Guidehouse

Hydrogen Fuelled Economies

Opportunities for economic value creation from green hydrogen in Oman

Prepared for:

German Federal Ministry for Economic Affairs and Climate Action (BMWK) and Ministry of Energy and Minerals of the Sultanate of Oman (MEM)

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Executive Summary

Oman could become one of the world's major green hydrogen producers. Green hydrogen is seen as a key for the country's decarbonisation, economic diversification, and energy security objectives.[1] The nascent hydrogen economy offers ample potential for unlocking new sources of value and diversifying the Omani economy in line with the national and global climate ambitions.

The scale-up of hydrogen production and related value chains in Oman holds significant employment potential. Oman's targeted 2050 hydrogen production volume of 8 Megatons (Mt) could create a total of 291,100–381,800 full-time employment opportunities[2] depending on the share of equipment imported along the value chain. Most employment opportunities (around 75%) are expected to be indirect, created throughout the economy. The employment potential from renewable energy scale-up is the largest driver representing around half the overall potential employment.

Future sales of green hydrogen and related products are also estimated to contribute the country's Gross Domestic Product (GDP) in an order of 31–51% of current GDP levels. These new revenue sources can compensate for expected declines in oil and gas revenues.

Scaling up green hydrogen production will not only require massive renewable energy deployment but also bring about synergies for renewables expansion, system integration and electricity grid flexibility. Proactive planning of hydrogen and renewables expansion as well as management of possible grid impacts is vital to secure those benefits. If green hydrogen replaces fossil energy sources in the refinery or the steel sector, it can reduce Oman's emissions by around 0.7% or 4.6% respectively.[3]

Oman can leverage experience and know-how from international technology leaders such as Germany to harness the potential benefits of green hydrogen. A supportive regulatory and policy environment is key for attracting (foreign) investment into the hydrogen sector. This includes clear long term energy transition plans, encompassing renewable energy targets and measures to create local hydrogen demand, long-term visibility of hydrogen auction schedules and transparent and fair criteria.

Key elements to achieve a fast ramp-up of the hydrogen market include support for first-mover and pilot projects, hydrogen infrastructure planning and/or provision, and alignment with key offtake markets regarding their requirements as well as on instruments for creating offtake certainty. In parallel to the hydrogen economy ramp-up, expanding renewables in the power sector should be a priority considering the many positive synergies and the employment and decarbonisation benefits to support Oman's Net-Zero by 2050 goal.

At the same time, local capacity needs to be developed and scaled up, both on the technical and manufacturing part and on the human capital part. Upskilling and (re-)training needs aligned with the requirements of the hydrogen economy must be identified and adequate educational programs developed. To that end, demonstration projects can offer a learning environment and testing field.

[1] Ministry of Energy and Minerals (2022): Oman announces 2050 Net Zero commitment and unveils ambitious green hydrogen strategy. Link

[2] The duration of these employment opportunities varies between 1 and 20+ years, depending on the type of employment, e.g., construction work typically is more short-term while operations is long-term. Not all positions needed will be full-time, they might be needed at different points in time of the hydrogen economy run-up and could also covered by existing positions or replace jobs in other areas.

[3] See 2.2.2 Reduction of emissions for more details.

1 Introduction

Oman, like many other countries in the MENA region, has historically created much of its economic value from oil and gas (O&G) revenues. In 2021, the oil and gas sector accounted for over one fourth (29%[4]) of Oman's Gross Domestic Product (GDP) and 74% of net government revenue.[5] At the same time, fossil resources are limited: as of 2020, oil reserves were expected to last another 15 years and natural gas reserves 18 years.[6] While new discoveries can push these dates backward, unlike many of its neighbouring countries Oman could soon be facing the limits of the fossil energy era.

Oman is blessed with excellent renewable energy resources offering excellent potential for green hydrogen production. Wind and solar generation costs are low, land is available and sea access is given, including existing O&G infrastructure. Against this backdrop, the country has embarked on an agenda to diversify its economic value creation towards green hydrogen. With production targets of 1 Megaton by 2030, 3.5 Mt by 2045 and 8 Mt by 2050, Oman is positioning itself as a major green hydrogen producer and exporter in the region.

In 2022, people under 30 years of age made up more than half of the country's population.[7] While in an international comparison the unemployment rate in the overall population is low (below 2.5%), youth unemployment rates have increased since 2017 to 15.8% in 2022 for youth aged 18 to 24 and 6.8% in the 24 to 29 age bracket.[8] The Vision 2040 seeks to increase the share of Omanis in new private sector jobs and increase the share of skilled labour in the private sector.[9] Creating perspectives for Oman's young population and promoting skills development is a key priority.

The hydrogen production targets of the Sultanate of Oman bear enormous domestic economic opportunities. Many large-scale projects in the Gigawatt-range are already in the planning. With the creation of Hydrom as one-stop-shop for hydrogen projects in late 2022 and the first hydrogen auctions for land availability held in early 2023 their implementation is moving closer. Oman's national champion for sustainable energy, OQ, is driving green energy projects including renewables and green hydrogen and derivatives with its "Alternative Energy" business.

> The creation of a hydrogen economy in Oman not only promises diversification from oil and gas and decarbonisation potential but it also offers new employment possibilities.

Renewable energy, a key ingredient for green hydrogen, has ample job creation potential. IRENA estimates that already 12.7 million jobs existed worldwide in 2021 in the field of renewable energies.[10] Two thirds of the estimated 25 million jobs associated with the energy transition by 2030 are expected to be medium-skilled, creating ample middle-class job opportunities.[11]

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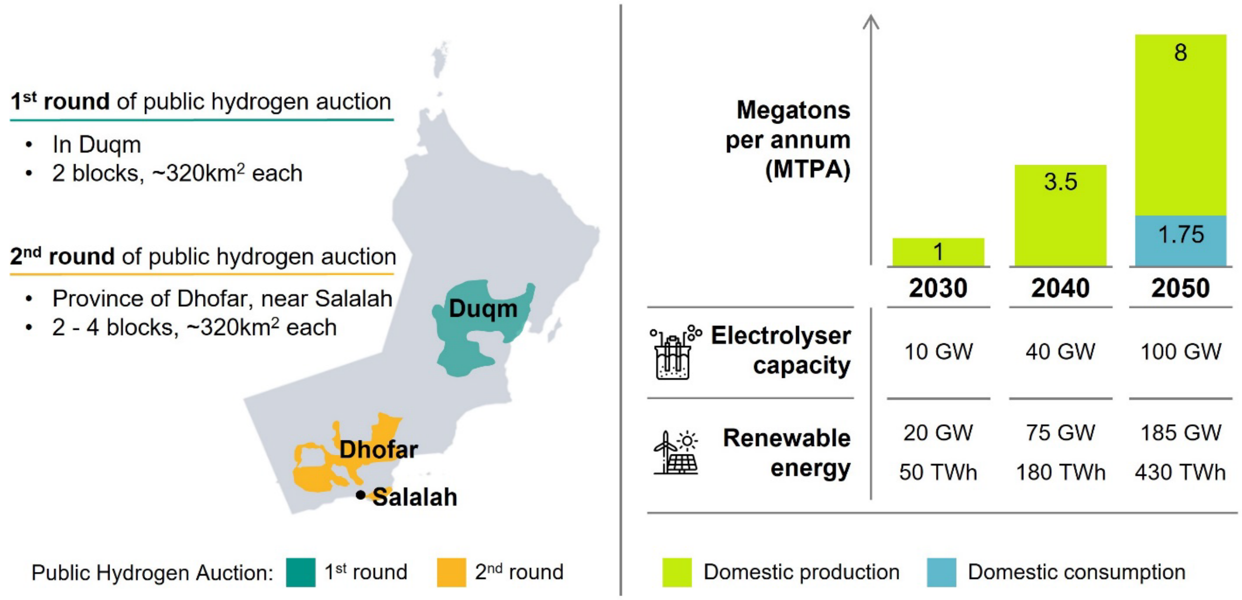
[4] National Centre for Statistics & Information (2023). National Accounts. Link
[5] Central Bank of Oman (2023). Analysis of Oman's State Budget during the period 2015- 2022. Link
[6] BP (2021). Statistical Review of World Energy. Link
[7] National Centre for Statistics & Information (2023). Population. Link
[8] National Centre for Statistics & Information (2023). Labour market. Link
[9] Sultanate of Oman (2021). Oman Vision 2040. Link
[10] IRENA (2022). Renewable energy and jobs: Annual review 2022. Link
[11] ILO (2019b). Skills for a Greener Future: A Global View. Link

