AN OVERVIEW OF THE HYDROGEN ECONOMY AND THE ROLE OF DEVELOPMENT FINANCE INSTITUTIONS IN ITS ESTABLISHMENT

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ABSTRACT

Hydrogen has the potential to power the future with clean, limitless energy and zero emissions. This research aims to define the properties of hydrogen, its production from various sources, its uses, and the challenges in establishing a hydrogen economy. It also identifies key opportunities and roles for development finance institutions (DFIs) in advancing the green hydrogen economy in South Africa, with reference to the broader Southern Africa context. The study employed a systematic review of existing literature on the hydrogen economy, complemented by interviews and questionnaires with key informants. Findings reveal that DFIs can play a pivotal role in scaling up renewable energy capacity for green hydrogen production, creating an enabling environment for investment, developing hydrogen infrastructure, preparing project facilities, and deploying innovative financing instruments to catalyse investment. These insights offer practical implications for development finance practitioners by outlining actionable initiatives to support the growth of the green hydrogen economy. The study's value lies in its recommended approaches for DFI interventions that foster climate resilience and accelerate the energy transition from fossil fuels to renewable sources. By aligning financial strategies with sustainability goals, DFIs can help unlock the potential of hydrogen as a transformative energy source. A noted limitation of the study was the low response rate to interview requests and completion of administered questionnaires, which may have constrained the breadth of stakeholder perspectives. Nonetheless, the research provides a foundational framework for guiding future investment and policy development in the hydrogen economy.

Keywords: Green hydrogen, development finance, renewable energy, hydrogen economy institutions.

INTRODUCTION

"Hydrogen holds great promise to meet many of our future energy needs, and it addresses national security and our environmental concerns. Hydrogen is the simplest, most abundant element in the universe." (Lipinski, 2021). The transition towards a low carbon economy globally to protect the environment has become an important issue for development finance institutions, governments, and other stakeholders with an interest in sustainable development. However, the limited gas supplies owing to the Russia invasion of Ukraine and extreme weather events have forced many countries to fall back on fossil fuels, which will delay the energy transition to green energy and net-zero emissions (EIU, 2023). Hydrogen has since emerged as an alternative energy carrier that produces no emissions when utilised to meet energy needs and can be produced from many sources. Hydrogen is a synthetic energy carrier for energy generated by other processes. High-grade electrical energy is transferred to hydrogen by the electrolysis of water and is used not only to produce hydrogen, but also to compress, liquefy, transport, transfer and store the medium. The use of hydrogen has the potential to help decarbonise the industrial, transport and heating sectors as hard-to-abate sectors such as steel and cement production will find it nearly impossible to decarbonise through electrification alone (Woodward, 2021). The 26th session of the Conference of the Parties (COP 26) urged development banks to scale up investments for climate resilience and explore innovative approaches and instruments for mobilising climate finance.

The objective of this paper is to define the properties of hydrogen, its production from different sources, and its various uses and challenges in establishing a hydrogen economy. The paper will further identify key opportunities and roles for DFIs in the establishment of the hydrogen economy in South Africa and the broader Southern African context.

This is because green hydrogen represents a transformative pathway to climate resilience, offering a clean, versatile, and scalable energy solution with applications across industries. A study of this nature is highly significant as the universal need to achieve net-zero emissions to protect the environment is highly dependent on decarbonising all sectors of the economy. However, certain sectors of the economy, such as heavy industries and long-distance transportation, will find it difficult to decarbonise through electrification.

Hydrogen thus provides an alternative energy source that has the potential to decarbonise such sectors, which makes it a key tool in the global effort to reduce greenhouse gas emissions and combat climate change (Boretti & Pollet, 2024). Hydrogen also provides a sustainable way to store and deliver renewable energy which can help to overcome one of the main challenges of renewable energy sources, namely their intermittency. It can further contribute to energy security by providing a way to store and transport energy and diversify energy sources, which is important as the world seeks to transition away from fossil fuels towards renewable energy sources. As a newly established energy source, there is a growing body of literature regarding hydrogen as an alternative source of energy; however, there is limited research regarding the involvement of DFIs in the establishment of the hydrogen economy.
This study therefore seeks to fill this research gap by providing an overview of the hydrogen economy and identifying roles that DFIs can play in its establishment. Hydrogen is an important energy carrier which can be stored, transported and used for fuel or converted to electrical energy in devices such as fuel cells.

A hydrogen economy as shown in Figure 1 is projected as a possible contribution to solving the current energy crisis and environmental degradation as hydrogen's conversion to heat or power is simple and clean. When combusted with oxygen, hydrogen forms water and no pollutants are generated or emitted (Bossel & Eliasson, 2003). The water is then also returned to nature, its original source. As such, hydrogen is emerging as a logical and appropriate type of chemical fuel to replace today's fossil fuels, mainly because hydrogen is a complementary energy carrier to electricity. Both energy carriers are necessary as each can satisfy a range of energy service demands, some of which cannot be satisfied by the other (Rosen & Koohi-Fayegh, 2016).

