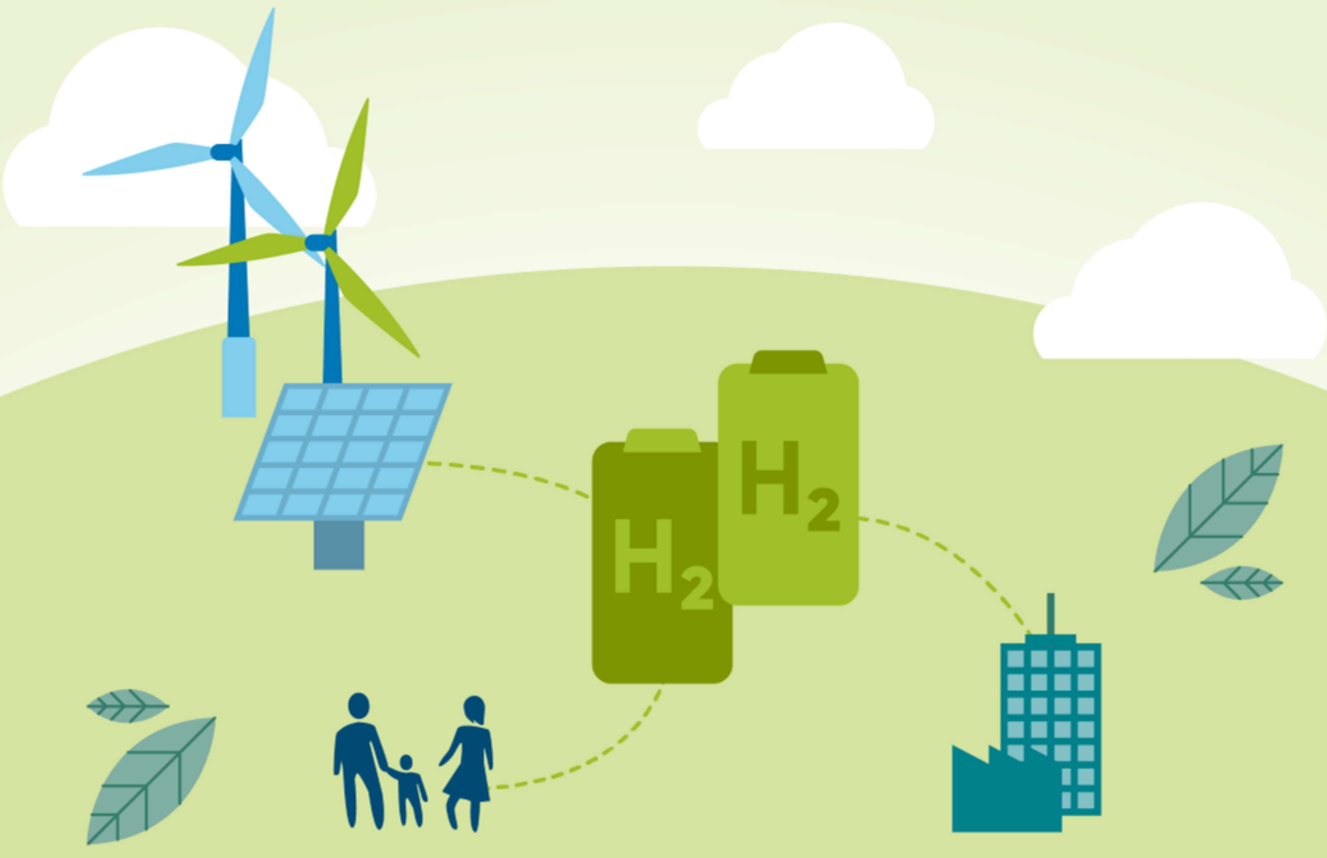
Brief technical analysis of potential Power-to-X application pathways in Brazil, Namibia, and South Africa



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Abbreviations

Abbreviation	Meaning
bbl	barrel
BEV	battery electric vehicles
BRA	Brazil
CCUS	carbon capture, utilization and storage
CO_2	carbon dioxide
CUI	common-use infrastructure
DRI	direct reduced iron
DWV	German Hydrogen and Fuel Cell Association e.V.
FCEV	Fuel Cell Electric Vehicles
GDP	gross domestic product
GHG	greenhouse gases
GW	gigawatt
HSRM	Hydrogen Society Roadmap for South Africa 2021
H_2	hydrogen
IEA	International Energy Agency
mtpa	million tonnes per annum
NAM	Namibia
N_2	nitrogen
NH_3	ammonia
ppm	parts per million
PVI	Platinum Valley Initiative
RE	renewable energies
SAF	sustainable aviation fuels
SCDI	Southern Corridor Development Initiative
SCF	standard cubic feet
SRC	short rotation coppice
t/a	tonnes per annum
TRL	technology readiness level
ULSD	ultra low sulphur diesel
WV Stahl	German Steel Association (Wirtschaftsvereinigung Stahl)
ZAF	South Africa

1. Executive summary

In order to assess the potential that hydrogen applications offer for national value creation in the partner countries Brazil, Namibia and South Africa, this analysis investigated (1) the policy potential, (2) the economic potential and (3) the potential for reducing greenhouse gas emissions by pursuing possible hydrogen pathways. For the sectors identified as meeting the potential-criteria in all three areas, the demand for hydrogen was calculated and in each case the hydrogen production capacity based on renewable energies was determined.

1.1 Brazil

1.1.1 Fertiliser production

In Brazil, there are significant opportunities for national value creation, particularly in the production of nitrogen fertiliser for agriculture. Currently, almost 100% of nitrogen fertiliser is imported. If ammonia, the raw material used in nitrogen fertiliser, were to be produced domestically today, the process could use 116,000 tonnes of hydrogen each year, rising to 604,400 tonnes per annum by 2040. This is equivalent to a production capacity of 1.2 GW of installed electrolysis capacity for 2022 and 6.3 GW for 2040. This could reduce both import dependencies and the associated price and default risks, in addition to achieving national value added through domestic production.

1.1.2 Oil refinery

Brazil's well-developed refineries sector has the potential to use green hydrogen for hydrodesulphurisation in the production of low-sulphur fuels. This would help Brazil both to reduce greenhouse gas emissions at the refinery and to satisfy the growing market for low-sulphur fuels. If green hydrogen is used for the generating capacities planned from 2025, 572,100 tonnes of hydrogen could be used annually. This would require a production capacity of 6.0 GW of installed electrolysis capacity.

1.1.3 Steel production

Brazil comes just behind Germany as the world's ninth largest steel producer, producing more than half of Latin America's total output. With a national target of achieving CO_2-neutrality by 2050, it is essential the country avoids the high level of process-related CO_2 emissions from iron ore reduction. Besides carbon capture, storage and use, direct iron ore reduction using green hydrogen could make the biggest contribution. Until the reduction process using only hydrogen is technically mature and economically feasible, this could initially be done by blending hydrogen with natural gas. This technology shift could help sustain the country's steel industry, while also serving the growing market for 'green steel'. The potential for hydrogen use is estimated at 448,000 tonnes per year from 2030 and 770,000 tonnes per year from 2050. This is equivalent to a production capacity of 4.7 GW of installed electrolysis capacity for 2030 and 8.1 GW for 2050.

1.1.4 Traffic and transport

For historical reasons and due to its strong agricultural sector, Brazil is taking a special approach to decarbonising the transport sector by focusing on biofuels. Brazil is the world's second-largest producer of bioethanol and third-largest producer of biodiesel. Biodiesel production requires large quantities of methanol, which is currently only imported. If production were in Brazil using locally produced green hydrogen, a total of 127,000 tonnes of hydrogen could already be used by 2025. This equates to a production capacity of 1.3 GW of installed electrolysis capacity. If the framework conditions were put in place for an alternative fuels market alongside biofuels, demand for hydrogen could rise further, in particular with the introduction of fuel cell vehicles in heavy goods road haulage and the use of ‘green kerosene’ in aviation. The demand for hydrogen in heavy goods transport is estimated at 180,000 tonnes from 2035 and 971,000 tonnes from 2040. The demand for synthetic kerosene in aviation is estimated at 355,000 tonnes of hydrogen annually from 2030. The total required production capacity would therefore increase from 1.3 GW of installed electrolysis capacity for 2025 to 6.1 GW for 2030, 8.0 GW for 2035 and 16.2 GW for 2024.

1.2 Namibia

1.2.1 Steel production

In Namibia, the national strategy focuses on the export of green hydrogen derivatives such as methanol and ammonia. Separately to this, the company Lodestone Namibia is developing the project H2yron, which aims to develop a local iron ore deposit in Namibia as well as producing sponge iron (direct reduced iron, DRI) for export using hydrogen. A preparatory feasibility study for the project is currently being carried out prior to an investment decision. If implemented, H2yron could benefit from the government’s efforts and gain access to shared infrastructure in the Southern Region of the planned hydrogen valley. This would make infrastructure available for production of the required quantities of green hydrogen and for steel exports. The planned production capacities would require 27,000 tonnes of hydrogen annually in the first development phase and 110,000 tonnes in the second development phase. The required production capacity would be 0.3 GW of installed electrolysis capacity for phase 1 and 1.2 GW for phase 2.

