLF members, including

- Japanese, Australian, European projects or programmes as well as other national and regional projects or programmes
- There will be a chapter on hydrogen production in the CSLF task force on Industrial CCS
- Several international initiatives on hydrogen.

Thus, it is recommended that the task force does not continue beyond the "Phase 0" fact finding activities because there is already much work in progress.

Alternatively, a workshop on hydrogen production with CCS will be useful. Such a workshop should be done in partnership with other organizations, including IEAGHG, IEA HIA and GOTCP, and others

Table of Contents

1. Introduction

1.1 Background

At the CSLF Technical Group (TG) meeting in Abu Dhabi, United Arab Emirates, 4 December 2017, it was decided to establish a task force on hydrogen production with CCS (HCCS). Globally, there are extensive activities on future demand and production of hydrogen, both by nations or regional groups of nations as well as by multinational energy companies. It was therefore agreed to start with a Phase 0 to map present international activities on the topic. A decision on whether or not to continue the task force will be made at the next TG meeting, in April 2018.

If agreed to, the task force would be led by Norway, with participation/contributions from Australia, Canada, France, Japan the Netherlands, Saudi Arabia, the United Arab Emirates, the United Kingdom, the IEAGHG, and the CSLF Secretariat.

Topics that could be addressed by the task force include:

- Hydrogen production and use
  - Present and future role, demand and use
  - Status technologies, costs
- Hydrogen with CCS
  - Status: examples, technologies, costs
  - Cost reductions and needs for improved technology
- Synergies with renewables
- Life cycle costs and carbon footprint
- Hydrogen value chain.

1.2 Work mode

Some information on international hydrogen activities had been mapped prior to the December 2017 meeting. A summary of this information was sent to all CSLF members in January 2018, with a request to supplement the information. In parallel, the task force lead collected information on international organizations and projects related to hydrogen use and demand.

In must be noted that the CSLF TG has a task force on energy intensive industries and their use of CCS (EIICCS). Hydrogen production is part of that task force. The work for EIICCS and HCCS has been coordinated with a focus on the industrial use of hydrogen. Detailed descriptions of technologies, CCS as well as non-CCS, to reduce CO_2 emissions from hydrogen production and costs associated with the technologies, can be found in CSLF EIICCS (2018, in preparation).

The task force also had in mind the recommendations and findings of the CSLF 2017 Technology Roadmap (CSLF 2017), which states that:

- 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.

2. Hydrogen demand, use and production – present

2.1 Use

Globally, approximately 55 million tonnes of hydrogen is produced and consumed annually (Hydrogen Council, 2017), of which 53 % is used in ammonia (fertilizers), 7 % in methanol production, 20 % in refining, and 20 % for other applications (Essential Chemical Industry – online, last amended July 2016), Figure 2.1. "Other" includes reducing agency in industry and 500 – 1000 demonstration vehicles (cars and buses).

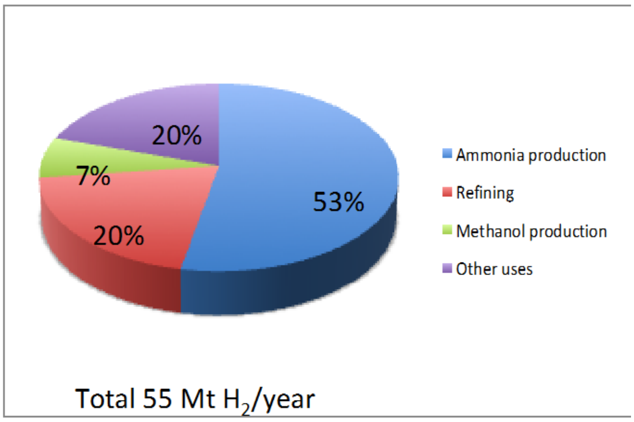

Figure 2.1. Global hydrogen use (from Essential Chemical Industry – online, last amended July 2016).