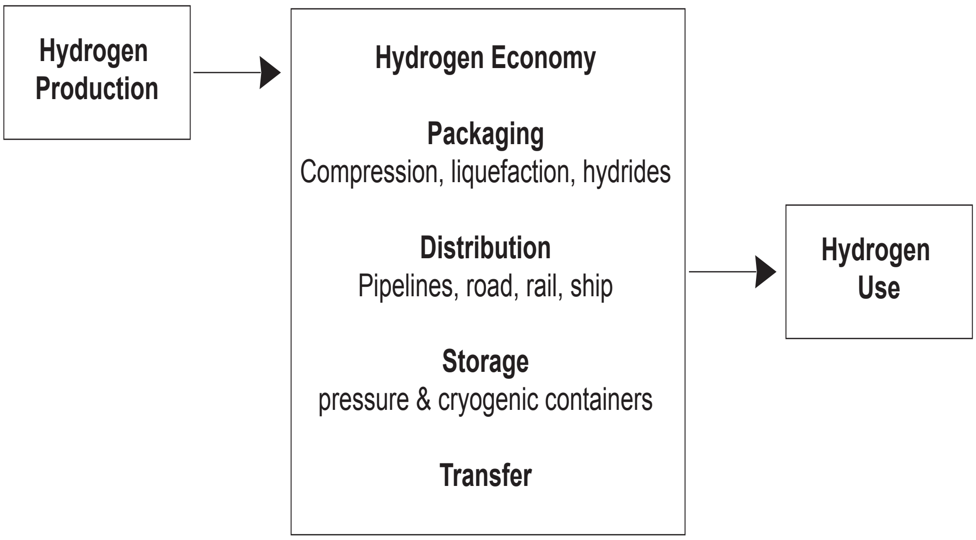

Figure 1: Schematic Presentation of a pure Hydrogen Economy

Physically, hydrogen is the smallest of all atoms and as such is the lightest gas (about eight times lighter than natural gas). Hydrogen also carries less energy per volume than natural gas at any pressure and has high lower heating values compared to traditional fossil fuels. Moreover, hydrogen offers the highest burning velocity compared to all other fuels (such as propane, methane, gasoline, diesel and methanol), whether liquids or gases. A high-performance indicator is offered by the hydrogen fuel cells in terms of efficiency, as fuel cells are not constrained by thermal efficiency limits of the thermal Carnot cycle (Ishaq et al., 2022). The Carnot cycle describes the maximum possible efficiency that a heat engine can achieve when operating between two temperature reservoirs. Currently, hydrogen production is dominated by fossil fuels, while natural gas is the most commonly used primary source of producing hydrogen. The steam methane reforming method is the most widely used method of producing hydrogen from natural gas (Amin et al., 2022). Hydrogen has also been widely produced from the coal gasification process, which is a process of converting any hydrocarbon source into useful synthetic gas, infusing a source such as oxygen in the process.

Furthermore, nuclear energy can also be used as a primary energy source for hydrogen production. This is because nuclear power plants can produce both electricity and heat which can be used for conventional water electrolysis and thermochemical or electrochemical processes in extracting hydrogen gas (Amin et al., 2022).

The production of hydrogen from non-renewable energy sources has garnered criticism because that type of production will have a negative impact on the environment, contradicting its status as a renewable energy source. This has resulted in the emergence of production methods of hydrogen using renewable energy sources. This has been termed green hydrogen and contributes to a small fraction of hydrogen production (Amin et al., 2022).
Hydrogen can be produced from biomass through biological processes and gasification. Hydrogen can also be produced from solar- and wind-powered electricity by means of water electrolysis. In South Africa, the role a hydrogen economy can play in the reindustrialisation of the country has been recognised (South African Government, 2023). In 2007, the South African Cabinet approved South Africa’s hydrogen strategy to initiate the development of hydrogen and fuel cell technologies through a 15-year programme. Currently, hydrogen cells have been used in the country as power sources in hospitals. Recently, the first ever hydrogen powered truck was unveiled (DIRCO, 2022).

RESEARCH METHODOLOGY AND METHOD

The methodology in this study followed a systematic review of existing literature with regard to the hydrogen economy and the roles DFIs can play in its establishment as proposed by Khan et al. (2003). Systematic reviews use repeatable analytical methods to collect secondary data and analyse it. Systematic reviews are a type of evidence synthesis which formulates research questions that are broad or narrow in scope, identify, and synthesise data that directly relate to the systematic review question (Khan et al., 2003). The following five steps were followed to conduct the systematic review:

Table 1: Steps of the systematic review

Framing questions for a review	The research goals were clearly and unambiguously stated to give an indication of the objectives of this study. The structured scope clearly identified the main topics as well as the subtopics to be addressed towards achieving the main objectives of this research.
Identifying relevant literature	An extensive search for relevant studies, reports and surveys was conducted and guided by the questions framed within the research scope.
Assessing the quality of studies	Selected studies were subjected to a more refined quality assessment using general critical appraisal guides and design-based quality checklists. The type, year, relevance, source, and credibility of each study were assessed for exploring heterogeneity and informing decisions regarding suitability of meta-analysis.
Summarising the evidence	For each subtopic listed in the scope, a data synthesis exercise took place to consolidate data from all the relevant literature included in this study, draw a conclusion from the body of evidence, and address the research objectives.
Interpreting the findings	An interpretation of the findings and results from the literature included in this study was conducted to identify any variability in study outcomes. If variability does exist, then outcomes observed from high-level quality studies were used for generating inferences.