1.2.2 Traffic and transport

According to the World Bank, emissions from the transport sector in Namibia accounted for 55.4% of total national emissions in 2014. By shifting fuel use away from diesel towards hydrogen, transport-related emissions are to be reduced by 42%. From 2026, hydrogen will be used above all in fuel cell vehicles for mining, thereafter in fuel cell vehicles for medium-duty road haulage and from 2030 to 2035 for heavy goods transport. Local demand for hydrogen applications in transport is estimated at 95,000 tonnes of hydrogen per year from 2040. Meeting this demand would require a production capacity of 1.0 GW of installed electrolysis capacity.

1.3 South Africa

1.3.1 Oil refinery

The fuel refining industry in South Africa is currently at a crossroads. The more stringent requirements of the fuel specification Cleaner Fuels II will come into force in 2023. To comply with these requirements, the country will either have to invest heavily to put in place the technical prerequisites for domestic production, or rely purely on imports. Construction of a new refinery in the Richard Bay region, with a production capacity of 400,000 barrels per day, is currently under discussion. If this refinery is built and comes on stream at the end of this decade, desulphurisation could be achieved using green hydrogen. The resulting potential hydrogen demand from 2030 onwards would amount to 275,000 tonnes per year, with a required production capacity of 2.9 GW of installed electrolysis capacity.

1.3.2 Steel production

South Africa is Africa's second largest steel producer behind Egypt and ranks 27th in the world. However, the domestic steel industry is under pressure from cheap imports from China, rising production costs in the country and lower domestic demand. According to the Steel Masterplan, the switch to DRI production and subsequent use of green hydrogen represents an opportunity to realise investment in the steel industry and open up export markets for green steel. The 2021 Hydrogen Society Roadmap for South Africa (HSRM) also describes green steel production as a national priority. The potential hydrogen demand for DRI production is estimated at 91,000 tonnes per year from 2030 and 182,000 tonnes per year from 2050. This would require a production capacity of 0.3 GW of installed electrolysis capacity for 2030 and 1.9 GW for 2050.

1.3.3 Traffic and transport

The transport sector is responsible for about 11% of greenhouse gas emissions in South Africa. One of the projects initiated as part of the HSRM is the Platinum Valley Initiative (PVI), also known as the South Africa Hydrogen Valley. The PVI aims to create a hydrogen corridor between Limpopo, Johannesburg and Durban, in particular to establish fuel cell vehicles in heavy goods road haulage and mining. The annual potential hydrogen demand for these applications is estimated at 19,300 tonnes per year from 2025 and 71,800 tonnes from 2030. Meeting this demand would require a production capacity of 0.2 GW of installed electrolysis capacity in 2025 and 0.8 GW in 2030.

2 Introduction

For this report, the countries Brazil, Namibia and South Africa were analysed for potential hydrogen (H_2) application pathways that could contribute to national value creation in each country. The analysis compared possible value chains with the policy and strategic goals of the partner countries ('policy potential'), as well as with individual economic sectors such as industry, transport or agriculture ('economic potential').

As potential hydrogen value chains, sectors were selected where the use of hydrogen has the potential to preserve or expand employment, and in each case to reduce greenhouse gases (GHG) in the short to medium term (see Figure 1).

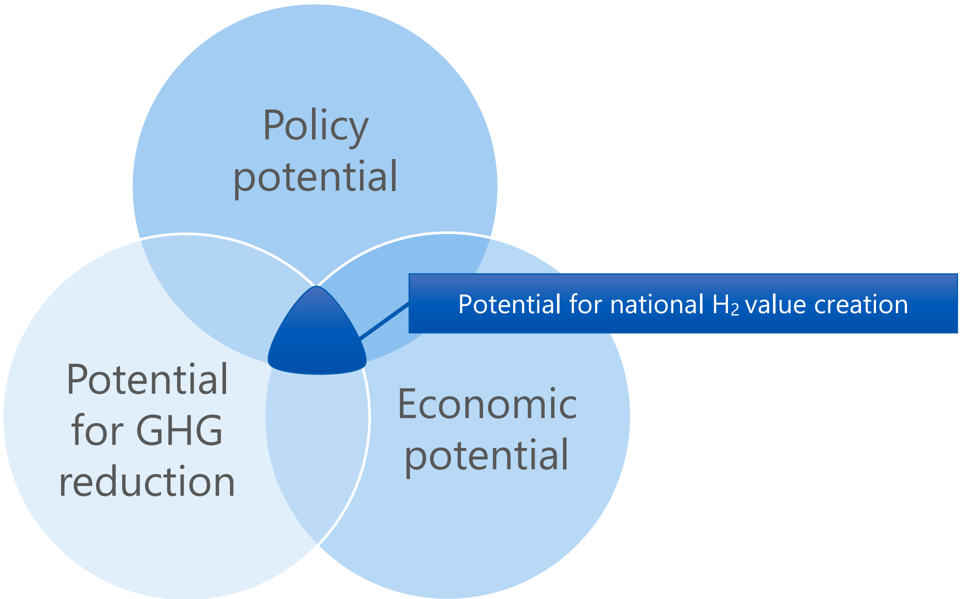


Figure 1 Determining the potential for national value creation

A special focus was placed on the so-called 'hard-to-abate' sectors, in which substituting an application is either not possible or necessitates a lot of effort and entail structural changes. This includes, for example, goods transport by road, rail, ship or air. Any shift away from liquid fuels through electrification in these sectors is only partially possible, if at all. For this reason, the focus is on the use of green, gaseous and liquid fuels. The situation is similar in industry, for example in steel production, where greenhouse gas emissions incurred through the essential process of iron ore reduction are very high. Alternative reduction processes that do not use fossil fuels are therefore being considered for steel production, with the focus on direct reduction of iron ore (DRI) to sponge iron, using hydrogen.

Components of the analysis for policy potential included:

- strategies and roadmaps for developing the hydrogen sector
- support programmes for research and development of hydrogen applications, and for their demonstration
- GHG reduction targets for the various economic sectors.

Analysis of the economic potential considered the following aspects, among others:

- relevance of the individual sectors with regard to:
    - contribution to gross domestic product (GDP)
    - type and quantity of fuels used that are suitable for partial or complete substitution by hydrogen
    - level of GHG emissions
- ongoing or announced projects which already involve the production and/or use of hydrogen
- forward-looking investments in the respective sectors
- expected break-even point for using hydrogen in individual applications.

On the basis of the criteria set out above, a maximum of four relevant hydrogen application pathways were identified for each partner country and the potential for hydrogen use was calculated in each case. In cases where there was insufficient data to calculate a specific potential for use, an equivalent qualitative assessment was carried out.

In addition, the analysis lists relevant industry stakeholders who already play or are able to play a role in the respective application pathways. A technical presentation of the relevant application pathways is given in Section 3 following this introduction. The basis used to calculate the production capacity required to produce the determined demand for hydrogen by means of electrolysis is shown in Table 1.

Table 1 Basis of the H_2 production capacity calculation

Position	Value	Unit
Hydrogen density	0.0898	kg/Nm³
Calorific value of hydrogen	3.00	kWh/Nm³
Specific energy demand for hydrogen production	4.70	kWh/Nm³
Full-load hours of electrolysis	5,000	h/a
Standard cubic feet of hydrogen	38.04	scf/Nm³

3 Technical presentation of potential application pathways for green hydrogen

3.1 Ammonia synthesis

Figure 2 shows the main process flows of an ammonia synthesis plant using the Haber-Bosch process.