2.2 Production

Hydrogen is produced by electrolysis of water or from fossil fuels, with the majority produced using fossil fuel feed-stocks, Figure 2.2 (several sources including Wikipedia, IEA 2012, and Evers, 2008. However, there are some references that give lower numbers, some below 50 Mt/year, e.g. Fraile et al., 2015 says 43 Mt/year).

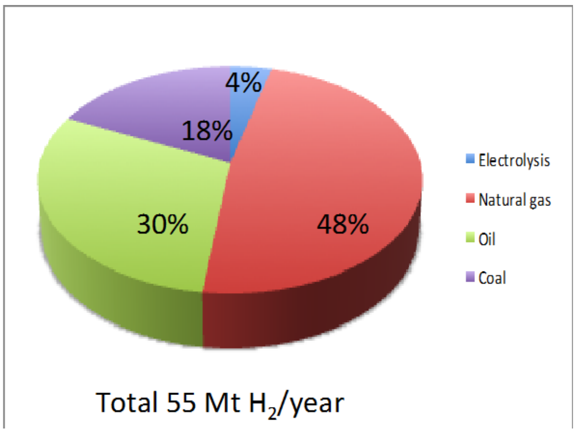

Figure 2.2. Global hydrogen production by source (based on several sources, including Evers, 2008.

Electrolysis of water is the decomposition of water into oxygen and hydrogen gas by passing an electric current through the water. Ideally, it requires a potential difference of 1.23 volts to split water. There are presently two technologies for electrolysis in use – alkaline electrolysis and proton exchange membrane, both with an electricity demand of around 50 kWh/kg H_2 or slightly below. The technique is used to make hydrogen fuel (hydrogen gas) and oxygen, but, as illustrated in Figure 2.2, the production by this approach is small. If the electricity is from renewable sources the CO_2 emissions from electrolysis will be virtually zero.

There are several processes for producing hydrogen from fossil fuel or biomass feed-stocks, all involving syngas production followed by separation of H_2 from CO_2. The syngas production approaches include 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). Technology selection depends on economics, plant flexibility and feedstock source. A schematic of hydrogen production from fossil fuels is shown in Figure 2.3.

SMR is a mature technology and produces low cost hydrogen in the range of $1.50/kilogram (kg) at plant gate at mid-2012 natural gas prices. The cost reduction experience curve indicates a steady but modest 0.5% annual cost decrease over the past 20 years (US Department of Energy, 2013).

CO_2 emissions depend on the feed-stocks and the technology. As natural gas is currently the dominant feedstock for H_2 production it will be used to illustrate the CO_2 sources.

A typical SMR hydrogen plant with the capacity of one million m^3 of hydrogen per day produces 0.3–0.4 million standard cubic meters of CO_2 per day. Estimates of CO_2 emissions from H_2 generation based on natural gas reforming varies but are in the range 8.0 tonnes CO_2/tonne H_2 (DOE/NETL, 2006) – 9.0 tonnes CO_2/ tonne H_2 (Bonaquist, 2010). When produced from gasified coal the emissions are in the range 11 – 12 tonnes CO_2/tonne H_2 (DOE/NETL, 2006). This can be compared to CO_2 emissions from electrolysis using electricity from fossil fuels. For a gas-fired power station without CCS the volume will be 18 tonnes CO_2/tonne H_2. However, if the power station is equipped with CCS, the emissions will be below 2 tonnes CO_2/tonne H_2 at a capture rate of 90%. For coal power, the emissions will be approximately doubled.

Thus, H_2 production using various existing technologies will produce different CO_2 emissions but the emission sources and points will be fairly similar. The total CO_2 emissions from hydrogen production in 2015 were probably 400 – 500 Mt.