Source: Khan et al. (2003)

The issues framed for the review were: hydrogen production, challenges in hydrogen production, storage of hydrogen, transmission and distribution of hydrogen, cost of hydrogen, present and potential uses of hydrogen in the context of a hydrogen economy, socio-economic impacts of the hydrogen economy, opportunities for development finance institutions in the hydrogen economy; and key roles development finance institutions can play in the hydrogen economy. Questionnaire surveys and interviews with key informants were also conducted to gather information on the hydrogen economy. The key informants' population was targeted and made up of renewable energy specialists within development finance and investment institutions. The questionnaire provided questions to be completed by the organisations' representatives and professionals. The questions were a combination of closed and open-ended ones and took about one (1) hour to complete. All information received was for the purpose of this study and was treated in confidence and not shared with third parties. Interviews were conducted on Microsoft Teams for one (1) hour, where questions were asked of the key informants with responses recorded. A 50% response rate to the questionnaires and interviews was achieved.

SYSTEMATIC LITERATURE REVIEW RESULTS

Hydrogen production

Globally, hydrogen is mainly produced by fossil fuels. The most widely used hydrogen production technology in recent years is natural gas steam reforming, oil reforming and coal gasification, with a small contribution coming from water electrolysis. Grey hydrogen is a fossil-derived hydrogen produced from natural gas or methane through steam reforming processes. This method of hydrogen production results in significant carbon emissions without applying any mitigation technologies (Chew et al., 2023). Brown hydrogen is fossil-derived hydrogen produced from coal through the gasification process. Hydrogen production from the coal gasification process is a well-established technological process already in use in countries with high coal endowment, such as China and Australia. However, this process is coupled with high carbon emissions and poses environmental concerns (Amin et al., 2022).

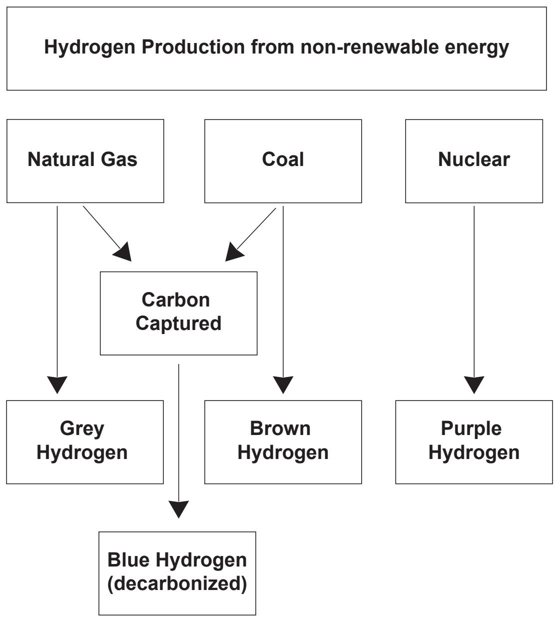

Figure 2: Hydrogen production from non-renewable energy sources
Sources: Adaptation from Chew, et al. (2023); Amin, et al. (2022); Ajanovic, et al. (2022)

Since both brown and grey hydrogen generate carbon emissions, blue hydrogen is a process whereby the grey and brown hydrogen processes are retrofitted with carbon capture and storage technology so that the carbon dioxide generated from grey and brown hydrogen processes can be captured and stored underground (Ajanovic et al., 2022). This results in low carbon hydrogen and relatively low emissions. Purple hydrogen results from the use of nuclear energy, which produces electricity and heat that can be utilised for conventional water electrolysis, thermochemical, or electrochemical processes in extracting hydrogen gas (Amin et al., 2022). Excess energy from nuclear reactors can be utilised to produce electrolytic-grade hydrogen on a massive scale instead of reforming hydrocarbons (Grigoriev et al., 2020).