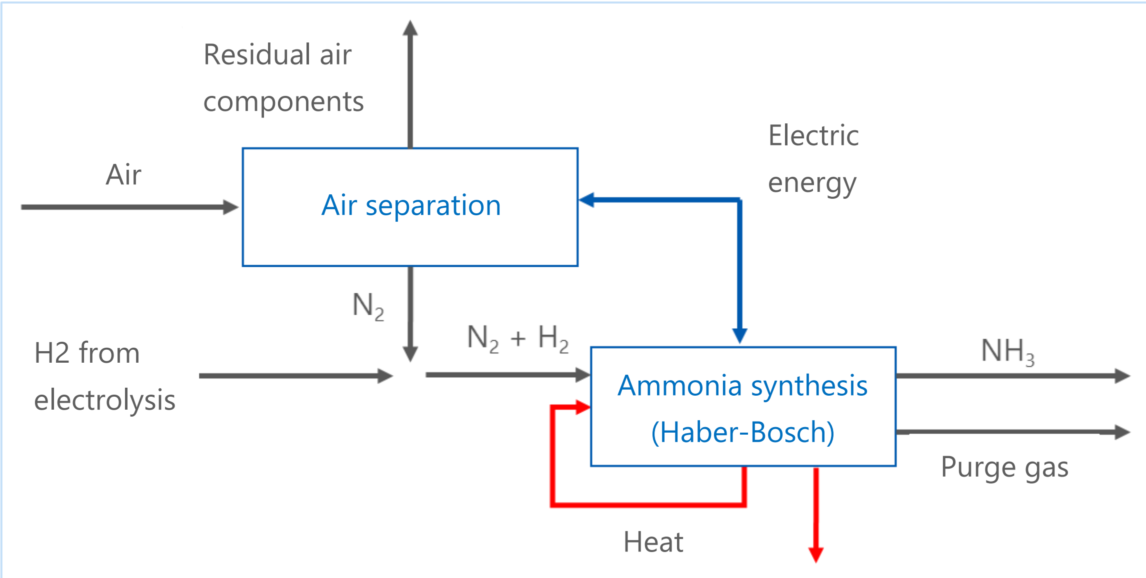


Figure 2 Ammonia synthesis

In ammonia synthesis, hydrogen (H_2) and nitrogen (N_2) are combined in an exothermic catalytic reaction to form ammonia (NH_3). The nitrogen is supplied from an air separation unit. This breaks down air into its components using electricity from renewable energies. The nitrogen and hydrogen are compressed, heated and fed into the Haber-Bosch reactor. The heat is regenerated from the exothermic synthesis process, while electricity from renewable energies is also used for compression. Depending on the purity of the hydrogen and nitrogen used, it may be necessary for a purge gas to be released during the Haber-Bosch process. This prevents inert gases from accumulating in the synthesis loop. There are no other relevant by-products.

Based on the stoichiometry of hydrogen (H: 1.00784 g/mol) and nitrogen (N: 14.0067 g/mol), the hydrogen demand is 177.53 kg per tonne of ammonia.

3.2 Desulphurisation at the refinery

Requirements governing sulphur content in liquid fuels such as diesel or petrol have been constantly tightened up in recent years. 'Hydrotreating' or hydrodesulphurisation to remove sulphur and other impurities such as nitrogen is therefore one of the key refining processes.[1] An overview of steps involved in the refining process for diesel, naphtha, kerosene and petrol, as well as for the required hydrodesulphurisation, is shown in Figure 3.

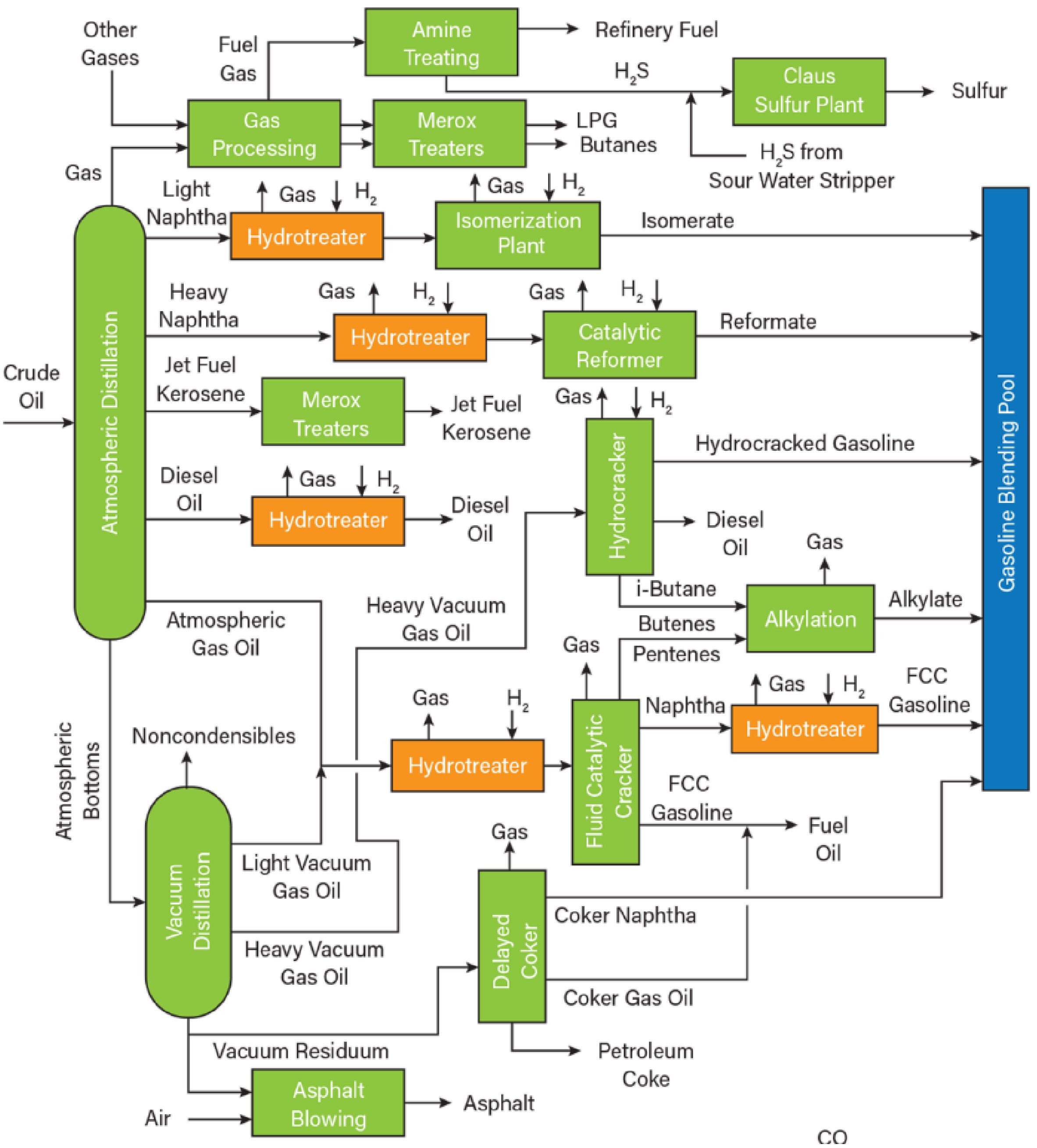


Figure 3 Steps in the hydrodesulphurisation process in a refinery[2]

[1] Hydrotreating | Wissenswertes | Home Aral Forschung
[2] An Overview of Hydrotreating | AIChE

The product, for example petrol or heating oil, is first mixed with hydrogen and heated. The hot mix is fed into a reactor filled with a catalyst. Here at a temperature between 300 and 400 degrees Celsius, the catalyst causes a reaction between the sulphur from the sulphur-containing product and the hydrogen to form hydrogen sulphide. The next step separates the purified product, the hydrogen sulphide produced and the remaining hydrogen from each other.[3]

Hydrogen is therefore one of the most important elements in the production of low-sulphur fuels. Only 15% to 30% of the hydrogen required for this can be obtained from internal processes at the refinery, for example from naphtha reforming. The rest must be supplied from external sources.[4]

The growing demand for fuels worldwide requires an increase in refinery productivity. In addition, fuel purity requirements are becoming increasingly stringent, with a simultaneous decline in the availability of crude oil with low sulphur content. The importance of hydrodesulphurisation is therefore set to increase in future, as is the demand for hydrogen in the production of liquid fuels in refineries.[5]

In order to determine the exact hydrogen demand for hydrodesulphurisation, it is necessary to ascertain both the quality of the crude oil and the relevant specifics of the technologies used. According to the literature, hydrogen demand ranges from 750 to 1,000 standard cubic feet of H_2 per barrel of crude oil[6]. A conservative value of 800 standard cubic feet H_2/bbl was used as the calculation basis for this study.

[3] Hydrotreating | Wissenswertes | Home Aral Forschung
[4] An Overview of Hydrotreating | AIChE
[5] An Overview of Hydrotreating | AIChE
[6] Microsoft Word - NPRA PAPER.doc (elessentct.com); Microsoft Word - PC_2_2007_Shokri.doc (vurup.sk)

3.3 Methanol synthesis

An example of methanol synthesis from green hydrogen and CO2 is shown in Figure 4 .