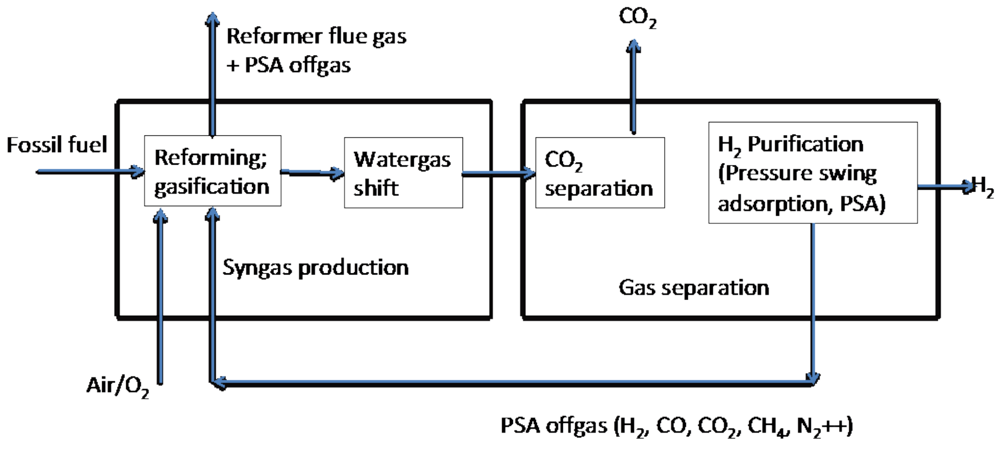

Figure 2.3. Schematic of hydrogen production from fossil fuels (after Voldsund et al., 2016)

While natural gas is the dominant fuel for H_2 production globally, coal is the dominant fuel in China. In China, hydrogen is produced from coal mainly by two methods: carbonization and gasification. After years of technology advancements, gasification has become the preferred technology for coal intensive processing. When hydrogen is produced by coal gasification, the amount of CO_2 emissions would be doubled compared to SMR.

Estimating cost of hydrogen depends on several assumptions and direct comparisons will not always be possible. Amongst the factors influencing the levelised cost are expected lifetime of plant, cost of feedstock and other inputs, discount rate, scale of facilities and production, time of comparison, location, and whether one considers commercial or industrial applications. For SMR the price of natural gas will be important, and it varies with time and region. For electrolysis the price of electricity will be a significant parameter that also has temporal and spatial variations.

An indication of the relative costs are given by Bazzanella and Ausfelder (2017). SMR costs are estimated at 1 - 4 €/kg H_2 and electrolysis costs 1.7 – 4.5 €/kg H_2 for alkaline electrolysis and 2.8 – 5.7 €/kg H_2 for proton-exchange-membrane (PEM) electrolysis. The ranges are due to different energy costs, which are the same for SMR and electrolysis.

In Figure 2.3 there are two points where CO_2 can be captured: 1) flue gas from the reformer; and 2) CO_2 from the separation process. CO_2 from the separation process has a very high concentration and is a “low-hanging fruit” that can be captured and prepared for transportation and storage with modest costs. The CO_2 from the reformer can be captured by a range of technologies.

CSLF member countries that responded to the survey indicate that at least six plants are presently capturing CO_2 from hydrogen production:

- Quest, Alberta, Canada. 1.08 Mt CO_2/year captured from bitumen upgrader by use of chemical solvent and stored in saline aquifer.
- Port Arthur, Texas, USA, 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
- Tomokomai, Japan. Amine scrubbing of PSA off-gas in hydrogen plant, CO_2 to offshore geologic storage
- Three in 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. CO_2 partially used for polycarbonate synthesis

3. Hydrogen demand, use and production – scenarios for the future

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 (Valladares, 2017); CertifHy (Fraile et al., 2015); IEA ETP, 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.

It is noteworthy that all the references devote much space to fuel cells and hydrogen.

There are large variations in what is envisioned as hydrogen demand by 2050. The European Commission (EC; 2006) indicated a demand of approximately 300 Mt H_2/year, whereas the Hydrogen Council (2017) predicts a demand of 550 Mt H_2/year in 2050. Thus, it seems that hydrogen will increase by a factor of between 5 and 10 from 2015 to 2050.

Figure 3.1 illustrates how the demand for hydrogen *could* increase between 2015 and 2050 according to the Hydrogen Council (2017). 78 EJ approximates to 550 Mt H_2. If this increase should be delivered by the same fraction of fossil fuel based hydrogen (96%), the CO_2 emissions from the production will be more than 4.5 Gt/year.