Figure 1: Hydrom economy vision of the Sultanate of Oman



Guidehouse (2023)
Based on Hydrom presentation at the Green Hydrogen Summit 2022, renewable energy production figures from IEA 2023

This study aims at identifying the potentials of the hydrogen economy for creating local value in Oman, with a particular focus on employment and economic impacts (GDP). It further investigates challenges and opportunities of the required renewables scale-up regarding system integration and capacity building. The study also highlights how Oman can leverage know-how and experience from international players such as German companies and remove possible barriers for their engagement. Finally, it explores necessary framework conditions for Oman to capitalize on this potential and derives recommendations for policy makers.

2 Value creation potentials from green hydrogen

Green hydrogen is an important piece of the energy transition puzzle. It can be an option to decarbonize emission intensive economic activities and accelerate the shift from natural gas towards renewable fuels. Building up a hydrogen economy also contributes to in-country value creation, particularly around employment, and creates broader macro-economic benefits adding to and diversifying GDP. This chapter models potential employment and GDP effects, assesses additional positive externalities associated with the ramp up of a hydrogen economy and discusses potential trade-offs.

2.1 Macroeconomic effects of green hydrogen scale up

This chapter estimates the impact of Oman's hydrogen economy vision on job creation using an input-output employment model. The model covers the hydrogen production process as well as local consumption of hydrogen and conditioning for exports. Based on the 2050 production targets, **the hydrogen economy is expected to create 291,000 to 381,800 employment opportunities, 46-50% of which** are connected to the deployment of renewable electricity, depending on the share of equipment and machinery that is imported to Oman (rather than produced locally). About a **quarter of the total employment is direct employment**[12] while the rest is created indirectly (75%). Depending on sale prices, the GDP-contribution of green steel and green ammonia exports is estimated to be as high, or even higher, that of today's oil and gas exports.

2.1.1 Employment effects of the hydrogen economy

An input-output model was used to estimate employment effects corresponding to Oman's 2050 hydrogen ambition. The analysis considers two scenarios: 1) *high local value* assumes 60% of equipment across the hydrogen value chain to be imported while 2) *low local value* assumes a 90% import share. These shares refer to all equipment needed for the creation of the hydrogen value chain, e.g., electrolysers, compressor stations, solar panels, wind turbines. Most equipment is required for the deployment of renewable energy plants. Both sensitivities assume relatively large shares of equipment imports as Oman has not yet developed own production capacities in the field of renewable energy and may not be able to compete against low-cost imports of technical components. Still, the *high local value* scenario would require substantial investments in both industry and workforce.

Methodology

Job creation is estimated across different sectors of the economy. The model uses assumptions on domestic green hydrogen production and consumption volumes, sector-specific wages, and assumptions regarding the distribution of financial flows along the green hydrogen value chain (see Appendix A).

To trace flows and interactions between economic sectors the model builds on an input-output table of the Omani economy. Such tables record the flows of final and intermediate goods and services between industries/economic sectors (represented by monetary values). They provide information

[12] *Direct employment* relates to increased labour activity in all economic sectors that are affected by investments in the hydrogen economy. Additionally, each sector needs to purchase materials, goods and services and hire workers to meet demand, causing an employment creation cascade throughout the economy, producing *indirect employment*.

about the sale and purchase relationships between producers and consumers within an economy.

Based on Oman's 2050 green hydrogen production targets, the necessary expenditures along the hydrogen value chain were derived, including the upstream, midstream, and downstream segments ammonia production, green steel production and power generation from green hydrogen. Expenditures are categorised into:

- Capital investment (CAPEX) in electrolysis, ammonia and steel plants, and related infrastructure annualised over the lifetime of the project (assumed at 20 years).
- Operation and maintenance costs (OPEX) of plants and infrastructure.
- Feedstock supply costs (feedstock EX), including all costs related to renewable capacity expansion needed in the upstream segment.

The key result is the total number of employment opportunities (full-time equivalent, FTE[13]) related to a production of 8 Mt of green hydrogen in 2050. They are represented as an annual number related to economic activities triggered by the 2050 production targets that could be available, on average, over the assumed hydrogen project lifetime.[14] FTE are divided into direct and indirect employment created in each sector. Direct employment is calculated based on the level of expenditure allocated to a sector multiplied by the employment factor of the sector (in employment per Omani Rial invested). The sector-specific employment factor is derived from the overall spending in a respective sector allocated to employee compensation (salaries) expressed in terms of FTE. Indirect impacts are derived analogously using the input-output interactions between the different sectors of the economy.

A similar methodology was used to estimate employment opportunities in the downstream segment of the hydrogen value chain. Key assumptions include domestic hydrogen demand levels for green steel production and power generation. To derive the downstream employment potential the expenditures associated with the domestic use of hydrogen were multiplied with the respective direct and indirect employment factors of each sector.

Results

The results presented in Figure 2 show that the production of 8 Mt of **green hydrogen per year by 2050 could trigger a total of 291,000 FTE** in the *low local value* scenario, **76,600** of which being **direct employment and 214,400 indirect employment** (Figure 2, centre). The total number of FTE increases by 31% to 381,000 in the *high local value* scenario.