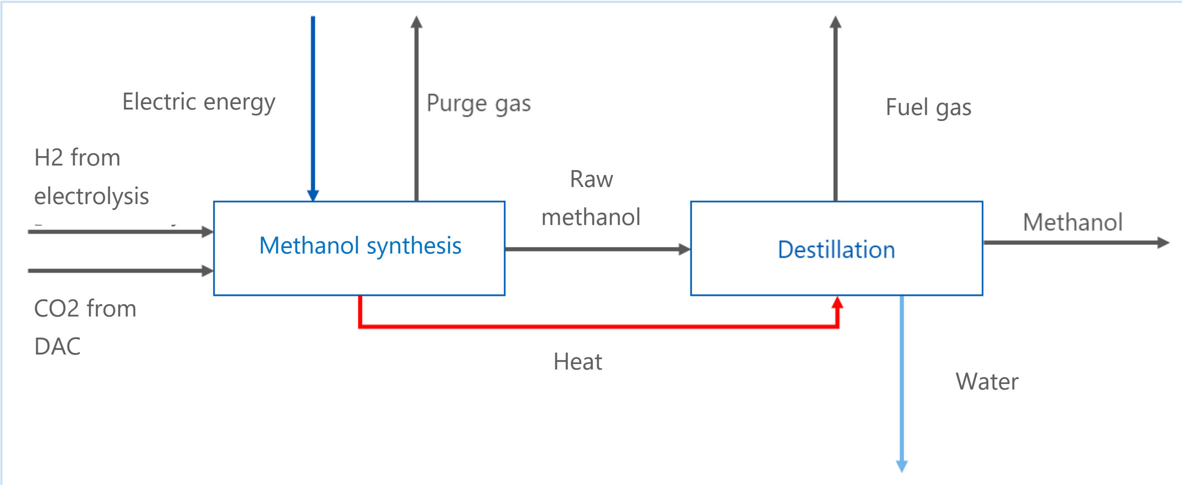


Figure 4 Methanol synthesis

Methanol synthesis is an exothermic process using hydrogen and carbon dioxide. The main product is methanol, the by-products are water, fuel gas and purge gas. The fuel gas can be burnt to generate heat. Since the required CO_2 is extracted from the air by means of direct air capture, any exhaust gases containing CO_2 can be considered as not actively contributing to greenhouse gases in terms of emissions balance. From this perspective, methanol synthesis emits zero process-related CO_2. Since methanol synthesis is exothermic and the waste heat can be used to distil the methanol through internal heat integration, no additional thermal energy is required during normal operation. Typically, methanol synthesis is operated at 200 to 300 bar, which means that electrical energy is required for compression.

In this study, the methanol demand for biodiesel production is analysed as a potential hydrogen application pathway. The production of one volume unit of biodiesel requires 0.2 volume units of methanol[7]. Based on the stoichiometry, the hydrogen demand to produce one tonne of methanol (CH3OH: 32.04 g/mol) is 125.84 kg.

[7] BiodieselEconomics.pdf (tnstate.edu)

3.4 Steel production through direct reduction

The iron and steel sector is one of the largest industrial sectors in terms of energy demand and accounts for 7% of global CO_2 emissions. About 75% of this energy demand is currently met by coal to provide process heat and coke for iron ore reduction. A relevant contribution to the industry's efforts to reduce process-related emissions can be made in particular by carbon capture, utilisation and storage (CCUS) and by the direct reduction of iron ore using green hydrogen.[8]

Below is a comparison of conventional steel production and direct reduction using hydrogen, with an explanation of the key technical differences.

The classic blast furnace route for primary steel production[9]

1. **Feeding**: Iron ore, coke and other fluxes such as limestone are fed into the top of the blast furnace.
2. **Raceway zone**: Coal is injected into the blast furnace via the tuyeres. The injected coal reacts with oxygen at over 2,000 degrees Celsius. In addition to heat, carbon monoxide is given off and flows up through the furnace.
3. **Pre-heating zone**: Hot reducing gases rise up from below. They heat and dry the ore-coke mix.
4. **Indirect reducing zone:** Carbon monoxide flows upwards from below. The iron ore is reduced in a chemical reduction with the carbon monoxide. This reduces the oxygen content of the iron ore.
5. **Direct reducing zone:** The mass slips further down the furnace where, on account of the increased temperature, the carbon can react directly with the iron oxides in the ore and reduce it further to produce pig iron.
6. **Melting zone**: There is now an accumulation of carbon in the iron, reducing its melting point. The pig iron melts.
7. **Product discharge**: Slag and pig iron collect in the lower part of the blast furnace and are discharged separately.
8. **Waste gas**: At the top of the blast furnace, the remaining reducing gas escapes as blast furnace gas – the gaseous by-product of the blast furnace.

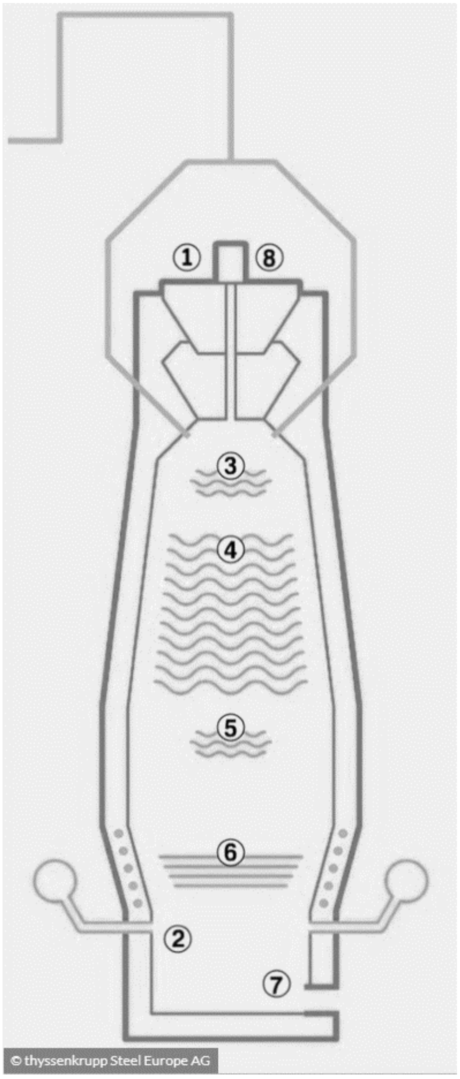
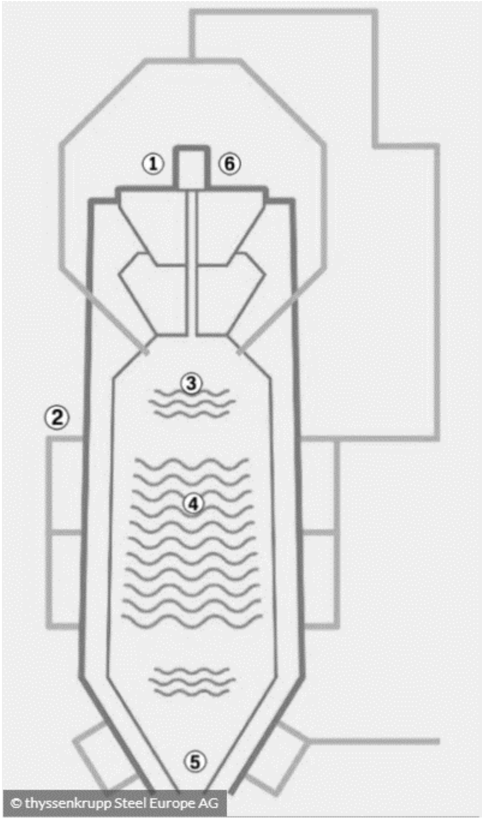


Figure 5 Classic blast furnace route for primary steel production

[8] Iron and Steel Technology Roadmap – Analysis – IEA
[9] Projekt H2Stahl - energiesystem-forschung.de

Direct reduction for primary steel production[10]



1. **Feeding**: Iron ores (pellets, lump ore) are fed into the direct reduction plant.
2. **Gas inlet**: In this area, the reducing gas hydrogen (or hydrogen-containing gases, e.g. natural gas) is fed into the reactor at a temperature above 1,050 degrees Celsius. Due to the catalytic effect of the metallic iron, carbon monoxide and hydrogen are formed in situ.
3. **Pre-heating zone**: The iron ore is dried and preheated by the rising hot reducing gas.
4. **Reducing zone:** The carbon monoxide and hydrogen contained in the upflowing reducing gas reduce the iron ore. Sponge iron is formed.
5. **Product discharge**: The reduced iron is discharged at the discharge with a degree of metallisation of up to 94 % and can be made available for further processes.
6. **Waste gas**: The process gas leaves the direct reduction unit at the upper end.

Figure 6 Direct reduction for primary steel production

Direct reduction is currently state of the art, but only with the use of natural gas as a reducing agent. There are several demonstration and pilot plants worldwide that use hydrogen, for example H2Stahl (Thyssenkrupp Steel Europe),[11] SALCOS (Salzgitter AG)[12] and ArcelorMittal[13] [14] in Germany, HYBRIT (SSAB)[15] [16] and H2 Green Steel (H2GS)[17] in Sweden, and the HBIS Xuansteel Hydrogen Project (HBIS Group)[18] in China.

According to the International Energy Agency (IEA), the technology readiness level (TRL) of direct reduction using only hydrogen is given as TRL 6, and in the case of direct reduction with natural gas and a hydrogen share of up to 30% as TRL 7.[19] Industrial-scale commercial production is expected from the period 2025 to 2030. According to the literature, hydrogen demand in DRI production is between 54 kg/t DRI and 58 kg/t DRI.[20] An average value of 56 kg H_2/t DRI was used to calculate the hydrogen demand in this study.