Japan alone has predicted a domestic demand of more than 16 Mt H_2 (50 Mtoe) in 2050, of which about two thirds is for power generation and one third for the transport sector (ZEP, 2017).

Some reflections on the Hydrogen Council(2017) prediction:
If 550 Mt H_2/year is produced by electrolysis and the power is obtained from renewables the hydrogen production will be without CO_2 emissions, but will require electricity input of around 26 000 TWh, assuming an electricity demand of 48 kWh/kg H2 (numbers in the literature vary around this). This is more than the global electricity production from all sources in 2014 and about 75% of the electricity generated from all CO_2-free sources in 2050 (IEA, 2017).

However, if electricity is produced with fossil fuels, there will be significant CO_2 emissions unless the CO_2 is captured and prevented from entering the atmosphere. The CO_2 intensity of hydrogen production from fossil fuels is 8-9 t CO_2/t H_2 for natural gas and 10-11 t CO_2/t H_2, for coal gasification. Thus a production of 300 – 550 Mt H_2/year with SMR implies CO_2 emissions in range 2.5 – 5.0 Gt/year from reforming. Thus, CCS will be needed.

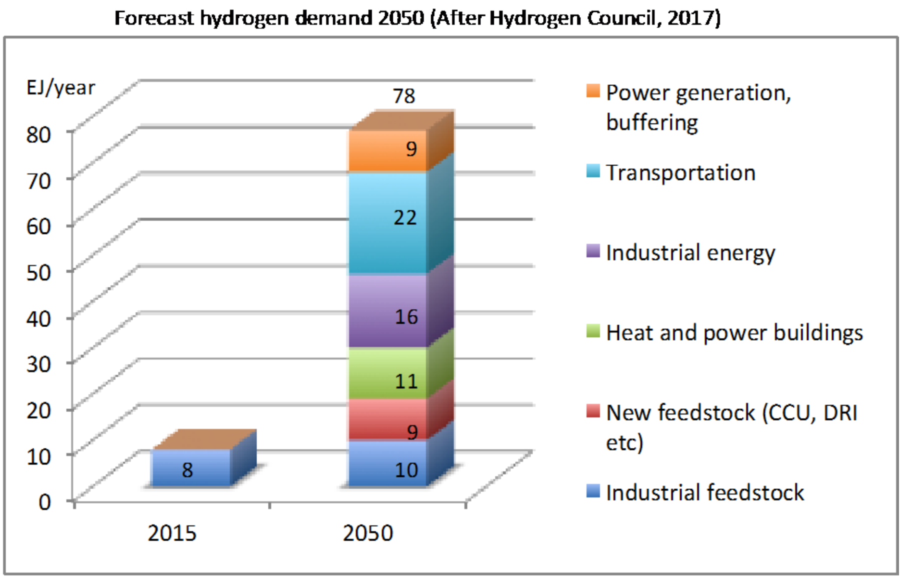

Figure 3.1. Possible increase in demand for hydrogen by 2050 (after Hydrogen Council, 2017)

4. Summary of CSLF member activities

4.1. Summary of national activities

Table 4.1 summarises national activities in CSLF member countries and allied organisation that submitted information.

Table 4.1. National activities on hydrogen in/by some CSLF members and allied organisations