Major employment benefits are seen in the construction and industry sectors resulting from the deployment of hydrogen production facilities, infrastructure, and related equipment manufacturing capacities. Those segments create 62-65% of all direct and indirect employment related to CAPEX and OPEX. Research and development services and non-technical services, such as legal and financial services, account for another 10-14% of the total CAPEX and OPEX job potential. The remaining employment potential in the OPEX

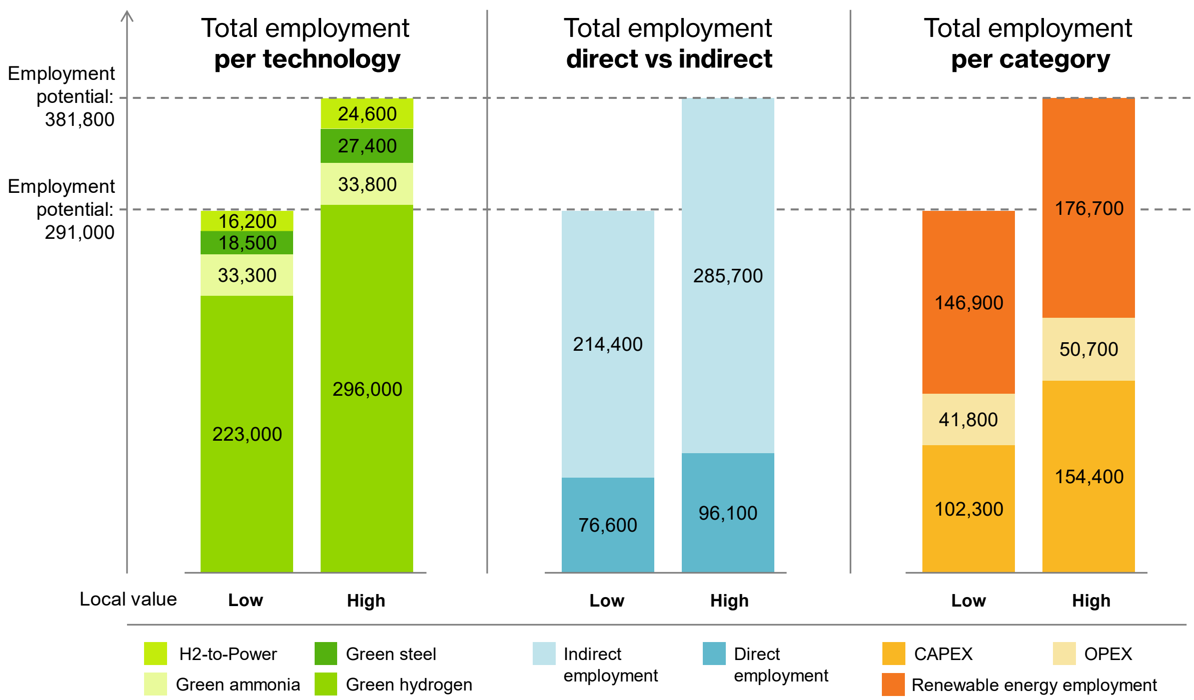
[13] Part-time employment, e.g., at 50% of the working hours, counts as partial FTE, e.g., 0.5.

[14] Input-output-model based estimates give a snapshot of the economy at a certain point in time. As such, they do not allow differentiating between when employment opportunities are available and for how long (construction jobs, for example, could be for one year while jobs related to the operation of plants would be longer term).

segment stems from operation and maintenance (O&M) of the electricity and water supply and the pipeline infrastructure.

The total FTE numbers represent an annual average across the lifetime of hydrogen projects. Not all of the actual employment opportunities will be full-time or permanent positions, they might be needed at different points in time of the hydrogen economy run-up. Most CAPEX-related jobs are linked to investment and would therefore phase out once construction activities are completed. OPEX-related jobs however would be needed to run facilities throughout projects' lifetime. The analysis does not differentiate between CAPEX and OPEX in the renewable energy segment which holds further long-term job potential (beyond the investment period, e.g., jobs in the fields of maintenance, monitoring etc.).

Figure 2: Estimated number of employment opportunities of Oman's 2050 hydrogen ambitions



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46-50% of all employment opportunities are related to the renewable electricity feedstock for green hydrogen (Figure 2, right).

Renewable electricity costs, which are largely based on capital investment in solar photovoltaic (PV) and wind, are a key factor for green hydrogen. Given that capital cost (both related to the electrolysers and the renewable electricity plants) dominates expenditure for renewables and green hydrogen production while operating costs are low, new jobs created in this segment will likely be of temporary nature and concentrated during the engineering and construction phase. A higher share of domestic manufacturing during the market uptake of the hydrogen economy could lead to higher longevity of these jobs. However, that needs to be weighed against the ensuing cost increment of local manufacturing on overall hydrogen production cost.

The potential resulting from the downstream use of green hydrogen accounts for 22-23% of total employment potential. This includes the conversion to ammonia, the production of green steel and the use of hydrogen for electricity generation (Figure 2, left). The estimates are based on a national hydrogen demand target of 1.75 Mt and assumptions regarding its distribution. The model estimates an employment **potential of 18,500-27,400 FTE for a steel production of 23.3 Mt per year.** The underlying job creation factor in the steel sector is in line to with job creation potential communicated by the planned Jindal Green Steel project in Duqm, which expects 4,500 direct and indirect jobs to be created by steel plant with a production capacity of 5 Mt per year.[15]

As hydrogen increasingly substitutes the use of natural gas throughout the economy, employment in the fossil fuel sector is expected to decline as O&G exploration decreases. Hence, the *net* employment effects are likely lower than those estimated. **Re- and upskilling is an important measure** to qualify the existing workforce for emerging opportunities from the hydrogen economy (see Chapter 4.2). At the same time, ambitious climate targets will require higher shares of renewable energy and system integration efforts – an area that typically creates many jobs not reflected in this analysis.