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[10] Projekt H2Stahl - energiesystem-forschung.de
[11] Projekt H2Stahl - energiesystem-forschung.de
[12] Wir machen Stahl grün | SALCOS® (salzgitter-ag.com)
[13] Air Liquide and ArcelorMittal join forces to accelerate the decarbonisation of steel production in the Dunkirk industrial basin | ArcelorMittal
[14] Hydrogen-based steelmaking to begin in Hamburg | ArcelorMittal
[15] HYBRIT – fossil-free steel (ssab.com)
[16] SSAB is leading the way in decarbonising the steel industry
[17] Green Steel — H2 Green Steel
[18] First of the World, HBIS Launches Hydrogen Steel Making Pilot Project (hbisco.com)
[19] ETP Clean Energy Technology Guide – Data Tools – IEA
[20] policybrief-green-steel.pdf (teriin.org); Metals | Free Full-Text | Hydrogen Ironmaking: How It Works | HTML (mdpi.com)

4 Brazil

4.1 Fertiliser production

4.1.1 Context

Brazil is the world's fourth largest importer of fertilisers and is responsible for 8% of global fertiliser use on account of its large agricultural sector. About 85% of fertilisers used in the country are imported. In 2020, the import volume was 40.5 million tonnes; this was forecast to rise to as much as 47.5 million tonnes in 2022.[21] [22]

The dependence on imports is particularly high for nitrogen fertilisers (approximately 96%) and potassium fertilisers (approximately 97%). Almost a quarter of all imports come from Russia; in the case of nitrogen fertilisers, almost all demand is met by Russia.[23]

In order to reduce dependence on fertiliser imports and as such also the risk of supply failure, which has risen sharply since the outbreak of Russia's war of aggression in Ukraine, the Brazilian Government this year published its National Fertilizer Plan. The plan's primary objective is to reduce import dependency to below 45% by 2050, and in the case of nitrogen fertilisers, to below 30%.[24]

4.1.2 Potential

Although Brazil's local production capacities for nitrogen fertiliser could meet about 17% of local demand, actual production is significantly lower. In 2020, the country produced 224,000 tonnes of nitrogen fertiliser, about 4% of total demand. These capacities are to be expanded, with up to 2.8 million tonnes of nitrogen being produced locally by 2050. To achieve this target, the Brazilian Government is planning to secure at least two additional nitrogen producers to select production sites in Brazil by 2030, and at least four more by 2050, achieving investments of USD 10 billion in 2030, and the same amount each decade from 2050.[25]

Production of nitrogen fertilisers, such as urea, ammonium nitrate and ammonium sulphate, involves the use of ammonia as a raw material. This is generally produced in the Haber-Bosch process by combining nitrogen and hydrogen, which at the moment are mainly derived from fossil feedstocks such as natural gas (steam reformation) or coal (coal gasification). By using hydrogen produced electrolytically with renewable energies, ammonia production could dispense entirely with fossil energies.

Assuming that the 2.8 million tonnes of nitrogen planned for 2050 are produced using the ammonia pathway based on green hydrogen from renewable energies, this would necessitate the production of 3.4 million tonnes of ammonia. This represents a hydrogen

[21] Brazil announces National Fertilizer Plan to reduce dependency on imports – Fastmarkets
[22] Market Talks: Brazil launches plan to reduce fertilizer imports dependency by 2050 | Argus Media
[23] DownloadReportByFileName (usda.gov)
[24] Market Talks: Brazil launches plan to reduce fertilizer imports dependency by 2050 | Argus Media
[25] DownloadReportByFileName (usda.gov)

demand of approximately 604,400 tonnes per year. An installed capacity of approximately 6.3 GW of electrolysis would be required to generate such a quantity (see Table 2).

Table 2 Potential H_2 demand for nitrogen fertiliser production (BRA)

Year	Hydrogen demand (t/a)	Electrolysis production capacity (GW)
2022	116,000	1.2
2040	604,400	6.3

4.1.3 Relevant companies

The following companies are active in the Brazilian market in the production of nitrogen fertilisers and have a role to play in producing ammonia using green hydrogen:

- Cibra
- Unigel
- Unipar
- Yara Brasil Fertilizantes

4.2 Oil refinery

4.2.1 Context

In Brazil in 2021, some 19 refineries were in operation, with a total production capacity of 2.4 million barrels per day. Driven by the Brazilian Government, the oil sector in Brazil has been undergoing significant change for a number of years. Petrobras, the state-owned petroleum company, will reduce its share in oil refining from 99% originally to about 50%, in order to facilitate privatisation of the market in a targeted manner, while enabling competition and stimulating investment. Part of this process will involve the sale of eight state-owned refineries.[26]

Changes in the oil sector are accompanied by stricter quality standards for fuels as demanded by the Brazilian Government, as well as by international organisations like the International Maritime Organization (IMO). For example, IMO has lowered the sulphur content limit for marine diesel from 3.5% to 0.5% (max. 5,000 ppm sulphur content).[27] In addition, the gradual renewal of the country's fleet of heavy goods vehicles will increase demand for S10 diesel (max. 10 ppm sulphur content). Compared to the existing fleet, the new vehicles are technically unsuited to using S500 diesel (max. 500 ppm sulphur content), which currently still accounts for most of Brazil's diesel demand.[28]

Implementing the S10 standard represents a major challenge for Brazil's refineries. The production of ultra low sulphur diesel (ULSD) entails a process called 'hydrotreating', i.e.

[26] Relatorio_PDE2031_Cap06_EUS.pdf (epe.gov.br)
[27] Analysis: Brazil's lower-sulphur fuel oil outsells LatAm peers in Asia | Reuters
[28] Relatorio_PDE2031_Cap06_EUS.pdf (epe.gov.br)

hydro-refining with hydrogen. The current capacity for ULSD production is 110,000 m³/d. Eight of the country's 19 refineries are not designed for ULSD production. Extensive investment in the refining park are therefore necessary to meet the rising demand for S10 diesel.[29]

4.2.2 Potential

Petrobras is currently planning to expand total S10 production capacities to 132,000 m³/d. To achieve this, up to USD 3.7 billion will have to be invested in developing production and logistics.[30] This capacity will be far from sufficient to meet local demand. An additional 70,000 m³/d of S10 diesel fuel imports are therefore expected for 2030.[31]

If local capacities for ULSD production using hydrogen refining are gradually converted to green hydrogen produced with renewable energies, this would equate to an annual hydrogen demand of up to 572,100 tonnes. An installed capacity of approximately 6 GW of electrolysis would be required to generate these quantities (see Table 3).

Table 3 Potential H_2 demand for ULSD production (BRA)

Year	Hydrogen demand (t/a)	Electrolysis production capacity (GW)
From 2025	572,100	6.0

4.2.3 Relevant companies

The following companies are active in the Brazilian market for the refining of diesel fuels and have a role to play in producing S10 diesel using green hydrogen:

- Petrobras
- Acelen
- Schist Industrialization Facility (SIX)

[29] Relatorio_PDE2031_Cap06_EUS.pdf (epe.gov.br)
[30] Microsoft PowerPoint - 2020-12 WS Mexico - Petrobras InglÃªs - FINAL (theicct.org)
[31] Relatorio_PDE2031_Cap06_EUS.pdf (epe.gov.br)

4.3 Steel production

4.3.1 Context

Brazil aims to be CO_2 neutral by 2050. Major steel producers in the country have declared similar targets, including ArcelorMittal and Vale. As stated in Section 2, conventional steel production is one of the largest CO_2 emitters in the industrial sector worldwide, on account of the burning of coke in the iron ore reduction process. Consequently, this sector also has great potential to avoid CO_2 emissions.

Brazil is the ninth largest steel producer in the world, just behind Germany, and produces over half of Latin America's total output. In 2020, steel production in Brazil was around 32 million tonnes a year.[32]

One feature in Brazil is the use of charcoal from short rotation coppices of eucalyptus as a substitute for fossil coke in iron ore reduction. This represented a total share of 25% in 2020. As a result, steel produced in Brazil has a relatively low carbon footprint compared to the rest of the world. In 2021, Aço Verde do Brasil was recognised as a CO_2-neutral steel producer by the Swiss certification company Société Générale de Surveillance (SGS). The steelworks has a production capacity of up to 600,000 tonnes of steel per year. However, this approach is only scalable to a limited extent, due to factors such as the high land requirement and a cultivation/harvest cycle of over seven years.[33]

To achieve its GHG reduction targets, the steel industry in Brazil must therefore also switch to alternative processes in the medium term. It should be noted in this context that there is currently no standard definition of 'green steel'. Position papers have been prepared on the subject, for example, by the German Steel Federation (WV Stahl; May 2022)[34] and the German Hydrogen and Fuel Cell Association (DWV) e.V. (June 2021).[35]

4.3.2 Potential

The state of the art is already direct reduction using natural gas, which accounts for a 5% share of steel production worldwide (2020).[36] In the medium term, natural gas is to be replaced by green hydrogen, produced using renewable energies such as solar or wind power, in order to reduce process-related CO_2 emissions to almost zero. In Brazil, this requirement applies to a steel industry whose steel plants will reach the end of their service life in the next 10 to 15 years and which therefore require significant investment if the industry is to continue in the years ahead.[37]

Estimates for steel production in Brazil in 2050 imply a demand for between 43 million and 67 million tonnes of hydrogen per year.[38] Accordingly, an average value of 55 million tonnes of hydrogen per year was assumed when calculating the hydrogen needs. According to IEA,

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[32] Brasiliens Stahlindustrie investiert | Branchen | Brasilien | Stahlindustrie (gtai.de)
[33] EDecarbonization_Steel_Industry.pdf (emaisenergia.org)
[34] 2022-05-31_Positionspapier_Gruene-Leitmaerkte_Gruenstahl-Definition_DE.pdf (stahl-online.de)
[35] 20210616-EP-Gruener-Stahl.pdf (dwv-info.de)
[36] Iron and Steel Technology Roadmap - Towards more sustainable steelmaking (windows.net)
[37] EDecarbonization_Steel_Industry.pdf (emaisenergia.org)
[38] EDecarbonization_Steel_Industry.pdf (emaisenergia.org)

at least 50% of CO_2 emissions from steel production must be avoided by 2050 if we are to meet global climate targets.[39] CCUS and DRI production are expected to make a particular contribution to this. It is estimated that DRI production will hold a market share of 20-25% by 2050. The current share of DRI worldwide is 5%, although only natural gas is used in industrial plants at present.