CSLF Member or allied organisation	Activities
Australia	Hydrogen Energy Supply Chain (HESC) Pilot Project • Objective: Demonstrate the financial and technical feasibility of a pilot Hydrogen Energy Supply Chain, from the gasification of brown coal in Victoria's Latrobe Valley, through refining, liquefaction, storage, to the safe shipping of liquefied hydrogen to Japan. Commonwealth Scientific and Industrial Research Organisation (CSIRO) Hydrogen Roadmap • Objective: To provide a blue-print for the development of a hydrogen industry in Australia. CSIRO Future Science Platform – Hydrogen Energy Systems • Objective: research low emission, energy efficient methods of generating hydrogen, to be used domestically in transport, power generation, and to offset more carbon-intensive resources. Mission Innovation – converting sunlight innovation challenge • Objective: Stimulate international cooperation and exchange to discover affordable ways to convert sunlight into storable solar fuels Clean Energy Finance Corporation (CEFC) and Firstmac financing program • Objective: accelerate business and personal adoption of low emissions fuel technologies, including hydrogen fuel cell and electric vehicles. CSIRO – Metal membrane for hydrogen separation • Objective: Investigating use of a metal membrane to convert ammonia to high-purity hydrogen for use in fuel cell vehicles. Australian Renewable Energy Agency (ARENA) – Request for information on exporting hydrogen • Objective: ARENA sought input from leading experts in the field to further the development of sustainable renewable energy export supply chains. Hydrogen Roadmap for South Australia • Objective: Accelerate South Australia's transition to a clean, safe and sustainable hydrogen economy. Hydrogen Mobility Australia o Objective includes: To accelerate the commercialisation of new hydrogen and fuel cell technologies for transportation, export, storage and stationary applications in Australia. Yara: Solar ammonia pilot plant • Objective: demonstration plant to produce ammonia using solar power at Yara's existing facilities in the Pilbara, Western Australia Future Fuels CRC – Cooperative Research Centre o Objective: future fuels technologies, systems and markets; address the issues around safety and social acceptance of new and changed fuels; infrastructure itself
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 • Northwest 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 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
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 • 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
European Commission	• ACT project ELEGANCY • Zero Emission Platform (ZEP) report on hydrogen and CCS • Magnum projects, see under Netherlands
Japan	• Already a sizeable hydrogen economy – 200 000 ”Ene-farms”, 1 800FCVs, 100 hydrogen refuelling station – Most hydrogen from natural gas or LPG, not CO_2-free • Hydrogen and fuel cells roadmap, three phases – Expansion of hydrogen for Ene-farms – Expansion of hydrogen for power and establishment of hydrogen supply systems – Establishment of CO_2-free hydrogen supply systems • Phase 3 includes hydrogen and CO_2 (power-to-gas) • METI CO_2-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. • Two NEDI projects – Hydrogen from steam reforming of natural gas in Brunei, with future capture of CO_2 from SMR – Hydrogen from Australian lignite, , with future capture of CO_2 • Tomokomai: Amine scrubbing of PSA off-gas in hydrogen plant, CO_2 to offshore geologic storage
Netherlands	• Hydrogen Roadmap Gigler and Weeda (2018) • Equinor (former 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 opportunities to use it.
Norway	• Equinor (former Statoil): Large Scale Hydrogen Solutions – Power generation, heat; maritime • Institute for Energy Technology (IFE) – Emerging technologies for reforming – sorption-enhanced reforming – Modelling aspects of hydrogen infrastructure – Hydrogen and heavy duty transport • 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
Saudi Arabia	• SABIC: Main focus on hydrogen from water • SABIC started hydrogen production from renewables in 2013.
United Kingdom	• Hy4Heat – Programme commissioned by Department for Business, Energy and Industrial Strategy (BEIS) looking at the feasibility of 100% hydrogen gas network conversion. – The programme will explore the practicalities of using hydrogen in homes and will facilitate the design and manufacture of new appliances such as fires, cookers, and boilers, for both domestic and commercial use • BEIS Hydrogen Supply competition – The £20 million Hydrogen Supply programme aims to accelerate the development of a low carbon bulk hydrogen supply solutions for industry, power, buildings and transport at a technology readiness level (TRL) between 4 to 7, which could result in lower capital or operating costs when compared to Steam Methane Reformer with Carbon Capture & Storage (SMR+CCS), or improve the capture rates at a comparable cost. • BEIS Industrial fuel switching to low-carbon alternatives – A £20 million innovation competition which focuses on market engagement and potential scope for fuel switching in industry to low-carbon fuels including hydrogen, electricity and biomass/ waste. The competition aims to stimulate early investment in fuel switching processes and technologies, so that a range of technologies are available by 2030 and beyond. • H21 (Northern Gas Networks) – Programme (with funding from Ofgem) looking at viability of gas network conversion to 100% hydrogen – Convert local gas grid in the city of Leeds to hydrogen – Hydrogen production planned to be from reformation of methane with CCUS