2.1.2 Contribution to GDP

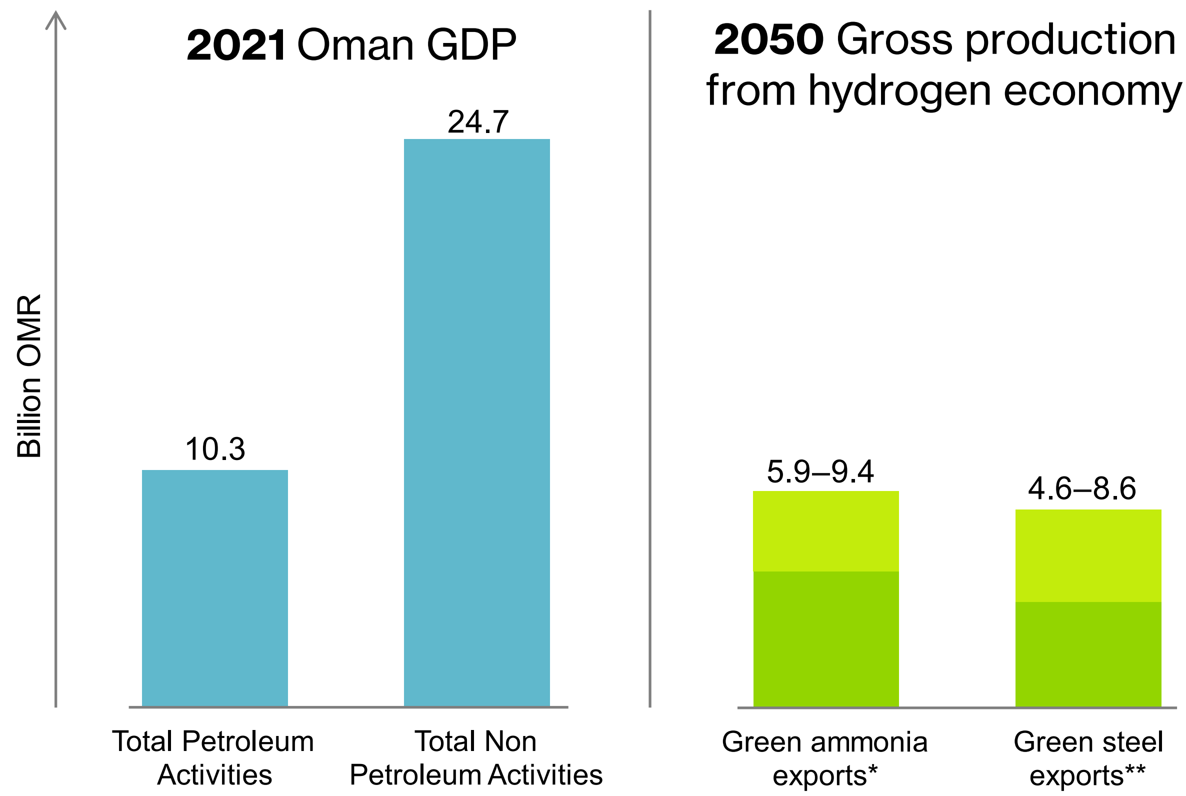
Beyond employment effects from green hydrogen production and local consumption, exports of hydrogen (and its derivatives) and green products (e.g., hydrogen-based steel) also contribute to Oman's GDP. This study assesses the possible GDP contribution of hydrogen-related exports. It assumes that around 80% of the green hydrogen earmarked for exports in 2050 is sold as green ammonia and the remainder as green steel. The resulting **green ammonia export volume of 6.25 Mt could generate a gross production value of up to 5.9-9.4 billion OMR** assuming an ammonia sale price range of 171-271 OMR/ton (450-712 USD/ton)[16] (see Figure 3, right). With a **green steel export volume of 1.4 Mt** and an assumed sales price range of 198-372 Omani Rial (OMR)/ton[17] (520-980 USD/ton) the **GDP contribution could be between 4.6-8.6 billion OMR**.

[15] Based on a presentation by Jindal Shadeed (2022) at the Green Hydrogen Summit Oman in Dec. 2022.

[16] Lower price limit assumption based on IEA (2023). Renewable Hydrogen from Oman (Link), higher price limit assumption based on the average value of IRENA (2022). Innovation outlook renewable ammonia (Link).

[17] Assumption based on IEA (2023). Towards hydrogen definitions based on their emissions intensity. Link

Figure 3: Oman GDP (2021) and revenues from hydrogen-related exports in 2050



Oman GDP based on National Centre for Statistics & Information (2023) .
* Estimates reflect a green ammonia price range of 171 OMR/t NH_3 (lower) to 271 OMR/t NH_3 (lower) (450-712 USD/t NH_3).
** Estimates reflect a green steel price range of 198 OMR/ t steel (lower) to 372 OMR/t steel (upper) (520 -980 USD/t steel).

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Taken together, green hydrogen derivatives and products in 2050 could represent 31-51% of Oman's current (2021) GDP of 35 billion OMR. Moreover, **hydrogen-related exports could be as high as – or even higher than – today's revenues from O&G activities** (see , left). However, a long-term decline of O&G revenues, which accounted for 29% of the GDP in 2021, will have a strong impact on the net GDP development of Oman that is not considered in this analysis.[18]

[18] Oman GDP based on National Centre for Statistics & Information (2023). National Accounts. Link

2.2 Additional effects

In addition to macroeconomic benefits, scaling up the hydrogen economy in Oman entails additional interaction effects with the country's energy and water sector while supporting the overall energy and climate targets.

2.2.1 Renewable energy expansion and integration

Oman's short- and long-term plans of green hydrogen production require substantial additional renewable electricity assets. Several renewable energy power plants dedicated for green hydrogen production have been announced. Their capacities (appr. 16 GW[19]) could translate into the production of 0.67 Mt hydrogen[20]. To reach the **2030 hydrogen production target** (1 Mt), around **16 TWh additional renewable energy will be needed**. Considering the long-term targets of hydrogen production in 2040 (3.5 Mt) and 2050 (8 Mt), total renewable electricity dedicated for hydrogen production must reach around 170 TWh and 380 TWh respectively, which requires additional capacity of around 12-times of that announced to date.

At the same time, additional renewable electricity will be needed in the power sector to meet the renewable electricity targets of 20% of electricity demand by 2030 and 35% by 2040[21]. The targets imply 7 TWh and 17 TWh[22] of additional renewables generation in 2030 and 2040 respectively, requiring an additional capacity of approximately 3.7 GW until 2030 and 9 GW until 2040. The simultaneous ramp-up of renewable energy in both the hydrogen and the power sector can **create synergies for renewables supply chains, grid infrastructure** and management, as well as **industry experience and skills formation** for the energy transition. Moreover, as the results in Chapter 2.1 show, renewables expansion creates significant employment opportunities.

Given the variable nature of renewable energy, the simultaneous ramp-up can also lead to **challenges for the power system**. A system-friendly expansion and integration of solar and wind plants to power systems will become increasingly important for Oman. Otherwise, the deployment of high shares of renewables could provoke grid congestions or a high need for grid expansion. The key challenge will be to harmonize variable generation and a rising demand for electricity, e.g., by hydrogen production.

Hydrogen production has the potential to provide a range of **flexibility services to the power system**, helping to address this challenge. Electrolysers could act as a flexible load in response to excess generation by shifting their consumption and thereby reducing the risk of renewables curtailment. They could also provide operating reserves to the system to balance frequency deviations. Regarding long-term deviations between electricity supply and demand, hydrogen can act as a storage medium for excess renewable electricity. It can be stored in salt

[19] Global Energy Monitor (2023). Summing up announced solar and wind power plants capacities. For Solar: Global Solar Power Tracker. Link. For Wind: Global Wind Power Tracker. Link. Accessed on 19 April 2023

[20] Considering i) electrolysis efficiency of 70%. ii) 1 kg of H_2 is equivalent to 33.3 kWh.

[21] Climate Change Laws of the World. Oman Vision 2040. Link

[22] Considering an average annual increase of electricity demand in Oman by 1 TWh. Source: CEIC Data - Global Database (2023). Oman Electricity Consumption. Link. Electricity demand in 2030 and in 2040 will be 43 TWh and 53 TWh respectively.

caverns[23] and used for power generation during times of high demand and scarcity. Such long-term storage can benefit Oman in view of the seasonal differences in electricity demand between winter and summer, where a substantial air conditioning demand arises. The economic attractiveness of using green hydrogen as a flexibility option in the power sector will however depend on the cost of hydrogen production, the availability of storage, and given incentives to provide flexibility to the power system.