Assuming that steel production in Brazil is approximately 55 million tonnes p.a. by 2050 and the share of DRI produced using hydrogen is 25%, then the demand for hydrogen would amount to 770,000 tonnes per year. An installed capacity of approximately 8 GW of electrolysis would be required to generate this amount (see Table 4).

According to The Energy and Resources Institute (TERI), DRI production using hydrogen, with a production cost of less than USD 2 per kg, is competitive with conventional steel production.[40] Thanks to the significant potential for renewable energies in Brazil (especially wind and solar), H_2 production costs of less than USD 1.5 per kg are already forecast for 2030[41]. This makes steel production using green hydrogen a realistic prospect for the Brazilian industry.

Assuming that the first DRI plants come on stream as early as 2030, 448,000 tonnes of hydrogen and an installed capacity of approximately 4.7 GW of electrolysis would be required annually (Table 4), based on current production capacity and a DRI production share of 25%.

Table 4 Potential H2 demand for the production of DRI (BRA)

Year	Hydrogen demand (t/a)	Electrolysis production capacity (GW)
2030	448,000	4.7
2050	770,000	8.1

4.3.3 Relevant companies

The following companies are active in the Brazilian market in steel production and have a role to play in converting production to DRI using hydrogen:

- Aço Verde do Brasil
- Aperam
- ArcelorMittal
- CSN
- Gerdau
- Usiminas
- Vale

[39] Iron and Steel Technology Roadmap - Towards more sustainable steelmaking (windows.net)
[40] policybrief-green-steel.pdf (teriin.org)
[41] Green Hydrogen: an opportunity to create sustainable wealth in Brazil and the world | McKinsey

4.4 Traffic and transport

4.4.1 Context

Biofuels have been used in Brazil since the 1930s. Since the beginning of the 21st century, the Brazilian Government has specifically promoted expansion of the biofuel market with measures that include the introduction of flex-fuel cars, mandatory blend levels for biofuels with petrol and diesel, as well as programmes to regulate and promote the biofuel market, such as the National Biodiesel Production Program (PNPB), the National Biofuels Policy (better known as RenovaBio) and the Fuel of the Future Program. RenovaBio and the Fuel of the Future Program aim, among other things, to decarbonise the transport sector through biofuels. Unlike most other countries, which are seeking to decarbonise using electric vehicles or synthetic fuels, Brazil has therefore adopted a different approach.[42]

Bioethanol and biodiesel are both produced in Brazil. Brazil is the world's second largest producer of bioethanol, for which local production this year is expected to reach 31.66 billion litres. The production involves mainly sugar cane and maize. Ethanol imports in 2022 are expected to be 605 million litres. Bioethanol is either blended with fossil petrol, currently with a mandatory quota of 27% (E27), or used as fuel at 100%.[43]

Brazil is the world's third largest producer of biodiesel. In 2020, local production was 6.4 billion litres, over 13% of global production. In 2030, this figure is expected to reach in excess of 11 billion litres. The obligatory amount of biodiesel to be blended with fossil fuel has been 12% since April 2023 (B12). In Brazil, biodiesel is produced mainly from soybeans. Animal fat is also used, as well as cottonseed oil, corn oil and residual oils.[44]

4.4.2 Potential

Thanks to Brazil's strong focus on biofuels, the main option for hydrogen applications in transport is methanol production for use in the manufacture of biodiesel. The methanol currently used in biodiesel production is 100% imported.[45] Approximately 127,000 tonnes of hydrogen would be needed annually to produce enough green methanol in Brazil to serve the existing local biodiesel production capacities (6.4 billion litres per year). To generate these quantities, an installed capacity of approximately 1.3 GW of electrolysis would be required. With the target of producing 11.3 billion litres of biodiesel per year by 2030, the figures would increase to 225,000 tonnes of hydrogen per year and a required installed capacity of 2.4 GW of electrolysis.

In addition to the biofuel market, other alternatives for decarbonising the transport sector in Brazil include fuel cell electric vehicles (FCEVs) and synthetic fuels. In the aviation sector in particular, production of biokerosene from plants is already reaching its limits[46] in terms of scalability. Biokerosene production competes directly for feedstock with the production of bioethanol.

[42] Relatorio_PDE2031_Cap08_EUS.pdf (epe.gov.br)
[43] DownloadReportByFileName (usda.gov)
[44] Relatorio_PDE2031_Cap08_EUS.pdf (epe.gov.br)
[45] Relatorio_PDE2031_Cap08_EUS.pdf (epe.gov.br)
[46] Biofuels set to drive Brazil's vehicle market | Upstream Online

According to a McKinsey study (2021), FCEVs for heavy goods transport could become competitive in Brazil and reach parity with diesel vehicles[47] in terms of total cost of ownership (TCO) from 2030 onwards due to the cheap renewable energy available. However, since the government has not yet made any efforts to promote fuel cell electric or battery electric vehicles (BEV), for example by building the necessary infrastructure such as hydrogen filling stations or fast charging stations, it is questionable whether FCEVs or BEVs will actually be able to compete in the short to medium term given the strong support for biofuels.

In 2022, SYSTEMIQ conducted a survey of stakeholders in the Brazilian market on behalf of GIZ to assess the potential for fuel cell vehicles and synthetic fuels from hydrogen. A distinction was made between direct hydrogen use in fuel cell vehicles for heavy goods road haulage and the production of green kerosene (sustainable aviation fuels, SAF) for aviation. The potential for heavy goods transport is estimated at 180,000 tonnes of hydrogen per year in 2035 and 970,000 tonnes by 2040. For the production of SAF, an annual demand of 350,000 tonnes of hydrogen is expected from 2030 onwards.

The cumulative demand values for hydrogen for the target years, as well as the resulting required production capacities for hydrogen, are shown in Table 5.

Table 5 Potential H_2 demand in the transport sector (BRA)

Year	H_2 demand Methanol (t/a)	H_2 demand FCEV (t/a)	H_2 demand SAF (t/a)	H_2 demand Total (t/a)	Production capacity Electrolysis (GW)
2025	127,000	–	–	127,000	1.3
2030	225,000	–	355,000	580,000	6.1
2035	225,000	180,000	355,000	760,000	8.0
2040	225,000	971,000	355,000	1,551,000	16.2

[47] Green Hydrogen: an opportunity to create sustainable wealth in Brazil and the world | McKinsey

4.4.3 Relevant companies

The following companies are active in the Brazilian market in the production of biofuels and have a role to play in using green hydrogen in the transport sector:

- Brasil Bio Fuels
- GranBio
- Humberg Agribrasil Comercio e Exportacao de Graos SA
- JBS Biodiesel
- Petrobras
- Raízen

5 Namibia

5.1 Steel production

5.1.1 Context

In November 2022, the Namibian Government published its Green Hydrogen and Derivatives Strategy, outlining objectives to be pursued in the production and application of green hydrogen and its derivatives in the country. This strategy paper and project activities in the country appear to suggest a clear focus on the export of cheap, green hydrogen derivatives, in particular ammonia. To this end, the Namibian Government has defined three 'green valleys' in which the relevant projects are to be implemented (Figure 7).[48]