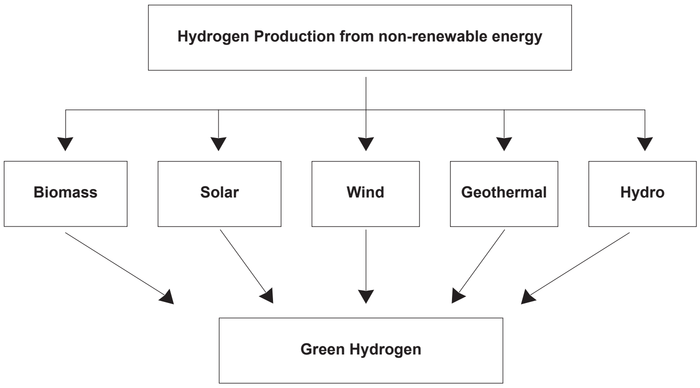

Figure 3: Hydrogen production from renewable energy sources
Sources: Adaptation from Chew, et al. (2023); Amin, etal (2022); Ishaq, et al., (2022)

Green hydrogen is produced from renewable energy sources, which include biomass fermentation, gasification, reforming, pyrolysis, and bio-photolysis processes. The process can result in minimal carbon emissions entering the atmosphere. This has been deemed acceptable owing to the life cycle assessments and audits showing the practice is near carbon neutral (Newborough & Cooley, 2020). Solar thermolysis, solar thermochemical cycle, solar gasification, solar cracking, and electrolysis can be used to produce green hydrogen. Solar photovoltaic sources generate electricity which is used in electrolysis and produces hydrogen. Thermal energy from concentrated solar thermal energy is also used to produce hydrogen through solar gasification and solar ammonia reforming (Ishaq et al., 2022). Wind energy-based hydrogen is produced from the electrical energy generated from wind as an energy source. The electricity is converted from alternate current (AC) to direct current (DC) and employed to the electrolyser which splits water into oxygen and hydrogen (Harrison, 2023). Geothermal energy is defined as the heat generated inside the earth's sub-surface (Lund, 2023). The geothermal energy is harvested from the underground to the surface through a heat transfer carrier whereby heat is first transferred through conduction heat transfer between rocks then through convective heat transfer. The hot water is then delivered to the surface (Ghazvini et al., 2019). The geothermal power can then be fed to water electrolysis for hydrogen production while the heat can also be used for thermochemical hydrogen production. Hydropower is the conversion of water-flowing energy into electricity (Kaunda et al., 2012) and is measured as a renewable energy source since the cycle of water is continually renewed. The electricity generated from hydropower can be employed to an electrolyser which splits water into oxygen and hydrogen.

Challenges in hydrogen production

The production of hydrogen faces challenges, particularly regarding energy security, energy equity, and environmental sustainability. These challenges differ depending on the renewability or non-renewability of the production source and method. Hydrogen production which is mainly dependent on fossil fuels faces issues of availability, as non-renewable energy sources have finite availability. The current global reserves-to-production ratio for coal – the ratio that represents the length of time that those remaining reserves would last if production were to continue at the previous year's rate – is 139 years (BP, 2021), while the same ratio for natural gas is 48.8 years (BP, 2021). The volatile market for energy prices places a challenge for the production of hydrogen using non-renewable energy sources. With the implementation of carbon emission taxes and the volatility in gas prices due to the recent Russia-Ukraine conflict, prices of non-renewable energy sources are likely to increase substantially, which poses a threat to energy equity (World Economic Forum, 2023).

Issues related to sustainability are magnified by the use of non-renewable energy sources when producing hydrogen. Both grey and brown hydrogen account for high carbon intensity, which contributes to annual carbon emissions that pose a threat to the environment. Brown hydrogen is twice as carbon intensive as grey hydrogen, while grey hydrogen is nine times more carbon intensive than green hydrogen (Gupta, 2022). The use of carbon capture and storage technology has been tried to reduce the emissions associated with hydrogen production from non-renewable energy sources; however, the technology is not 100% efficient in removing emissions, thereby affecting its reliability (Chew et al., 2023). The carbon capture and storage technology are also energy-intensive, expensive and takes a long time to build (Stephenson, 2023).

With increased gas prices, coupled with expensive carbon capture and storage technology, the production of blue hydrogen is very costly and not 100% sustainable. Hydrogen produced from renewable energy also presents issues with availability owing to the reliability of the renewable energy source. The intermittent nature of renewable energy sources such as solar and wind create reliability issues (Dixon, 2023).

Furthermore, location and weather conditions play a role in the efficiency of both solar and wind energy. This creates a cause for concern as to their sustainability in hydrogen production. Solar and wind technology prices have been gradually decreasing over time and now have a significant cost advantage over fossil fuels (Allen, 2023). This has led to increased construction of solar and wind farms. The life span of solar panels is between 25 to 30 years, while that of wind turbines is between 20 to 25 years (Bowman, 2021). It remains unclear what will happen to the technology once it has reached its useful life, and this may create environmental damage. As such, the waste material will need to be treated before disposal or recycling. The use of renewables in producing hydrogen heavily involves electrolysis, which has an energy efficiency of between 40% and 60%, which means it has a conversion loss of between 60% and 40% (Chew et al., 2023). The method itself is not highly efficient and coupled with solar panels (with efficiency of between 18 to 22%) and wind turbines (with 60% efficiency), the efficiency issue could be aggravated (Harrisons Solar, 2022). Renewable energy sources are mainly deployed in the generation of electricity to increase electricity generation capacity and decrease energy poverty. Without heavily increasing the capacity of renewable energy sources, diverting some of their current capacity towards producing green hydrogen will likely cause a decrease in their capacity to produce electricity for other end uses (Graaf, 2022). This has the potential to cause unintended energy poverty-related concerns.