In return, the expansion of renewables in the power sector will also help achieve **faster cost-reductions for renewable electricity** and contribute to a competitive hydrogen price.[24] As costs continue to decrease further, green hydrogen will become an economically more attractive option in the Omani energy mix. Moreover, **excess renewable electricity** from the power sector can also be **exported to neighbouring countries** at competitive prices. In this context, Oman's wind energy potential could complement solar PV generation assets abroad enabling higher electrolyser full load hours and allowing to match renewables generation and overall power demand more closely whilst supporting regional power market integration.

2.2.2 Reduction of emissions

Domestically, **green hydrogen could replace fossil fuel-based feedstocks in industrial facilities** such as oil refineries and steel industries. They are expected to be early market off-takers of green hydrogen and generate an immediate effect in emissions reduction. Iron and steel industries use hydrogen for annealing and other treatments. In primary steel production, direct reduction is a more energy-efficient and hydrogen-ready alternative to blast furnace technology. **Using green hydrogen instead of natural gas in both the direct reduction and crude steel production** stages **can reduce CO2 emissions by up to 97%**[25] across the entire value chain compared to the blast furnace route. Emissions of steel production ranges between 1.4-1.9 tons CO_2-equivalent ($CO_{2\text{-eq}}$) per ton of steel produced.[26] Considering Oman's current level of crude steel production of around 3 Mt in 2022[27], a switch to green hydrogen in the steel industry could save between 4.0-5.2 Mt of $CO_{2\text{-eq}}$ per year, which accounts on average for 4.6% of Oman's overall annual $CO_{2\text{-eq}}$ emissions.[28]

Oil refineries use hydrogen for hydrocracking and for desulfurisation of fuels, which contributes to 19%[29] of overall refinery emissions. The carbon intensity of refining varies globally between 13.9-62.1 kg of $CO_{2\text{-eq}}$ per oil barrel.[30] As Oman's refining capacity reaches approximately 84 million barrels per

[23] Oman has a good potential of utilising salt caverns for hydrogen storage. Source: Al Rizeiqi et al. (2022). Potential of Underground Hydrogen Storage in Oman. Link

[24] IEA (2023). Renewable Hydrogen from Oman. Link

[25] Agora Energiewende and Wuppertal Institute (2021): Breakthrough Strategies for Climate-Neutral Industry in Europe: Policy and Technology Pathways for Raising EU Climate Ambition. Link

[26] Sustainable Ships (2022). What is the carbon footprint of steel? Accessed on: 10 May 2023. Link

[27] World Steel Association (2023). World Steel in Figures. Link

[28] Oman's annual emissions equal 100,259 kt.$CO_{2\text{-eq}}$. Source: World Resources Institute. Climate Watch Historical GHG Emissions. 2022. Accessed on: 20 June 2023. Link

[29] Sunny et al. (2022). A Pathway Towards Net-Zero Emissions in Oil Refineries. Link

[30] Jing et al. (2020). Carbon intensity of global crude oil refining and mitigation potential. Link

year[31], using **green hydrogen in oil refineries could potentially save on average 0.7 Mt of CO2-eq per year**, i.e., approximately 0.7% of Oman's overall annual $CO_{2\text{-eq}}$ emissions. To decarbonize the entire refinery value chain in line with Oman's net-zero by 2050 target a multi-track approach is needed, considering energy efficiency measures and carbon capture and storage. Taken together, these measures could save around 3.4 Mt of $CO_{2\text{-eq}}$ per year (around 3.4% of the country's overall annual emissions) if current refining activity levels are continued. Nevertheless, to reach global climate targets, refinery activity will have to decline as fossil fuels need to be replaced by low- and zero-carbon fuels.

2.2.3 Water consumption

Every kilogram of hydrogen produced through electrolysis requires 9 litres[32] of pure water. Water requirements for production of green hydrogen will account for 0.4% (2030) and 3% (2050) of Oman's current annual water demand.[33] It is worth noting that **fossil fuel-based electricity generation consumes significantly more water** than green hydrogen production via water electrolysis.[34] In the context of shifting electricity production from fossil fuels to renewables, the amount of water consumed in electrolysis will potentially be compensated by the amount of water saved from conventional power plants.

Given the limited freshwater resources in Oman, seawater desalination needs to be scaled-up to meet the water requirements of electrolysis. The currently leading desalination technology, reverse osmosis, requires 3.5−4.5 kWh[35] of **electricity** for each cubic meter of clean water produced, **only a small fraction** of the renewable energy required for hydrogen production.[36] Thus, the desalination and electrolysis processes can technically be connected to the same power plant.[37] Planning those new desalination plants at overcapacity can also help reduce pressure on freshwater resources in the water system and meet growing freshwater demand.

The brine water produced by desalination plants can however create **adverse environmental impacts**. For every litre of freshwater, desalination produces around 1.5 litres of highly saline brine-water containing cleaning chemicals, reaction by-products, and metals from equipment corrosion.[38] Brine is commonly discharged into the ocean or into a saline coastal aquifer. Given its higher density, brine fed into the sea sinks to the bottom where its high salinity reduces oxygen levels disrupting aquatic life.[39] The toxins and metals contained in brine further endanger marine environments. Increased local salinity

[31] Average daily refining capacity in Oman is 230,000 barrels. Source: Oil & Gas Middle East (2023). Oman's $7 billion Duqm Refinery to begin operations by year end. Accessed on: 9 May 2023 Link

[32] Beswick et al. (2021). ACS Energy Letters 2021 6 (9). Link

[33] The forecasted water demand in Oman will reach 2,480 million cubic meters (MCM). Source: Water Fanack (2018). Water Challenges in Oman. Accessed on: 8 May 2023. Link

[34] The amount of water required to produce 1 kWh of fossil fuel-based electricity equals to 1.8 litres (equivalent to 60 litres per kg of hydrogen). Source: NREL (2003). Consumptive Water Use for U.S. Power Production. Link

[35] Kim et al. (2019). A comprehensive review of energy consumption of seawater reverse osmosis desalination plants. Link

[36] The additional capacity required for desalination accounts for less than 0.1% of the installed capacity used for electrolysis to produce the needed amount of hydrogen.

[37] This conclusion is in line with the results of Beswick et al. (2021) Link

[38] Jones et al. (2019). The state of desalination and brine production: A global outlook. Link

[39] Panagopoulos & Haralambous (2020). Environmental impacts of desalination and brine treatment. Link

of sea water not only affects sea life but also makes further desalination at those sites more expensive.