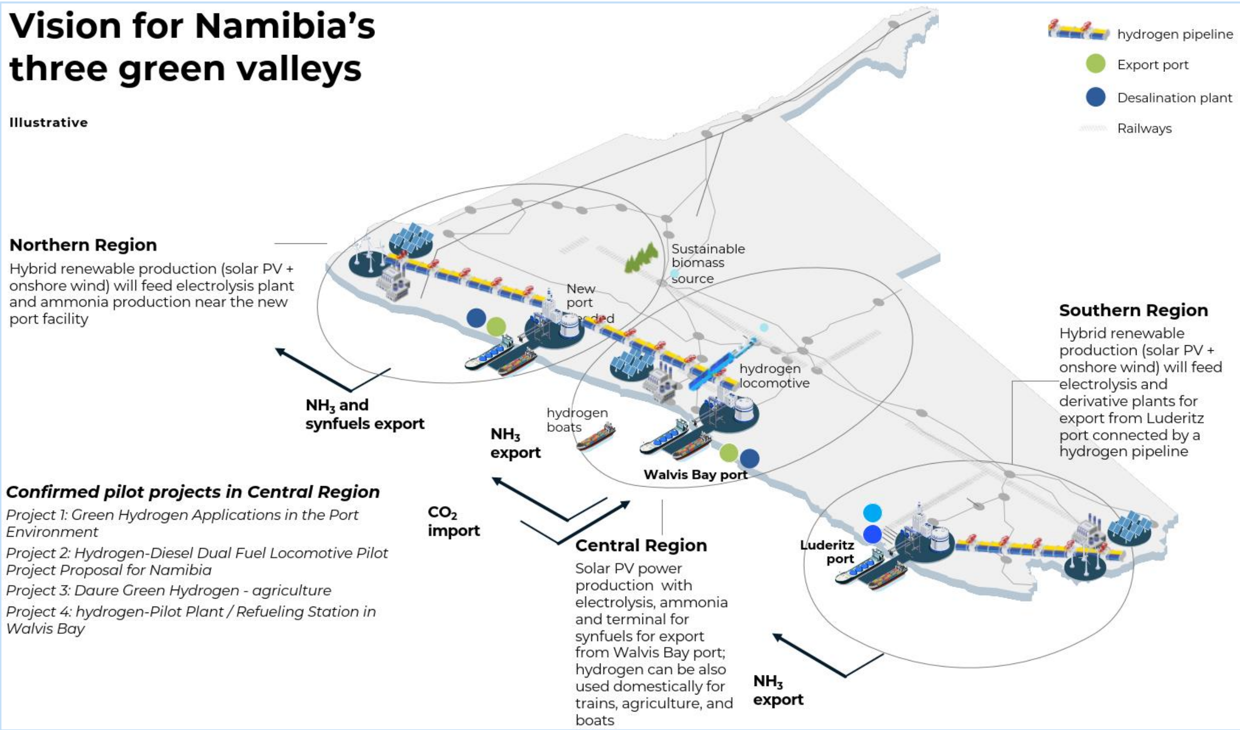

Figure 7 Namibia's green valleys[49]

The use of green hydrogen in Namibia itself is of secondary importance, although steel production using green hydrogen is cited as an option for local value creation. The Namibian Government sees an opportunity to import iron ore from Brazil or South Africa, for example, and process it in the country. This is projected for the Southern Region, one of the three planned 'green valleys' along the west coast of Namibia. In the Southern Region, the focus is on the Southern Corridor Development Initiative (SCDI), which aims to develop a common-use infrastructure (CUI) as an enabler for hydrogen and ammonia production projects. Also to be implemented in this context is the Hyphen project, an initial large-scale project to produce ammonia for export and provide CUI for potential follow-on projects.

[48] Namibia GH2 Strategy (gh2namibia.com)
[49] Namibia GH2 Strategy (gh2namibia.com)

5.1.2 Potential

Projects to implement DRI production using green hydrogen are not currently being pushed by the government. However, Lodestone Namibia (Pty) Ltd is developing the H2yron project, which would be located in the Southern Region and could benefit from the CUI. The project aims to develop the Dordabis iron ore deposit in Namibia, as well as produce DRI for export.[50]

A feasibility study for the project is currently being carried out prior to an investment decision.[51] If a positive decision is reached, the project will be pursued in two phases.[52] The planned production volumes for DRI, as well as the hydrogen demand derived from them and the required electrolysis capacity are shown in Table 6.

Table 6 Potential H_2 demand for DRI production in the H2yron project (NAM)

Phase	DRI production capacity (t/a)	Hydrogen demand (t/a)	Electrolysis production capacity (GW)
1	500,000	27,000	0.29
2	2,000,000	110,000	1.15

5.1.3 Relevant companies

The H2yron project is developed by Lodestone Namibia (Pty) Ltd. Anglo American is also a potential investor in the project.

5.2 Traffic and transport

5.2.1 Context

According to the World Bank, Namibia's transport sector produced a 55.4% share of the country's CO_2 emissions in 2014.[53] If the target of saving 91% of GHG emissions in total by 2030 compared to 2015 is to be achieved, the transport sector's relatively high emissions share has to be addressed.[54] The corresponding reduction targets for the different areas of transport are shown in Figure 8. Some 42% of the transport-related emissions are to be reduced through a switch in fuel used, from diesel to hydrogen.[55]

[50] Presentations (miningexponamibia.com)
[51] Namibia's iron ore secret – WhyAfrica
[52] Presentations (miningexponamibia.com)
[53] CO2 emissions from transport (% of total fuel combustion) - Namibia | Data (worldbank.org)
[54] Namibia | Climate Promise (undp.org)
[55] Namibia's NDC UPDATE (unfccc.int)

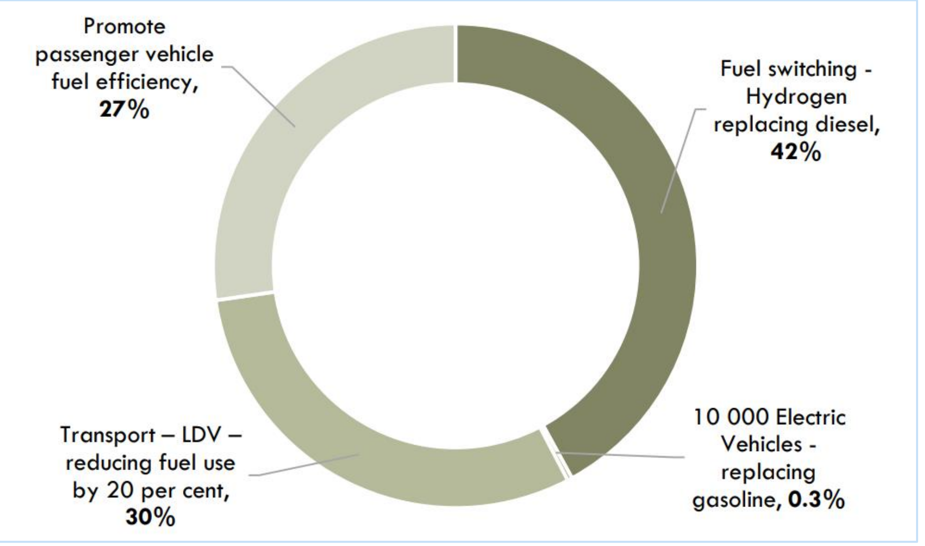

Figure 8 GHG avoidance potential in the transport sector[56]

5.2.2 Potential

The plan for the Central Region green valley includes a number of demonstration projects for using green hydrogen in traffic and transport. This will focus on using hydrogen, methanol or ammonia:

- for heavy goods transport by road and rail, including for the copper trade with Zambia and zinc ore transport along the Northern Cape (South Africa) and Karas region
- in mining, through the use of FCEVs
- in ships, including for offshore mining to extract diamonds.

Local demand for hydrogen applications in Namibia is estimated at 95,000 tonnes of hydrogen per year from 2040. From 2026, hydrogen will be used primarily in fuel cell vehicles for mining, then from 2030 to 2035 in fuel cell vehicles for medium-duty road transport and heavy goods haulage.[57] Meeting this demand would require 1.0 GW of installed electrolysis capacity (see Table 7).

Table 7 Potential H_2 demand in the transport sector (NAM)

Year	Hydrogen demand (t/a)	Electrolysis production capacity (GW)
2040	95,000	1.0 GW

5.2.3 Relevant companies

The following companies are involved in the various demonstration projects that use green hydrogen, methanol and ammonia in traffic and transport:

[56] Namibia's NDC UPDATE (unfccc.int)
[57] Namibia GH2 Strategy (gh2namibia.com)

- Debmarine
- Hyphen Technical
- Ohlthaver & List and British CMB.TECH (both Cleanenergy Namibia as JV)
- TransNamib

6 South Africa

6.1 Oil refinery

6.1.1 Context

In its Hydrogen Society Roadmap for South Africa 2021 (HSRM), the South African Government sets out how the production and use of hydrogen in South Africa will help achieve CO_2 neutrality as well as economic growth and social prosperity by 2050:

- decarbonisation of heavy goods transport
- decarbonisation of energy-intensive industries (cement, steel, mining, refining)
- improved and greener energy sector
- competence centre for the production of hydrogen products and fuel cell components
- creation of an export market for South African green hydrogen
- expansion of the role of hydrogen in South Africa's energy system to achieve a zero-emissions economy

The transport sector accounts for about 95% of local demand for liquid fuels. Over 90% of petrol and kerosene is produced locally, while a third of the diesel required is imported. in 2019 there were six refineries in operation in South Africa, with a total production capacity of around 700,000 barrels per day. Of these six, only three are still operational today. This has reduced production capacity to 388,000 barrels per day. The crude oil required is imported, since South Africa has no oil wells of its own.[58]