	• H100 (SGN) – Evaluate the suitability of sites and requirements for a 100% Hydrogen demonstration project. – Select the most practical and cost effective site for development – Complete the initial design of the site. – Carry out on site or off site testing of aspects supporting the quantification of risk. • HyNet North West (Cadent Gas) – Low-carbon hydrogen through reformation of methane using ATR – Planned to re-use existing offshore oil and gas pipeline to the Hamilton field in the East Irish sea for CO2 storage – Supply low-carbon hydrogen to 10 energy intensive industrial users in the Liverpool-Manchester area – Blend hydrogen in to the local gas distribution network up to 15-20%
United States of America	• 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)
IEA Greenhouse gas R&D Programme (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 ammonia/urea or methanol production 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 – 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

4.2. Examples of collaboration initiatives and projects

4.2.1. Australia and Japan

In April 2018 the Australian government entered into a partnership with Japan's Kawasaki Heavy Industries in a A$500m (US$388m) pilot project to turn Australia's brown coal into hydrogen for use in Japan as part of its drive towards a hydrogen-powered economy. The Global CCS Institute (GCSSI) is also involved in the project.

Australia has one of the world's most abundant supplies of lignite, in the Latrobe Valley, and the project has been granted funding of A$50m from the Australian Government, and a further A$50m by the Victorian Government.

AGL, Australia's biggest energy company, will host the pilot facility and construction, which is due to begin in early 2019, with the first shipment of hydrogen scheduled for 2020/2021. If the trial is successful, a commercial plant will be built on a site near the Loy Yang lignite mine in the Latrobe Valley. When a commercial plant gets into operation, the CO_2 emissions will be curbed by implementing carbon capture and storage (CCS). The Latrobe Valley has excellent carbon dioxide storage options nearby in the well-characterised offshore Gippsland Basin.

The project needs to develop a cost-effective supply chain for transporting the gas to a liquefaction facility at the Port of Hastings, and then transporting the liquid hydrogen to Japan. Kawasaki is well on its way to develop the infrastructure, as it already has hydrogen ships operative.

More information on the project can be found at
https://industry.gov.au/resource/LowEmissionsFossilFuelTech/Pages/Hydrogen-Energy-Supply-Chain-Pilot-Project.aspx; and
https://hydrogenenergysupplychain.com; and
https://static1.squarespace.com/static/574c47228259b5de6737fbfe/t/5b02643a0e2e7216afd982de/1526883394029/2.+R.Tanaka_180502+Emerging+hydrogen+value+chains+for+Japan_S1+RTanaka_0423.pdf

4.2.2. ELEGANCY – a European ACT project

ELEGANCY is a European project with ten partners from nine countries. Its objectives are:

Fast-track the decarbonisation of Europe's energy system by exploiting the synergies between two key low-carbon technologies: CCS and H_2. To this end, ELEGANCY will:

- Develop and demonstrate effective CCS technologies with high industrial relevance
- Identify and promote business opportunities for industrial CCS enabled by H_2 as a key energy carrier by performing five national case studies
- Validate key elements of the CCS chain by frontier pilot- and laboratory-scale experiments using inter alia ECCSEL and EPOS research infrastructure
- Optimize combined systems for CO_2 separation
- De-risk storage of CO_2 from H production by providing experimental data and validated models
- Develop simulators enabling safe, cost-efficient design and operation of key elements of the CCS chain
- Provide an open source techno-economic design and operation simulation tool for the full CCS chain, including H_2 as energy carrier
- Assess societal support of key elements of CCS

ELEGANCY work packages include

- H_2 supply chain and H_2-CO_2 separation
- CO_2 transport, injection and storage
- Business case development for H_2-CCS integrated chains
- H_2-CCS chain tool and evaluation methodologies for integrated chains
- Case studies