To minimize these impacts, **brine management is essential**. This can include reducing brine waste through technological improvement, brine pre- and post-treatment, mining pollutants such as metals from the brine prior to discharge for reuse, and spreading disposal over larger areas or near strong sea currents.[40]

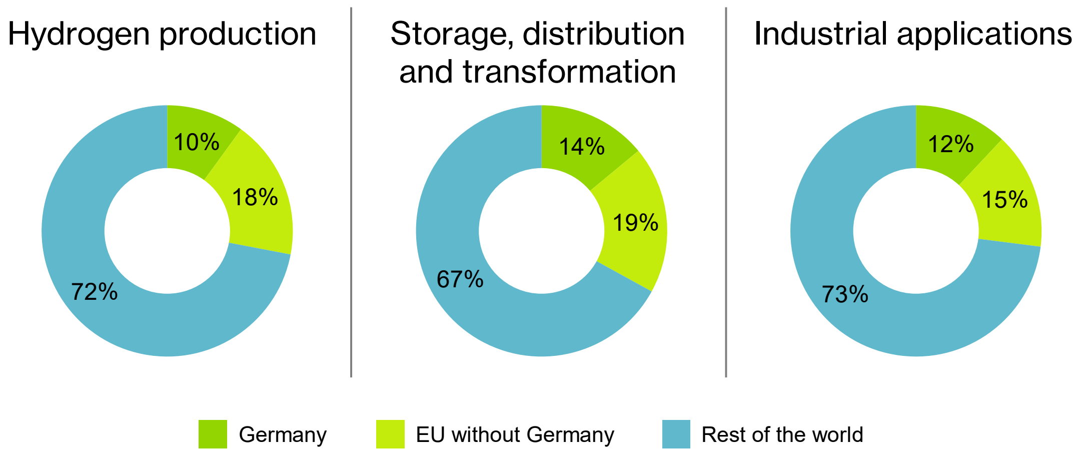
[40] Backer et al. (2022). Brine Solution: Current Status, Future Management and Technology Development. Link

3 Leveraging German experience and know-how

Experience and know-how from international partners such as Germany can play an important role in supporting the run-up of Oman's hydrogen economy. Germany is not only at the forefront of technological development in the field of hydrogen but will also have the highest hydrogen import demand in Europe. This chapter casts light on German solution providers[41] along the hydrogen value chain that could be leveraged for Oman. A list of German hydrogen solution providers[42] can be found in Appendix B.

Among European countries, Germany is leading the development of technologies along the hydrogen value chain. This is reflected in the share of hydrogen-related international patent families (IPF) issued in Germany. An IPF represents a single invention that was filed and published at one or multiple patent offices in different countries and is considered a reliable indicator for 'inventive activity'.[43] Figure 4 shows the IPF shares in different parts of the hydrogen value chain. Germany's share of all hydrogen related IPFs between 2011 and 2020 was at 11%, ranking 3rd worldwide and 1st in Europe.

Figure 4: IPFs issued in different parts of the hydrogen value chain



Guidehouse (2023) based on EPO, IEA (2023)

In the field of **hydrogen production,** Germany is well positioned both in established and in emerging electrolyser technologies. Research, development and production of electrolyser technology includes Alkaline Electrolysers (e.g., thyssenkrupp Nucera), Proton Exchange Membrane (PEM) electrolysers (e.g., Siemens and Bosch (ranked 6th and 9th among the top ten applicants for electrolyser technologies) as well as companies developing Solid Oxide Electrolyser Cells (SOEC) and Anion Exchange Membrane (AEM) electrolysers (e.g., Enapter). Siemens alongside the Japanese company Toshiba are the only firms to invest in all four technologies.

In the area of **storage, distribution and transformation** Germany has an IPF share

[41] The German companies directly referenced in this chapter are taken from EPO, IEA (2023) which focuses on the top ten companies in the respective fields.

[42] Based on Federal Ministry for Economic Affairs and Climate Action (2022). Germany's innovative solutions for the energy transition in the Gulf region. Link

[43] EPO, IEA (2023). Hydrogen patents for a clean energy future. Link

of 14%. Six of the top ten applicants in this field are European companies, among them four German companies Linde, BMW, Bosch, and Siemens. Europe is also leading the emerging field of liquid organic hydrogen carriers (LOHC) with a patent-share of 49%, with Germany alone accounting for 30%.

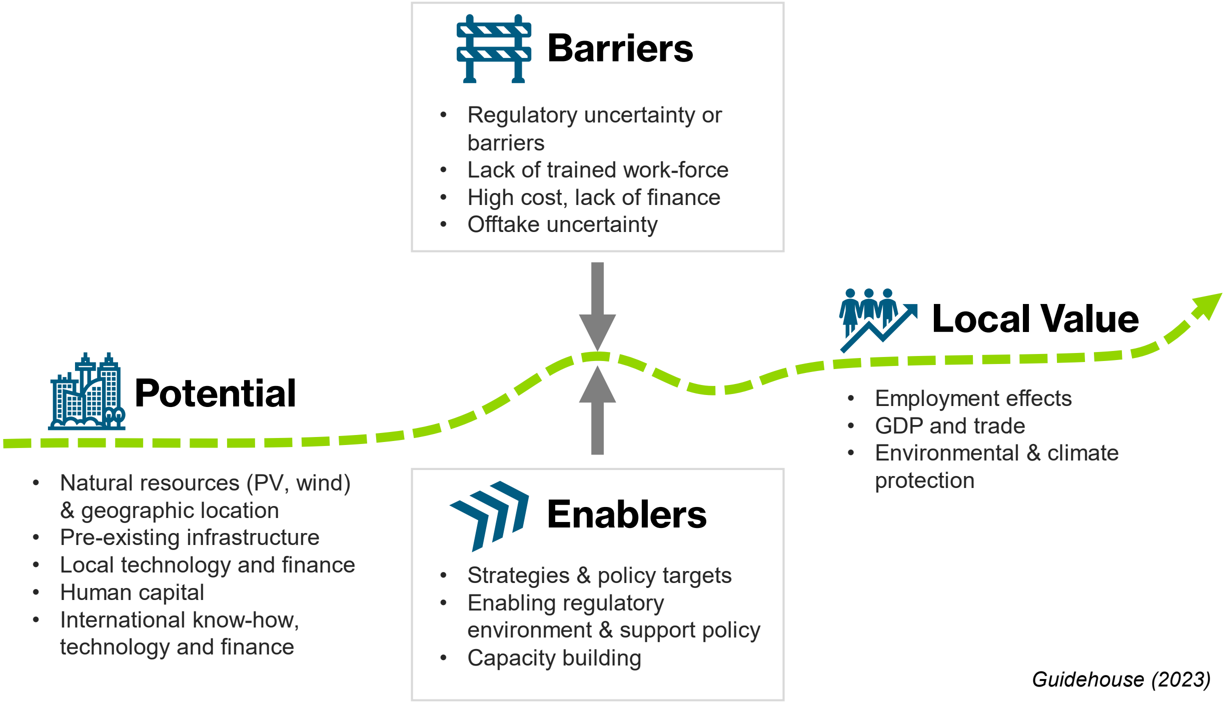
According to the IPF analysis, two of the global top ten hydrogen innovation clusters are in Germany, that is in Munich and in the Ruhr Area. Combining nearly 5% of global IPF shares, those clusters specialize on hydrogen applications, storage, ammonia production and separation/purification with Linde, thyssenkrupp, BMW, Airbus, BASF and Kautex Textron as the largest IPF applicants.