Storage of hydrogen

Hydrogen is mostly stored physically as a gas or liquid in tanks for small-scale mobile and stationary applications. Storage of hydrogen as a gas requires high-pressure tanks (TWI Global, 2023). Compressed or liquefied hydrogen is also stored in tanks which have high discharge rates and efficiencies of close to 99% (International Energy Agency [IEA], 2019). Hydrogen can also be stored in chemical bonds with other materials such as metal hydrides, which allow large quantities of gaseous hydrogen to be thermally adsorbed and desorbed in chemical bonds with the surface of certain metals (Rosen & Koohi-Fayegh, 2016). Hydrogen can also be stored in ammonia, which is a combination of hydrogen and nitrogen gas. The process to combine both gases is the Haber-Bosch process; the hydrogen can be extracted from ammonia when and where it is needed by heating the ammonia to high temperatures (Serpell et al., 2023). There has also been research on the potential of salt caverns, depleted natural gas or oil reservoirs, and aquifers as options for large-scale and long-term hydrogen storage. They are currently mainly used for storage of natural gas; however, they also have the advantage of providing significant economies of scale, high efficiency, and low operational and land costs which is ideal for hydrogen storage (IEA, 2019).

Transmission and distribution of hydrogen

In recent times, around 85% of hydrogen is produced and consumed on site while only around 15% of hydrogen is transported via trucks or pipelines (IEA, 2019). This is owing to the low energy density of hydrogen which makes it very expensive to transport over long distances. To overcome the density challenges, hydrogen is usually either compressed, liquefied, or incorporated into larger molecules that can be transported as liquids. In many countries, existing natural gas pipeline networks could be used to transport and distribute hydrogen as there are around 3 million km of natural gas transmission pipelines worldwide. New infrastructure with hydrogen dedicated pipelines and shipping networks can also be developed to allow for large-scale overseas hydrogen transportation (Ishaq et al., 2022). Approximately 5 000 km of hydrogen pipelines exist worldwide, largely in the United States of America (USA), Belgium, and Germany (Burchard, 2023). These are operated by industrial hydrogen producers and are mainly used to deliver hydrogen to chemical and refinery facilities. Currently, there are no ships that can transport hydrogen. If such ships existed, they would be similar to liquefied natural gas ships, which would require the hydrogen to be liquefied prior to transportation (IEA, 2019).

The shipping supply chain would require new infrastructure which will include storage tanks, liquefaction plants, conversion, and reconversion plants to be built at the loading and receiving terminals as appropriate.

In terms of local distribution, hydrogen is mainly distributed through compressed gas trailer trucks for distances which are less than 300 km (Li et al., 2020). Hydrogen can also be transported by cryogenic tanker trucks, which can carry up to 4 000 kg of liquefied hydrogen (Brown, 2019). These types of tanker trucks are commonly used for long journeys of up to 4 000 km; however, they are not suitable for distances beyond that, as the hydrogen will heat up and cause a rise in pressure.

Cost of hydrogen

The cost of hydrogen production, transportation and storage will play an important role in establishing the competitiveness of hydrogen within the global energy mix. If hydrogen was to be produced and consumed on site, then its cost can be low. If, however, the produced hydrogen must travel a long distance before it is used, then the cost of the transmission and distribution may be significant.

Production cost of hydrogen:

Table 2 shows the costs of each of the listed methods of hydrogen production. The most economically advantageous methods are steam methane reforming and coal gasification. The costs of producing hydrogen from these non-renewable methods are lower than other methods in the table. This is owing to the technology being widely used and highly well-established in the production of hydrogen (Ji & Wang, 2021). The use of nuclear for hydrogen production is also relatively inexpensive, as existing nuclear facilities can be used in producing hydrogen either through electrolysis or thermolysis (Amin et al., 2022). The use of biomass in producing hydrogen is also relatively inexpensive, as processes such as biomass gasification can use waste as feed stocks instead of already commercialised fossil fuels (Ji & Wang, 2021). The production of hydrogen from geothermal energy has also been documented to be relatively inexpensive and largely depends on the level of efficiency of the geothermal power plant. Highly efficient geothermal plants produce hydrogen at lower costs as compared to less efficient plants (Ghazvini et al., 2019). The production of hydrogen from renewable energy sources is relatively expensive as the costs take into consideration the construction of renewable energy plants. These costs also vary depending on the type of renewable energy used. Solar PV has the highest costs depending on the energy conversion method and level of efficiency (Amin et al., 2022). Highly efficient solar plants produce hydrogen at a lower cost as compared to low efficiency plants. The cost of hydrogen produced from wind turbines depends on the amount produced and the type of turbines used. Larger turbines tend to produce hydrogen at a lower cost as compared to smaller turbines (Amin et al., 2022).

