Blue Hydrogen as an Interim Phase of the Just Transition; Is it a Feasible Proposition for South Africa?

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Abstract

Hydrogen could play a critical role as both an energy carrier and a chemical feedstock in the decarbonisation of South Africa's electricity and liquid fuel sectors. This potential has sparked major international and local effort in technologies for the production of green hydrogen, with much of the focus being directed at the use of hydrolysis and renewable energy. Unfortunately, this route is still severalfold more expensive than the conventional process, the latter being based on the steam reforming of fossil fuels. Given the existing infrastructure in Mpumulanga, and the importance of green and inclusive industrial development, which is one of the themes of this conference and also an important priority for the country's energy transition, it may be important to consider in more detail alternative hydrogen technologies. In this paper, the production of hydrogen using coal or gas with carbon capture and storage (CCS), known as blue hydrogen, is outlined. The present status of the technology for CCS and the techno-economic feasibility of a local blue hydrogen facility, as an interim measure to address decarbonisation while maintaining some of the employment and industrial activity within coal-producing areas, is discussed. The results are used to propose the necessary industrial policy framework to support a new hydrogen technological innovation system in South Africa.

Keywords
Blue hydrogen; just transition; carbon capture

1. Introduction

Hydrogen is increasingly important as a solution to the negative environmental impact of fossil fuels and as a means to decarbonise socio-technical systems (Noussan, Raimondi, Scita and Hafner, 2021). It can be used as both an energy carrier and a feedstock in multiple sectors including the chemical industry, minerals processing, transport and heating. In view of this potential, South Africa adopted the National Hydrogen and Fuel Cell Technologies Research, Development and Innovation Strategy in 2007 and more recently, the Hydrogen Society Roadmap (Department of Science and Innovation, 2021; Department of Science and Technology, 2007).

The roadmap specifies a key milestone as "increasing the use of hydrogen across all sectors in support of South Africa's move towards a net-zero carbon economy". In terms of the various types of hydrogen (see box), it proposes a process of transition from "from grey to blue to green hydrogen", thereby essentially ensuring that clean hydrogen is integrated as an energy vector in the South African energy system (Department of Science and Innovation, 2021). To quote from the document:

> "The focus will be on scaling up the generation, storage and distribution of all forms of hydrogen to support the HSRM, while positioning the country to make a responsible transition from grey,

blue and green hydrogen in response to market demand while supporting the achievement of climate change targets.”

The document even presents a theory of change for this transition, with the intention being to prioritise blue hydrogen over the period 2021 to 2050, driven by the need to preserve asset value, conserve employment whilst diversifying employment opportunities, and allow the slow introduction of socio-economic adjustments to the new business practices (of the hydrogen economy).

Although these arguments are persuasive, the obvious advocacy for blue hydrogen ignores a number of important drawbacks in its role as a transitionary technology. In the remainder of this article, I give an overview of the technology, including its present state of development, its technical challenges and the lack of a strong business case for its widespread use, even as a temporary measure.

The Colours of Hydrogen

Colour	Source of Hydrogen
Black	Coal without carbon capture and storage (CCS)
Grey	Oil/gas without CCS
Blue	Oil/Gas/Coal with CCS
Pink	Nuclear energy via hydrolysis
Turquoise	Gas to produce hydrogen and carbon black
Green	Renewable energy via electrolysis

2. Background

2.1 Carbon Capture and Utilisation

The manufacture of blue hydrogen from coal takes place in two steps, both of which are well established. In the first step, the coal is gasified to produce syngas, which consists mainly of hydrogen and carbon monoxide, with some carbon dioxide (CO_2), methane (known as “fugitive methane”) and other impurities. The syngas is cleaned and then passed into a water-gas shift reactor where the carbon monoxide is converted into hydrogen and CO_2.

In the second step, the CO_2 must be removed. Typically, this is achieved using the Rectisol process, although the technology is expensive to operate since the CO_2 is removed using low temperature methanol. Sasol has been operating similar technology for the manufacture of liquid fuels and the process is now well established (van Dyk, Keyser and Coertzen, 2006). The overall process is shown in Figure 1.