German companies are also active in **industrial applications** and other later stages of the value chain. Thyssenkrupp is developing one of the first industrial hydrogen steel plants, using direct reduction iron (DRI) in Duisburg with an expected hydrogen demand of 0.7 Mt per year starting 2026. The companies Audi, Bosch and BMW are among the top ten IPF applicants in automotive hydrogen applications.

4 Unlocking economic value potential

Economic value creation is an interplay between local potential, barriers, and enablers (see Figure 5). Regulation and policy can act as enablers supporting the ramp-up of the hydrogen economy in Oman. Removing barriers and creating a conducive environment for foreign investment helps leverage know-how and finance flows from international technology leaders and investors. Promoting the development of local capacity, both in terms of skills and suppliers, is crucial for enhancing employment and economic value creation.

Figure 5: Key factors for local value creation from the hydrogen economy



4.1 Regulatory and policy enablers for the hydrogen economy

Regulation and policy are key for enabling the build-up of hydrogen supply chains. A well-balanced approach between regulatory certainty and targeted incentives on the one hand and flexibility and a competitive market environment on the other hand is important to facilitate the development of a sustainable hydrogen economy.

Setting policy targets

Clear policy targets and strategies send strong signals to project developers and investors. To be credible and result in the desired unlocking of the hydrogen economy's full potential, targets must be **realistic, yet ambitious and fully budgeted**.[44] These targets need to be accompanied by a clear **roadmap with intermediate milestones**, associated policies and

[44] OECD (2015). Policy Guidance for Investment in Clean Energy Infrastructure. Link

regular monitoring to ensure the achievement of the goals.[45] It is important to ensure buy-in of all relevant stakeholders at the inception phase of such a roadmap. The absence of coherent, stable policies with long-term visibility on the contrary can be a barrier for investors.

Oman has already taken important steps in setting ambitious **hydrogen production targets** for 2030, 2040 and 2050 and established institutional structures under Hydrom to support those. Auctions for renewable energy lots for hydrogen production are a key element for supporting the achievement of targets.

In parallel, country-wide binding **renewable electricity expansion targets** can support the fast build-out of renewable energy capacity and infrastructure, produce learning effects, cost reductions and synergies, and send a strong signal to international investors[46] regarding the clean energy market potential in Oman. Competitive auctions or administratively set tariffs for renewable energy are effective policy tools for reaching those targets.

Oman targets a 20% renewable energy share in the power sector by 2030, and 35-39% by 2040.[47] The corresponding capacity is auctioned by the Oman Power and Water Procurement Company (OPWP) in regular intervals. Further support policies such as the existing Renewable Energy Initiative incentive scheme for rooftop solar PV can facilitate the local build-up of technical renewable energy capacities if there is sufficient uptake.

Best practices for auction implementation:
Planning security is crucial for businesses to build up project pipelines and value chains needed to reach the hydrogen (and renewable energy) targets on time. Experience from renewable energy auctions shows that **long-term visibility and certainty** over schedule and volumes, and **transparent eligibility and selection criteria** play an important role in attracting investors, mitigating unnecessary risk for project developers, and ultimately achieving a cost-effective buildout.

Source: AURES (2021). Auction design and renewable energy financing. Available online: Link.

Moreover, putting a price on carbon provides clear visibility of the economic transformation and supports domestic decarbonisation. Emissions trading systems are powerful instruments for reducing carbon emissions while using market mechanisms to achieve cost-efficient emissions reductions. Importantly, their introduction makes avoidable domestic carbon emissions, e.g., from industry, utilisable for the production of hydrogen-based synthetic fuels in line with the EU sustainability criteria for exports to EU markets.[48]

[45] OECD (2015). Policy Guidance for Investment in Clean Energy Infrastructure.

[46] OECD (2015). Policy Guidance for Investment in Clean Energy Infrastructure.

[47] Sultanate of Oman (2021). Oman Vision 2040. Link

[48] The EU requires carbon-molecules used in synthetic fuel production to be covered upstream by an effective carbon pricing scheme (see Delegated Act on Article 28 of the EU Renewable Energy Directive II, Link)

Spurring offtake demand

Hydrogen **projects need reliable offtake demand** to be bankable. Unlike in the natural gas sector, where a liquid market for a well-defined commodity already exists, the global green hydrogen market is just evolving. Fixed offtake agreements will be critical to make investments into production capacities worthwhile in the first place. International hydrogen support schemes such as H2Global can help de-risk projects by providing fixed offtake contracts (see below).

While export demand will be subject to international competition, domestic demand can in many cases be served cost-efficiently by local production. Ensuring a **base-level of domestic hydrogen** demand supports investment decisions in the early market phase through a secured level of local offtake and demonstrates Oman's commitment to building a hydrogen economy vis à vis international investors.

Policy pathways and **strategies for domestic decarbonisation** can spur local demand for hydrogen offtake. At the same time, support for **economic activities** that leverage the country's large green hydrogen potential unlocks additional employment and economic benefits. To this end, strategies, and targets for the decarbonisation of domestic industry can be supported by providing support for innovation, research, and development on hydrogen use, lowering cost barriers of hydrogen use, as well as proactive infrastructure planning and development.[49]

Defining an export strategy and aligning with major importers

With large shares of Oman's mid- and long-term hydrogen production being designated to exports, it will be crucial to **align with the needs of importers**. Aside from commercial aspects (e.g., quantities and prices of specific consignments) important dimensions for alignment with key export markets include timelines, products, qualities, and sustainability criteria.

As a first step, the **definition of key offtake regions** for exports is central. Those regions could also be anchored in a national hydrogen strategy. In a second step, implementing **hydrogen production criteria** in accordance with the requirements in those markets, e.g., for meeting sustainability and quality standards, would be advisable. This gives guidance to local companies while providing a strong signal for international firms from target offtake regions. At the same time, it can be useful to **involve offtakers in the planning** of the first projects from the onset to ensure project viability and bankability. Once the global hydrogen market has reached liquidity, projects will be able to secure offtake at competitive markets.

[49] IEA 2023: Renewable Hydrogen from Oman. Link

The **German H2Global scheme** supports the run up of international hydrogen trade by bridging the cost gap between supply and demand of green hydrogen, thereby promoting hydrogen offtake. Long-term (10-year) purchase agreements for the supply side and short term (1-year) agreements on the offtake side are auctioned through the intermediary Hint.Co. A contract for differences (CfD) between the lowest possible production cost and the highest willingness to pay bridges the cost difference between producers and offtakers while cost declines and willingness to pay increases. The H2Global scheme also features joint funding windows with supplier countries.

For more information on H2Global see: https://www.h2-global.de/project/h2g-mechanism

Creating a supportive regulatory framework for hydrogen production and infrastructure

In the emerging hydrogen sector, appropriate **regulatory frameworks** must be developed for both **hydrogen production and infrastructure**. In general, conditions and regulatory requirements must be applied fairly and in a non-discriminatory way and projects be shielded from (adverse implications of) retroactive policy or regulatory changes. Moreover, roles and responsibilities in the emerging hydrogen sector (e.g., regulator vs. policy maker vs. auctioneer) must be defined and communicated in a transparent way.