Table 2: Cost of various hydrogen production technologies

Method		Cost ($/KgH2)
Fossil fuels to hydrogen	Steam methane reforming	2.08
	Coal gasification	1.34
	Steam methane reforming (with carbon capture and storage)	2.27
	Coal gasification (with carbon capture and storage)	1.63
Biomass to hydrogen	Biomass gasification	1.77-2.77
	Direct bio-photolysis	2.13
	Photo fermentation	2.83
Electrolysis	Solar PV electrolysis	5.78-23.27
	Wind electrolysis	5.27-9.37
	Nuclear electrolysis	3.56-7.00
	Geothermal electrolysis	1.08-2.05
Thermolysis & thermochemical cycles	Nuclear thermolysis	2.17-2.63
	Solar thermolysis	7.98-8.40

Sources: Ji & Wang (2021); Amin et al. (2022)

Storage, transmission, and distribution costs of hydrogen:
The potential use of salt caverns for hydrogen storage presents a low-cost option for hydrogen, as they have low operational and land costs. Salt caverns have been used for hydrogen storage in the chemical sector in the United Kingdom (UK) and the USA and cost less than USD 0.6/kgH2 with around 98% efficiency (IEA, 2019). The IEA has also estimated that the cost of converting and storing hydrogen in chemicals such as ammonia costs around USD 1/kgH2. The use of existing natural gas infrastructure would avoid significant costs associated with developing new transmission and distribution infrastructure for hydrogen. However, the development of new hydrogen transmission and distribution infrastructure will result in high capital costs. Pipelines have low operational costs and a lifespan of around 40 years; however, they require high capital cost (Molnar, 2022). The IEA has estimated that it would cost around USD 1/kgH2 to transport hydrogen as a gas for around 1 500 km. On the potential of shipping hydrogen, significant costs can be incurred as part of the necessary shipping supply chain infrastructure, the actual ships, liquefaction process and the conversion process (IEA, 2019). The IEA has estimated that transporting liquid hydrogen by ship for around 1 500 km can cost USD 2/kgH2. The costs for transporting hydrogen using trucks is relatively high. Considering costs associated with hydrogen extraction, conversion and reconversion, the overall cost of transporting hydrogen via trucks for a distance of 500 km can be up to USD 2.9/kgH2 (IEA, 2019). Therefore, overall, the cost of transporting hydrogen depends on the mode and distance, plus any additional costs associated with conversions.

Currently, the production cost of green hydrogen is not competitive when compared to hydrogen produced from natural gas and other fossil fuels. High capital costs are a major factor constraining its cost competitiveness. Improving the cost competitiveness requires policy backing, including stricter climate change mitigation policies and stimulating not only the production of renewable power and electrolysers but also green hydrogen demand. Improving green hydrogen technology accessibility and affordability is thus vital in South Africa to ensure the integration of green hydrogen into the South African energy mix as well as ensuring that green hydrogen produced in South Africa is cheaper than in other regions to support its green hydrogen export ambitions.

Present and potential uses of hydrogen in the context of a hydrogen economy

Present uses of hydrogen:
The current usage of hydrogen is dominated by industrial application. Oil refining is the largest user of hydrogen, with about 33% of the global demand for hydrogen being consumed by refineries in order to turn crude oil into various end-user products such as transport fuels (IEA, 2019). Hydrogen is also used in smaller volumes for oil sands and biofuels. The chemical industry is the second largest user of hydrogen as it consumes it in the production of methanol and ammonia (D’hont, 2021). Ammonia is mostly used in the manufacturing of fertilisers while methanol is used for a diverse range of industrial applications. Hydrogen is also used in the production of iron and steel as steel is produced from a process called direct reduction iron, which requires hydrogen (IEA, 2019). An emerging usage of hydrogen is through fuel cells which require hydrogen to produce electricity, water and heat cleanly and efficiently (EIA, 2023). In South Africa, hydrogen fuel cells have been used to power field hospitals set up for COVID-19 patients during the various waves of the COVID-19 pandemic (DSI, 2020). In the USA, hydrogen fuel cells are used to power the electrical systems on spacecrafts (EIA, 2023).

Potential uses of hydrogen:
Hydrogen can be considered an alternative vehicle fuel, as it can power fuel cells in zero-emission vehicles. The fuel cell has the potential to be twice to three times more efficient than an internal combustion engine running on gasoline (EIA, 2023). Hydrogen fuel cell electric vehicles would reduce local air pollution as they have zero tailpipe emissions. Hydrogen-based fuels can also be used in shipping and aviation, which have limited low-carbon fuel options available (IATA, 2019). Hydrogen also has the potential to be used for high temperature heat. The heat can be used in industries for melting, gasifying, drying and mobilising a wide array of chemical reactions (IEA, 2019). Furthermore, hydrogen has the potential to be used in households for heating, though appliances such as boilers, cooking appliances and gas fires will need to be hydrogen ready. Hydrogen boiler technology is already being developed and used in the manufacturing industry; it has the potential to be adapted to serve households, provided there is a government-led transition (Nationalgrid, 2022).