6.1.2 Potential

The fuel refining industry in South Africa is currently at a crossroads. The more stringent requirements of the Cleaner Fuels II specification will come into force in 2023, raising the quality standard for fuels used in South Africa to Euro 5 standard. Among other things, the specification stipulates a maximum sulphur content of 10 ppm in petrol and diesel fuels.[59] If it is to meet these requirements, the country must either invest massively in its own industry in order to create the technical conditions for domestic production, or dispense with this approach and rely purely on imports.[60]

Construction of a new refinery in the Richard Bay region, with a production capacity of 400,000 barrels per day, is currently being discussed. If this refinery is built and comes on stream at the end of this decade, desulphurisation could be achieved using green hydrogen. The resulting potential hydrogen demand is shown in

Table 8.[61]

[58] South_African_Hydrogen_Society_RoadmapV1.pdf (dst.gov.za)
[59] Cleaner fuels II – SAPIA
[60] South_African_Hydrogen_Society_RoadmapV1.pdf (dst.gov.za)
[61] South_African_Hydrogen_Society_RoadmapV1.pdf (dst.gov.za)

Table 8 Potential H_2 demand in the refining sector (ZAF)

Year	Hydrogen demand (t/a)	Electrolysis production capacity (GW)
2030	275,600	2.9 GW

6.1.3 Relevant companies

The following companies have a role to play in the use of green hydrogen in refineries in South Africa:

- Astron Energy
- BP
- Engen
- Petroleum Oil and Gas Corporation of South Africa (PetroSA)
- Sasol
- Shell

6.2 Steel production

6.2.1 Context

South Africa is Africa's second largest steel producer after Egypt[62] and ranks 27th in the world.[63] Production capacity in 2020 totalled 6.5 million tonnes.[64]

The steel industry in South Africa faces pressure from cheap imports from China, rising production costs in the country and lower domestic demand. The industry is therefore currently in survival mode, which means that companies are more interested in reducing costs than in investing in a sustainable industry. The Steel Masterplan sets out various measures to support the steel industry. It states that switching to DRI production and concomitant use of green hydrogen represents an opportunity for the industry to realise investment in the steel industry and open up export markets for green steel.[65]

6.2.2 Potential

According to the HSRM, production of green steel is a national priority. The Steel Masterplan is therefore to be revised and adapted to the HSRM.[66]

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62 Steel_Industry_Master_Plan.pdf (thedtic.gov.za)
63 https://www.saisi.org/steel-statistics/overview-of-the-primary-steel-industry-in-south-africa/
64 South Africa imported record volumes of steel in 2021, new report shows (engineeringnews.co.za)
65 Steel_Industry_Master_Plan.pdf (thedtic.gov.za)
66 South_African_Hydrogen_Society_RoadmapV1.pdf (dst.gov.za)

Potential hydrogen demand for DRI production was determined based on current capacities and assuming a 25% DRI share of total production in 2030 and 50% in 2050. The resulting hydrogen demand and required production capacity are shown in Table .

Table 9 Potential H_2 demand for the production of DRI (ZAF)

Year	Hydrogen demand (t/a)	Electrolysis production capacity (GW)
2030	91,000	1.0
2050	182,000	1.9

6.2.3 Relevant companies

A first demonstration project for producing DRI is to be implemented by ArcelorMittal as part of the Platinum Valley Initiative (PVI). Other companies that could potentially produce DRI in South Africa include:

- Cape Gate
- Columbus Stainless
- Force Steels
- SA Steel Mills
- Scaw Metals
- Unica Iron and Steel
- Veel Steel Mills

6.3 Traffic and transport

6.3.1 Context

The transport sector is responsible for about 11% of GHG emissions in South Africa. More than 90% of this figure is accounted for by road transport. For this reason, the HSRM focuses on using hydrogen in heavy goods road haulage.[67] This path was outlined in the Department of Transport's Green Transport Strategy along with recommendations of appropriate measures.[68]

One of the projects launched under the HSRM is the Platinum Valley Initiative (PVI), also called South Africa Hydrogen Valley. The PVI will establish a hydrogen corridor between Limpopo, Johannesburg and Durban. In addition to heavy goods transport, it also addresses the mining sector.

According to Anglo American, large mining dump trucks are responsible for about 80% of the demand for diesel at mining sites and could account for up to 3% of global CO_2 emissions.[69] Coal is the major commodity mined in South Africa, accounting for 75% of total

[67] South_African_Hydrogen_Society_RoadmapV1.pdf (dst.gov.za)
[68] Green_Transport_Strategy_2018_2050_onlineversion.pdf
[69] The world's biggest hydrogen fuel cell EV has started work in South Africa | Ars Technica

mining production. Otherwise, the most important mining commodities are iron ore, chromium and manganese.[70]

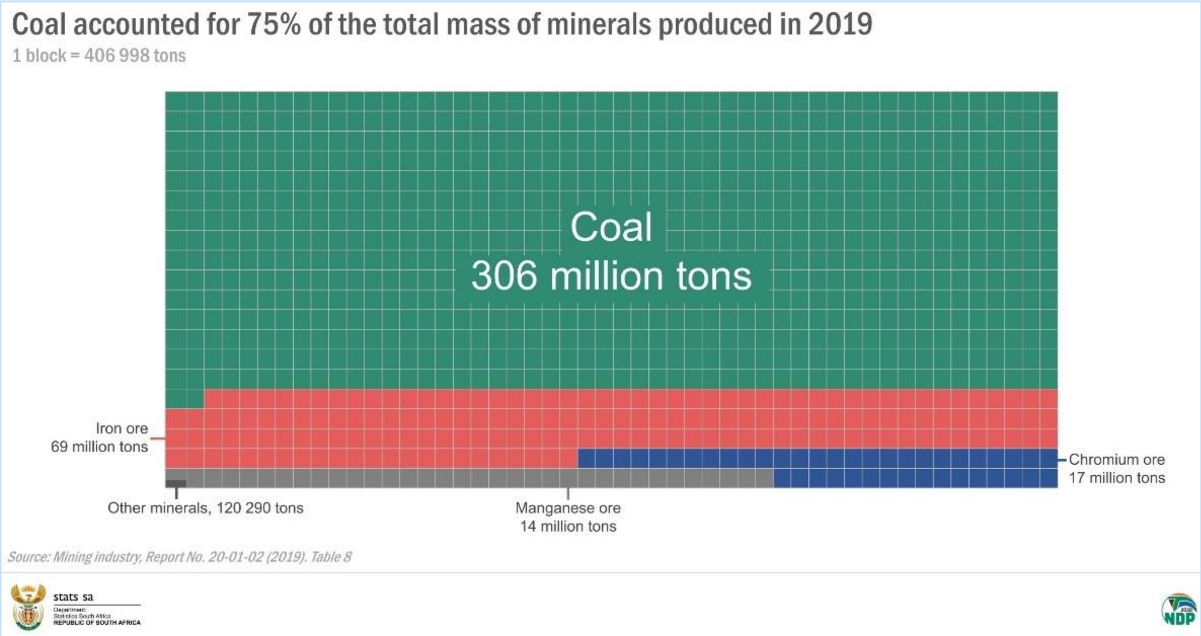

Figure 9 Mining in South Africa[71]

Other minerals (see Figure 9) include in particular platinum metals (platinum, palladium, ruthenium, rhodium, iridium and osmium). Here, South Africa accounts for 75% of global production capacities, which makes it the largest producer of these rare earth minerals, which are used, for example, in the production of electrolyser and fuel cell components.[72]

6.3.2 Potential

The potential for shifting heavy goods transport to FCEVs was looked at as part of a feasibility study for implementing the South African Hydrogen Valley. The first demonstration projects are to be implemented as part of the PVI at the Johannesburg, Durban and Mogalakwena sites. The potential hydrogen demand for FCEVs in heavy goods transport is estimated at 11,300 tonnes in 2025 and 46,800 tonnes by 2030 (see Table 10).[73]

[70] Four facts about the mining industry (2019) | Statistics South Africa (statssa.gov.za)
[71] pic1.jpg (1204×641) (statssa.gov.za)
[72] South_African_Hydrogen_Society_RoadmapV1.pdf (dst.gov.za)
[73] South Africa Hydrogen Valley Final Report (dst.gov.za)

Table 10 Potential H_2 demand in FCEVs for heavy goods transport (ZAF)

Year	Hydrogen demand (t/a)	Electrolysis production capacity (GW)
2025	11,300	0.1
2030	46,800	0.5

To reduce the emissions from mining, 40 FCEVs should be in operation at the Mogalakwena site in the Limpopo region by the end of this decade. The TCO for these vehicles is expected to reach parity with diesel vehicles in 2030. Thus, a further uptake of FCEVs in the mining sector can be expected. The resulting potential hydrogen demand is shown in Table [74].

Table 11 Potential H_2 demand for FCEVs in the mining sector (ZAF)

Year	Hydrogen demand (t/a)	Electrolysis production capacity (GW)
2025	8,000	0.1
2030	25,000	0.3

6.3.3 Relevant companies

The following companies are involved in the feasibility study on implementing the South African Hydrogen Valley:

- SANEDI
- Anglo-American Platinum
- Bambili Energy
- ENGIE

[74] South Africa Hydrogen Valley Final Report (dst.gov.za)