More information can be found at

https://www.sintef.no/elegancy/; and
http://www.act-ccs.eu/elegancy/; and
https://www.cslforum.orgcslf/sites/default/files/documents/Venice2018/Munkejord_ELEGANCY-Project-Update.pdf

4.2.3. Equinor's (former Statoil) engagement

Equinor sees converting natural gas to hydrogen with capture and storage of the CO_2 as an opportunity to develop low carbon energy supply and transportation solutions. The Norwegian company has a hydrogen portfolio that includes hydrogen for power and heat generation and maritime transportation. Included in the portfolio is engagement in some of the projects reported by the CSLF members, most notably the Statoil, Vattenfall and Gasunie Memorandum of Understanding (MoU) to evaluate the possibilities of converting Vattenfall's gas power plant Magnum in the Netherlands into a hydrogen-powered plant, and the UK H21 North of England Hydrogen Supply Concept, which includes the project to convert the local gas grid in the city of Leeds to hydrogen (e.g. NGN, 2016; IEA ETP, 2017).

For more information on Equinor's hydrogen engagement, see
https://www.equinor.com/en/news/evaluating-conversion-natural-gas-hydrogen.html: and
https://static1.squarespace.com/static/574c47228259b5de6737fbfe/t/5b0263a888251b93765ad6c1/1526883279034/1.Eikaas_low-carbon_Solutions.pdf;

5. Summary of some international initiatives

Table 5.1 below lists some international initiatives and their objective, with links to the web-sites.

Table 5.1 Some international hydrogen initiatives

Initiative	Objective
Hydrogen Council http://hydrogencouncil.com	Foster High level support for hydrogen technology and see that hydrogen technologies play an essential role in global energy transitions
IEA Hydrogen Technology Collaboration Program (TCP) (former IEA Hydrogen Implementation agreement, HIA) https://www.iea.org/tcp/renewables/hydrogen/	Accelerate hydrogen implementation and widespread utilization to optimize environmental protection, improve energy security and promote economic development internationally
International Partnership for Hydrogen and Fuels Cells in the Economy (IPHE) https://www.iphe.net	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) http://www.h2euro.org	Promote the role of hydrogen in the energy system in Europe
CertifHy http://www.certifhy.eu	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) http://www.fch.europa.eu	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 http://mission-innovation.net	New Challenge on hydrogen??
Numerous other regional	Many related to hydrogen, fuel cells and transport

6. Findings (include findings from open literature)

The task force's investigations covered the future outlook for hydrogen production with CCS as well as how it is presently being implemented in specific parts of the world. CSLF members are amongst nations that already have implemented hydrogen production facilities with CCS. Several members, or companies within the members, are, alone or in joint undertakings, looking at applications of and infrastructure for hydrogen. Much activity on the role of hydrogen and hydrogen demand is directed towards hydrogen and fuel cells, particularly in the transport sector. There are also activities on improving efficiency of electrolysers and on alternative ways of splitting water.

Further, there are extensive RD&D activities related to technologies for CO_2 capture based on adsorption, absorption and membranes, including some important but fewer activities on applications to H_2 production with CCS. However, there may be need for some follow-up of the 2017 CSLF Technology Roadmap recommendations related to CO_2 capture technologies.

7. Conclusions

The value of a task force may be limited, given efforts and activities within and outside CSLF members, including

- Projects like ELEGANCY
- Japanese, Australian, European as well as other national and regional projects or programmes
- There will be a chapter on hydrogen production in the CSLF task force on Industrial CCS
- Several international initiatives on hydrogen.

Thus, it is recommended that the task force does not continue beyond the "Phase 0" fact finding activities because there is already much work in progress.

Alternatively, a workshop on hydrogen production with CCS will be useful. Such a workshop should be done in partnership with other organizations, including IEAGHG, IEA HIA and GOTCP, and others

The workshop could be held with the Task Force on industrial CCS, as hydrogen and hydrogen use in industry are receiving significant attention.