Hydrogen can potentially be used for power generation and electricity storage. The carbon intensity of conventional coal power plants can be reduced by co-firing ammonia and hydrogen-fired gas turbines as a potential source of flexibility in electricity systems. Hydrogen in the form of either compressed gas, ammonia or synthetic methane could be used for long-term storage options to balance seasonal variations in electricity generation from renewables (EIA, 2023).

Socioeconomic impacts of the hydrogen economy

Food security:
The agriculture sector is key to food security and economic growth. However, the sector is highly carbon intensive and relies on unsustainable fossil fuels for food production (Hamukoshi et al., 2022). Green hydrogen can provide a sustainable and clean alternative for food production in agriculture, thereby strengthening food security. Hydrogen is already used in some agriculture activities such as grain drying and cooling. However, it has the potential to be used in more agriculture activities such as hydrogen-powered harvesters, irrigation systems, greenhouses, and autonomous farming machinery (Conklin & Beresnya, 2023).

Transport sector:
With the large potential for green hydrogen use in the transport sector via electric vehicles and fuel cells, countries which produce green hydrogen can export it to countries which require it to decarbonise their transport sector, as part of the Paris Agreement towards carbon-neutrality (United Nations Climate Change, 2015). This will be beneficial for the exporting countries as companies in such countries would benefit from the sale and value addition of material required in the green hydrogen economy, such as platinum for fuel cells and electrolysis. South Africa’s rich endowment of minerals, particularly the platinum group metals (PGMs), presents a significant strategic advantage in the global energy transition as PGMs serve as critical components within electrolysers used for hydrogen production and catalysts employed in fuel cells.

Geopolitical issues:
The use of hydrogen to fuel vehicles poses a major threat to the petroleum sector, which generates large amounts of revenue and creates many employment opportunities globally. As such, replacing crude oil with green hydrogen has the potential to cause major economic, social, and political instability (Fickling, 2020). Governments then have the responsibility to assess this transition to green hydrogen and ensure no one is negatively affected or left behind. The construction of new green hydrogen infrastructure will create new jobs and opportunities for training new skills which can stimulate the economy. There have also been concerns that African countries may not have the market locally to consume green hydrogen (owing to its costs), which will then mean that most of the hydrogen produced in countries such as South Africa and Namibia will then be exported overseas.

This is a geopolitical concern, as it may be misperceived that African countries produce energy for the consumption of European or Western countries, while Africa remains an energy poor continent. However, the emergence of the electric vehicle market particularly presents an opportunity for consumption of hydrogen locally, and not necessarily only for export purposes. The large-scale use of water for electrolysis during green hydrogen production can also pose a concern for water-scarce countries. Communities in water-scarce countries may believe that water should be intended for their own consumption or at least consumption of the agriculture sector; as such they may view hydrogen production as a waste of scarce water resources.

Opportunities for development finance institutions in the hydrogen economy[1]
DFIs are at the early stages of formulating and implementing their support for green hydrogen. There are some pioneering projects led by DFIs in the hydrogen space such as the SA-H2 Fund in South Africa and the SDG Namibia One sovereign wealth fund. DFIs are uniquely placed to develop the green hydrogen economy for emerging and developing economies. This section highlights some key opportunities for DFIs within this space.

1 Information sourced from interviews with key informants: Participant 1 - Climate Change Specialist; Participant 2 - Climate Finance Specialist

Climate finance commitments
DFIs have already made commitments to align their operations with climate change mitigation and adaptation goals in support of achieving net-zero emissions targets set by the Paris Agreement (United Nations Climate Change, 2015). As such, an opportunity for DFIs to invest in the establishment of the green hydrogen economy is aligned with their existing climate financing commitments.

Risk reduction capacity
The development of the green hydrogen economy may have offtake risks associated with it, particularly in developing and emerging economies. An offtake risk relates to not being paid for the power output, which is a major barrier for energy investing in developing and emerging economies which are faced with poor economic growth and low income. These can lead to the potential for bad debts, tariff-underpricing and even theft. These in turn increase financing costs and delay the much-needed investment in power infrastructure. DFIs are well placed to mitigate such risks by managing and sharing the risk, while also reducing the cost of investment capital to allow such economies the opportunity to benefit from green hydrogen projects (GH2, 2022).

Knowledge and expertise
DFIs have vast experience in successfully scaling up investment in the development of the renewable energy sector (Xu & Gallagher, 2022). This experience and expertise are highly required to ensure the appropriate development of the hydrogen economy by employing effective climate financing strategies and infrastructure development.