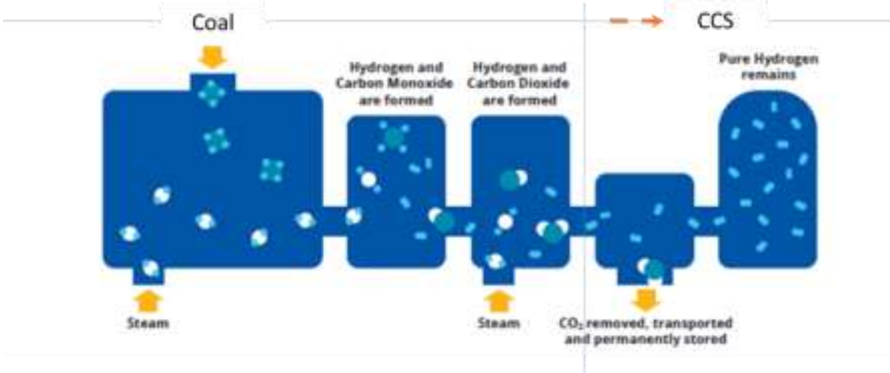

Figure 1. Blue hydrogen production process

Unfortunately, removal of CO_2 from the syngas is not the only carbon capture requirement. The whole process requires a large amount of heat and electricity, which is obtained from the burning of coal and generates a large volume of flue gas for which the technology is still under development and is untested for long periods at large scale (Raza, Gholami, Rezaee, Rasouli and Rabiei, 2019). The most likely option is shown in Figure 2. Syngas is passed through an absorption column where the CO_2 is removed into a solvent, typically an alkyl amine. The solvent with the CO_2, known as the rich stream or extract, is then passed to the stripper, where the CO_2 is removed through contact with high pressure steam, then compressed to high pressure and sent by pipeline to the storage facility (Pires, Martins, Alvim-Ferraz and Simões, 2011). The solvent, known as the lean stream and now stripped of CO_2, is returned to the absorber.

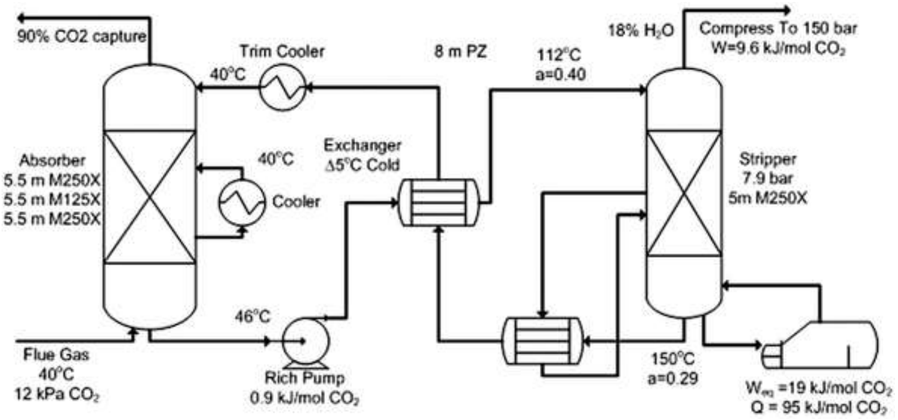

Figure 2. Process flowsheet for carbon capture

Source: Boot-Handford, Abanades, Anthony, Blunt, Brandani, Mac Dowell, Fernández, Ferrari, Gross and Hallett (2014)

Apart from the alkyl amine route, many other processes are being tested at pilot scale (Global CCS Institute, 2022; Boot-Handford et al., 2014). All processes, however are not very efficient, with a capture ratio of 80% to 90%, and the present technologies fails to capture the fugitive methane, which is a more damaging greenhouse gas than CO_2 (Howarth and Jacobson, 2021; Rapier, 2020). In order to reach 100% carbon removal, the absorber would have to be infinitely high. Larger recoveries are possible but more expensive to install and operate.

Transportation, storage and monitoring (TSM) is another problem. The only completed CO_2 storage projects are on a small scale in the Norwegian Sleipner and Snovit fields, which have a total combined capacity of only 1.5 million tonnes per annum (Deduleasa, 2021). In South Africa, the South African Centre for Carbon Capture and Storage (SACCCS) was established in 2009 in order to "examine the technical potential for carbon capture and storage (CCS) in South Africa" (Beck, Surridge and Hietkamp, 2013, p 6504). SACCS is a division of the South African National Energy Development Institute, which is itself a state-owned entity reporting to the Department of Energy and responsible for energy-related research and development in South Africa. SACCCS identified four potential geological sites for CO_2 storage, all of which are located offshore. In addition to efficiently capturing the CO_2 at source, there is also the non-trivial engineering problem of how to collect the CO_2 from highly variable and geographically distributed emitters, and then transport it to a subsea depository. The cost of this infrastructure will be exorbitant.