8. References

Bazzanella, A.M., F.Ausfelder (2017). Low carbon energy nd feedstock for the European chemical industry. Dechema Gesellschaft für Chemische Technic und Biotechnologie e.V. https://dechema.de/dechema_media/Technology_study_Low_carbon_energy_and_feedstock_for_the_European_chemical_industry-p-20002750.pdf (accessed 24 may 2018)

Bonaquist, D. (2010) *Analysis of CO2 emissions, reductions, and capture for large-scale hydrogen production plants.* A White Paper, Praxair.

CSLF (2017) Technology Roadmap 2017.
https://www.cslforum.org/cslf/Resources/Publications/CSLFTechRM2017

CSLF (2018) Energy Intensive Industries and CCS (in preparation)

Department of Energy (2006) Life-cycle analysis of greenhouse gas emissions for hydrogen fuel production in the United States from LNG and coal. DOE/NETL-2006/1227.
https://www.netl.doe.gov/File%20Library/Research/Energy%20Analysis/Life%20Cycle%20Analysis/h2_from_coal_lng_final.pdf

Essential Chemical Industry (2016). Hydrogen.
http://essentialchemicalindustry.org/chemicals/hydrogen.html

European Commission, EC (2006). World Energy Technology Outlook - 2050. WETO-H_2.
https://cordis.europa.eu/result/rcn/47836_en.html

Evers, A. A. (2008) *Actual worldwide hydrogen production*. Poster presentation, Hannover FAIR Presentation. Available at: http://www.hydrogenambassadors.com/background/worldwide-hydrogen-production-analysis.php

Fraile, D., J-C. Lanoix, P. Maio, A. Rangel, A. Torres (2015) Overview of the market segmentation for hydrogen across potential customer groups, based on key application areas. CertifHy Deliverable No.1.2.
http://www.fch.europa.eu/sites/default/files/project_results_and_deliverables/D%201.2.%20Overview%20of%20the%20market%20segmenatation%20for%20hydrogen%20across%20potential%20customer%20groups%20based%20on%20key%20application%20areas.pdf (accessed 24 May 2018)

Gigler, J., M. Weeda (2018) Outline of a Hydrogen Roadmap. TKI NIEUW GAS May 2018.
https://topsectorenergie.nl/tki-nieuw-gas/documenten (accessed 06 May 2018)

Hydrogen Council (2017). Hydrogen scaling up. A sustainable parthway for the global energy transition. http://hydrogencouncil.com/wp-content/uploads/2017/11/Hydrogen-scaling-up-Hydrogen-Council.pdf

IEA (2017) Energy Technology Perspectives 2017. https://www.iea.org/etp2017/

James, B.D., A. D. DeSantis, G.Saur (2016) Final Report: Hydrogen Production Pathways Cost Analysis (2013 – 2016). Strategic Analysis Inc, Arlington, Virgina, USA.
https://www.osti.gov/servlets/purl/1346418 (accessed 24 May 2018)

NGN (Northern Gas Networks) (2016), H21 Leeds City Gate Full Report, https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Report-Interactive-PDF-July-2016.compressed.pdf (accessed June 2018).

US Department of Energy, 2013, Report of the hydrogen production expert panel: a subcommittee of the hydrogen & fuel cell technical advisory committee, May 2013, USDOE

Valladares,M-R. (2017) Global trends and outlook for hydrogen. IEA Hydrogen Technology Collaboration Program (TCP (formerly IEA HIA). http://ieahydrogen.org/pdfs/Global-Outlook-and-Trends-for-Hydrogen_Dec2017_WEB.aspx (accessed 24 May 2015)

Voldsund, M., K.Jordal, R. Anantharaman, 2016. Hydrogen production with CO2 capture. Intetnational Journal of Hydrogen Energy, 41, 4969-4992

Wikipedia Hydrogen production. https://en.wikipedia.org/wiki/Hydrogen_production (Last accessed January 2018).

ZEP (2017) Commercial Scale Feasibility of Clean Hydrogen. Report from European Zero Emission Technolgy and Innovation Platform. http://www.zeroemissionsplatform.eu/news/news/1669-launch-of-zep-report-commercial-scale-feasibility-of-clean-hydrogen.html (accessed 24 may 2018)