Key roles development finance institutions can play in the hydrogen economy[2]
This study has assessed the hydrogen economy in terms of three phases: hydrogen production; hydrogen storage, transmission and distribution; and hydrogen current and potential usage. For hydrogen to be a sustainable energy source, green hydrogen should be used. This section looks at the roles development finance institutions can play in the green hydrogen economy based on the three phases of the hydrogen economy.

Scaling up renewable energy capacity
Green hydrogen is largely dependent on the capacity of renewable energy sources which are required for its production. DFIs have already played a significant role in renewable energy development as an alternative source of electricity. For renewables to meet the growing demands of hydrogen production, however, their capacity should be scaled up significantly. Therefore, DFIs have a role to play in significantly increasing the capacity of renewables such as solar, wind and hydro to meet the growing demands of hydrogen production and the existing demand of green electricity.

Creating an enabling environment for green hydrogen investments
As the demand for green hydrogen increases, regulatory frameworks play a crucial role in fostering a supportive environment for investment, ensuring safety standards, and promoting sustainable practices. In creating an enabling environment for green hydrogen investment, DFIs have a role to play in supporting government's capacity in establishing regulatory, contractual and policy regimes for green hydrogen (Alix & Burns, 2023). Such frameworks can include common procurement standards for public sector projects financed by DFIs. Such consistent standards can help reduce the administrative burden in hydrogen projects and subsequently reduce project costs (GH2, 2022). DFIs can also provide technical assistance to governments in order to support the integration of green hydrogen into their national energy mix by identifying policy instruments that can increase green hydrogen demand such as carbon taxes.

2 Information sourced from interviews with key informants: Participant 3 - Lead Green Hydrogen Developments; Participant 4 - Principal Project Preparation.

Hydrogen infrastructure development

The transmission and distribution of hydrogen require the development of new infrastructure, particularly pipelines and shipping networks, to allow for large-scale hydrogen transportation. The shipping supply chain requires new infrastructure such as storage, liquefaction plants, conversion, and reconversion plants. With DFIs' vast experience in infrastructure development, they have a role to play in facilitating the development of new hydrogen storage, transmission, and distribution infrastructure.

Project preparation facilities

DFIs can also support early project development in terms of scoping and feasibility studies for green hydrogen projects. This can be achieved through a dedicated facility or fund with fast approval procedures to tackle specific bottlenecks in renewable and green hydrogen sectors. DFIs can also support catalytic projects in the green hydrogen space, as they demonstrate the bankability of such projects and introduce the potential for modern technologies and innovations within that space.

Scale up innovative financing instruments to catalyse green hydrogen investment

DFIs have vast experience in scaling up innovative financing instruments, such as green bonds, to catalyse investment into renewable energy sources. The same experience can be channelled into scaling up green hydrogen investment through innovative financing such as green bonds specifically for hydrogen projects. Concessional and blended financing as well as grants can be used in emerging and developing economies to de-risk and crowd in private investment through co-financing. Guarantees, as climate financing commitments, can also play a significant role in improving and de-risking investments in green hydrogen projects (GH2, 2022).

CONCLUSION

The first objective of this research was to define the properties of hydrogen, its production from different sources, its various uses, and the challenges in establishing a hydrogen economy. The second objective was to identify key opportunities and roles for DFIs in the establishment of the hydrogen economy in South Africa with reference to the broader Southern African context. The research first analysed hydrogen production from both renewable and non-renewable energy sources, focusing on the costs and challenges associated with each method of production. The research then assessed hydrogen storage, transmission and distribution as well as hydrogen's current and potential uses and the likely socio-economic impact of the transition to a green hydrogen economy. The socioeconomic impacts included potential impacts on food security, the transport sector, and geopolitical issues such as employment or energy trade dependencies.

Findings from the study highlighted key opportunities for DFIs in the establishment of a green hydrogen economy, such as climate finance commitments, risk reduction capacities and the knowledge and expertise they can provide in support of green hydrogen projects. The study further identified practical implications and roles that DFIs can play in the green hydrogen space such as scaling up renewable energy capacity in order to produce green hydrogen, creating an enabling environment for green hydrogen investments, developing hydrogen infrastructure, creating facilities for green hydrogen project preparation, and scaling up innovative financing instruments to catalyse green hydrogen investment. Development of the green economy supports the just energy transition to renewables, which strengthens climate resilience to adverse climate events and extreme weather conditions as green hydrogen reduces reliance on fossil fuels in hard-to-abate industries.

RECOMMENDATIONS

This study recommends that DFIs should support the establishment of the green hydrogen economy by scaling up renewable energy capacity to produce green hydrogen and creating an enabling environment for green hydrogen investments through technically supporting the government's capacity in establishing regulatory, contractual and policy regimes for green hydrogen. This study also recommends that DFIs should support the development of green hydrogen-related infrastructure, project preparation facilities and the scale-up of innovative financing instruments to catalyse green hydrogen investment.

Green hydrogen remains a key energy source for achieving net zero emissions, especially for sectors that would find it difficult to decarbonise otherwise. It is thus important for DFIs to play a significant role in its establishment into the global energy mix.

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