The cost of carbon capture from flue gas is significant, with estimates ranging from $40 to $45 per tonne CO_2 in China and $70 to $75 per tonne CO_2 in USA (Singh, Lu, Cui, Li, Zhao, Xu and Ku, 2018). Much of the cost lies in the stripper, where large amounts of heat need to be supplied. Carbon capture consumes between 25% to 40% of the total energy generated, and increase costs per unit of hydrogen produced by up to 70% (Haszeldine, 2009). Moreover, not all the CO_2 is captured, meaning that some carbon tax would also be paid, leading a slightly different comparison known as the CO_2 avoidance cost, which is the CO_2 tax at which the hydrogen cost is the same for the two options of a fossil fuel plant without mitigation, but paying the tax, or the same fossil fuel plant with CCS, but avoiding most of the CO_2 tax (Simbeck and Beecy, 2011). CO_2 avoidance costs are always higher than the cost of carbon capture since the commercial processes are never 100% efficient. It is noted that the cost of carbon removal from syngas is much lower since the feed gas is available at higher CO_2 concentration, with the present estimate being about \$16 per tonne CO_2 (Vickers, 2019).

Most of the literature values for the cost of CCS exclude the TSM component due to limited knowledge of large-scale systems. Presently, it is estimated that TSM will add about \$60 per tonne CO_2, depending on the depth of storage and the transport distance (Schmelz, Hochman and Miller, 2020). It is noted that the U.S. Department of Energy has set a target for captured cost at \$40 per tonne of CO_2, captured and compressed to 153 bar for sequestration in a saline aquifer, which is at least one quarter of the present value (Bui, Adjiman, Bardow, Anthony, Boston, Brown, Fennell, Fuss, Galindo and Hackett, 2018).

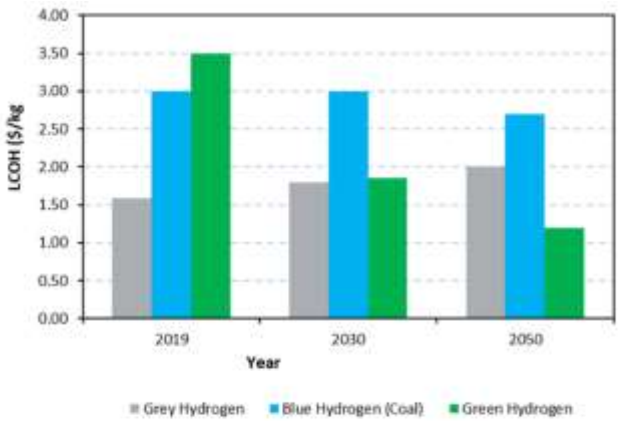

Figure 3. Cost of blue hydrogen vs grey and green; 2019 to 2050

Source: Noussan et al. (2021)

In summary, the total cost of CCS from for blue hydrogen, including TSM, is estimated at \$100 to \$170 per tonne CO_2. Given that the emissions of CO_2 are about 23 kg per kg hydrogen, and assuming a 90% carbon capture efficiency, the net premium for blue hydrogen ex-coal relative to grey hydrogen is estimated to be \$1.6/kg, leading to a total cost of \$3 to \$3.5 per kg hydrogen. Similar values are reported elsewhere in the literature (Zapantis, 2021; BloombergNEF, 2020; IEAGHG, 2014). Projections for the relative costs of grey, blue and green hydrogen are shown in Figure 3.

3. Blue Hydrogen as a Stop-Gap

Even under the best of predictions, within the economic limits for energy sources, the gasification of coal combined with CCS, leading to the production of blue hydrogen, will still result in significant green house gas emissions, consisting of CO_2 and fugitive methane. Blue hydrogen can never be a zero carbon technology, but will act instead to divert necessary finance from the further development of green hydrogen and create lock-in for sub-optimal solutions which will delay the attainment of decarbonisation targets (Rosenow and Lowes, 2021).

It will be preferable to adopt a slower scale-down of grey hydrogen, including coal-based power generation, and accelerate the development of green hydrogen, rather than attempt blue, notwithstanding the dependence of many communities in South Africa on coal mining. The goals of the Just Transition, articulated by the Presidential Climate Commission, can be equally achieved through other approaches (Presidential Climate Commission, 2021).

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