Introduction

Hydrogen can be produced from a variety of sources; water, biomass, fossil fuel etc. At present, nearly all industrial hydrogen production processes involve the use of hydrocarbon fossil fuel [1]. With continuous technological advances, a shift in hydrogen production from fossil fuel sources to renewable sources is expected. CO_2 emission is a major by-product of hydrogen production from fossil fuel. There is a need to reduce or completely prevent CO_2 from being released into the atmosphere because of its harmful effect on the environment. One method of doing this, is to capture the CO_2, another method is to produce hydrogen by thermal decomposition of hydrocarbon (by-product is solid coke). There are severally studies on CO_2 Capture and storage systems and its economics. An innovative method of producing hydrogen from hydrocarbon reservoirs while keeping the associated by-products in the reservoir is discussed here. Field application of this technology has been demonstrated by Proton-Energy [2]. The key processes involved in this technique are:

1. Injection of oxygen or oxygen enriched air.
2. Control of subsurface combustion
3. Selective extraction of hydrogen from combustion gas
4. Storage and transportation of produced Hydrogen gas.

A schematic of these production processes is presented in figure 1.

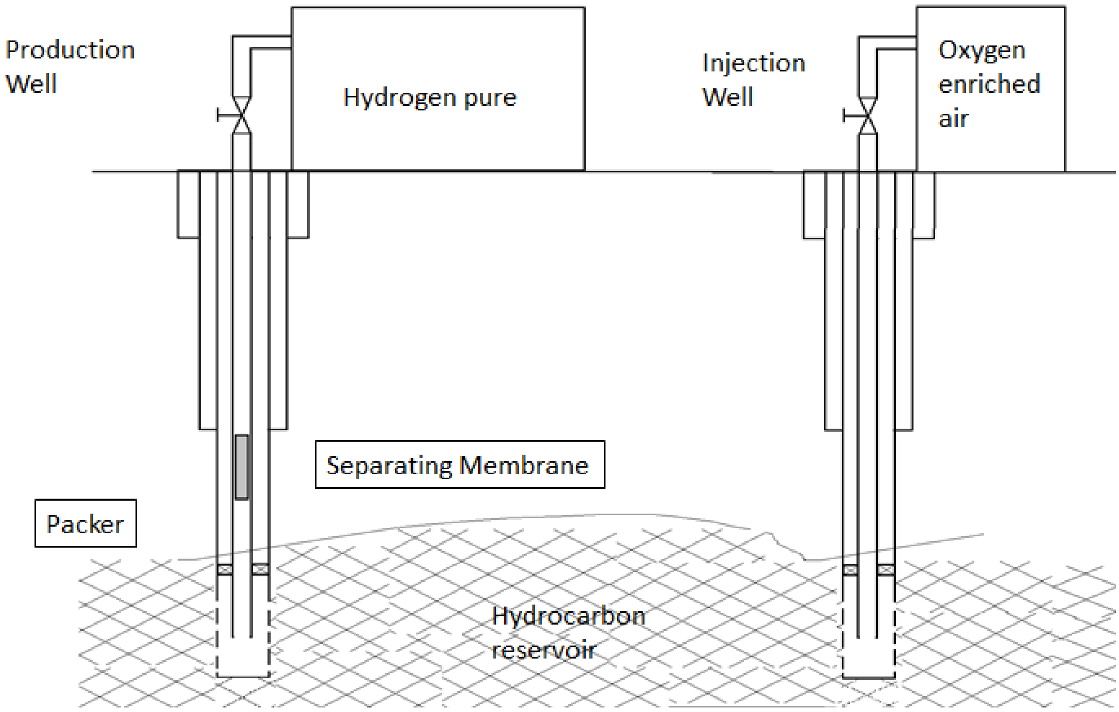

Figure 1 *Schematic of In-situ Hydrogen Production Process*

The key challenges to be surmounted are highlighted and possible research directions are identified.

Method

A SWOT analysis based on the 18S concept for innovation studies indicated by Dincer and Acar, 2017 [3], was applied to assess the prospect of this technology. The 18S concept identifies critical areas for innovation: source, system, service, scope, staff, scale-up, safety, scheme, sector, solution, stakeholder, standardization, subsidy, stimulation, structure, strategy, support and sustainability.

<u>Strength:</u>

1. Source: Substantial hydrocarbon resources exist in the subsurface even after the reservoir has been depleted via tertiary oil recovery. This remaining hydrocarbon becomes accessible for

hydrogen production using this technology. Depleted wells, abandoned wells and live wells have the potential to be used for hydrogen production. In addition, different hydrocarbon reservoir type: heavy oil, gas, conventional oil, shale e.t.c can be used without any significant disruption in hydrogen output.

2. Safety: The design, construction, operation and maintenance of this technology are considered safer than conventional steam methane reforming (SMR) because critical combustion processes occur at the subsurface.
3. Structure: Availability of existing oil and gas infrastructure and potential to re-purpose these infrastructures presents a very strong case for the adoption of this technology.
4. Solution: This technology has the potential to provide cheaper, cleaner and safer source of hydrogen when compared to the conventional SMR technology being used. There is zero surface emission and considerable reduction in production cost compared to the cheapest hydrogen production process.

Weakness:

1. System: Over time as in-situ combustion processes continues, the reservoir would be saturated with flue gas. This can lead to eventual escape through faults and improper well seals to the surface. The integrity of the reservoir seal structure becomes a critical factor towards the success of this technology.
2. Stimulation: The rate of hydrogen production is proportional to the in-situ combustion rate. The combustion rate is also a function of the rate of oxygen injection from the surface. Hence to increase hydrogen production rate, more oxygen will need to be injected. This presents a challenge as the rate of oxygen injection is expected to decline as the reservoir pressure increases.
3. Scale-up: The size and efficiency of the membrane separation technology is an important aspect of this technology. A good hydrogen production membrane should possess high selectivity for hydrogen, high permeability to operate with high flows and good structural and chemical stability [4]. Depending on the separation technology, operating condition and composition of the flue gas, the lifespan of the membrane would differ.

Opportunities:

1. Service: Selective membranes can be installed downhole to produce other by products of the combustion gases such as helium, syngas and steam for electricity generation. This presents opportunities to monetize the technology through sales of these gases[5].
2. Stakeholder: This technology presents a transition path from conventional hydrocarbon production to hydrogen production. The oil and gas industry is a mature industry with strong financial capacity to drive the technology.
3. Staff and Support: Adoption of this technology will require support from academia, government incentives, and financial institution. Manpower development will also be needed with regards to operating and maintaining installed equipment. Research opportunities on optimizing membrane separation efficiency, oxygen separation from air and modelling the rate of combustion under different reservoir conditions will be needed.
4. Sector: Adoption of hydrogen fuelled vehicles will increase the end-use demand for hydrogen from the transportation sector. Opportunities to expand the production of hydrogen using this technique will stimulate more research on low cost oxygen-air separation, hydrogen separation membranes etc.

Threats

1. Sustainability: Hydrogen production from renewable sources such as electrolysis; solar photovoltaic and wind leave no carbon and sulphur by-products. As technology level increase, production from renewable sources will become the preferred choice for hydrogen production.
2. Standardization: The composition of hydrocarbons found in reservoirs differs considerably from one reservoir to another. Therefore the development and deployment of underground separation membranes would be on a case by case basis.

A summary of this analysis is presented in figure 2

Figure 2 *SWOT-18S Analysis of In-situ hydrogen production technology*

Conclusion

Re-purposing depleted and abandoned oil and gas wells to produce hydrogen is an innovative approach to large scale hydrogen at low cost. However, as identified in this study, not all reservoir conditions may be suitable for this technique. Important considerations should be given to the reservoir seal structure, controlling subsurface combustion and oxygen injection processes. Potential for the use of Nickel-based catalyst can also be explored. This technology supports the main pillars of sustainability: better efficiency, better cost effectiveness, better resources use, better design and analysis, better energy security, and better environment[6]

Acknowledgement

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