For hydrogen **production**, key regulatory aspects concern criteria regarding the siting of electrolysers (e.g., taking into account their impact on the electricity grid), hydrogen sustainability and quality, water sourcing and other aspects. As the hydrogen sector in Oman is still in its very beginning and some regulatory requirements will only become clear with **experience from first pilot projects** (see below). Against this backdrop, Germany devises so-called regulatory sandboxes[50] as testing environments for energy technologies, including green hydrogen. They promote innovation and support the development of a forward-thinking regulatory frameworks. Oman too is devising regulatory sandboxes for blue hydrogen production in combination with CCUS regulation. This could be replicated for pilot projects of green hydrogen production.

Investments in dedicated hydrogen **infrastructure** or retrofitting of natural gas pipelines are a prerequisite for hydrogen transport and require regulatory clarity from the onset.[51] Integrated network planning, considering hydrogen, gas and electricity, involving transmission and distribution network companies can leverage synergies. Various time horizons should be taken into account to ensure infrastructure meets current and future demand, both domestically (e.g., new industrial centres) and for exports (access to harbours or pipelines). To create a level playing field, access rules to hydrogen infrastructure must be transparent and fair, ensuring third-party access to accelerate the upscaling of the hydrogen economy.

[50] A handbook on regulatory sandboxes can be found online: Link

[51] Guidehouse (2022). Covering Germany's green hydrogen demand: Transport options for enabling imports. Link

In addition, more targeted measures include setting up a **one-stop shop for land allocation** and registration (which in the case of Oman was created by Hydrom), **facilitating permitting and licensing** for clean energy plants including hydrogen, **providing necessary infrastructure** including grid infrastructure for renewable energy sourcing and hydrogen transport and export infrastructure (e.g., pre-developed sites at ports) to reduce overall project cost, as well as cultivating openness for private actors to invest in adequate infrastructure, and financial or fiscal incentives (see below).

The Organisation for Economic Cooperation and Development (OECD) has developed guidance for policy makers seeking to promote investment in clean energy infrastructure.[52] General provisions include ensuring the **enforcement of contracts**, protecting **intellectual property rights**, and offering a streamlined, non-discriminatory processes for patent applications, **transparent and fair tenders**, and access to **long-term finance** at domestic and international financial markets.

Supporting first mover projects through dedicated schemes

Early projects are instrumental for establishing proof of concept of green hydrogen production in Oman, **creating learning effects** for policy, regulation, training, and infrastructure needs and building up first supply chains. Supporting (first mover) projects during the initial stages of the market can help investors overcome the initially high upfront costs and reach a competitive, levelised cost of hydrogen. Removing subsidies for fossil energy and introducing a carbon pricing can unlock public revenue streams for financing investment incentives in renewable energy.

Possible **support schemes** can either address the technology development, the production side, or the offtake side. Possible options include grants, loans or tax rebates for producers, de-risking schemes such as credit default guarantees for producers or offtakers, bridging differential cost (see box on H2Global) as well as support in the form of infrastructure provision or pre-approval of site.

Chile's economic development agency, "Corporación de Fomento de la Producción de Chile" (CORFO) pursues goals similar to those in Oman's Vision 2040 while providing strategic investment incentives to support the development of technological and human capital capabilities in the sustainable energy field. CORFO offers investment grants for national and foreign companies developing green hydrogen projects in Chile, totaling up to USD 50 million. The program also includes support for projects at pre-investment stage, investment guarantees, innovation grants and R&D tax incentives.

For more information on the Chilean scheme see: https://www.corfo.cl/sites/cpp/webingles

[52] OECD (2015). Policy Guidance for Investment in Clean Energy Infrastructure.

Support measures should be transitional and focus on unlocking initial market opportunities for green hydrogen projects in the early market phase with view to transitioning to liberalised, competitive markets in the long run.

Utilising local and international resources to unlock the full potential of Oman's hydrogen economy

Several countries have devised Local Content Requirements (LCRs) to promote in-country value, particularly in extractive industries and the energy sector. One of the primary purposes of LCRs is to **protect infant industries** (e.g., renewable energy or hydrogen technology and manufacturing capabilities) from outside competition and allow them to reach international competitiveness. The benefits LCRs can produce are dependent on the local potential, e.g., presence of relevant industries and trained personnel or training and skilling opportunities. In countries with established industries, LCRs can additionally create employment benefits.

Norway took an early policy decision to **actively develop domestic industry** instead of relying solely on LCR. It devised strong incentives to encourage the development of local industry, giving preference to domestic companies if they were considered competitive with international players in terms of price and quality. These requirements were relaxed over time as Norway's industry reached international competitiveness levels. At the same time, a supplier development program was established to address the needs of the nascent oil industry through local firms.

See also: UNCTAD (2014).

Foreign Direct Investment (FDI) in the form of greenfield investments that create new assets in the host country can support the development and build-up of domestic industry capacities. There are however **major trade-offs between FDI and LCRs**. LCRs can represent a **major hindrance for foreign investors and businesses** to engage in the sector because they set additional obligations and shift the playing field in favour of local firms or larger companies that are better able to absorb the additional cost.[53] By increasing cost for multinationals LCRs can lead to lower profits and consequently reduced tax income for the host country[54] or – if cost is passed on – make products less competitive against other international suppliers.

Studies also find LCRs to be ultimately harmful to trade (particularly those that are trade related) and competitiveness.[55] Experience from solar technology shows that measures aimed at **protecting local manufacturing** are actually **inefficient** for local value creation. More than 60% associated with the sector and nearly 70% of the value created occur after the manufacturing phase (example from of the United States' solar industry).[56] This is in line with the modelling results on the employment effects in Chapter 2.1.1 which indicate that 29-42% of

[53] UNCTAD (2014). Local Content Requirements and The Green Economy. Link
[54] Kolstad & Kinyondo (2017). Alternatives to local content requirements in resource-rich countries. Link
[55] OECD (2015). Localisation barriers to trade. OECD Trade Policy Papers No. 180. Link
[56] OECD (2015). Policy Guidance for Investment in Clean Energy Infrastructure. Link

the total employment opportunities (excluding jobs associated with the deployment of renewable energies) are linked to manufacturing activities.

It is therefore vital to assess the objectives behind these measures and **evaluate alternative ways of achieving** them, e.g., by joining forces on research and development and local workforce development to improve the competitiveness of local companies. If considered, LCRs should be phased in and eventually phased out gradually and transparently to give sufficient time for actors to react to new information.[57]

4.2 Capacity building

Two aspects help to enable local value creation: (1) an innovative and reliable environment to develop and integrate technologies along the entire hydrogen value chain and drive down costs, as outlined above and (2) the availability of a skilled workforce and capacities to execute the planned projects. The latest Global Innovation Index for Oman identifies key shortcomings in the areas of R&D (low research talent in businesses, large share of high-tech imports, low gross domestic expenditure on R&D, to name some)[58]. Regarding the necessary pool of qualified talents, Oman can capitalize on its human resources from the oil and gas industry. Technical expertise on the safe handling of hydrogen already exists in downstream segments, such as the oil refining sector and grey ammonia production. However, this workforce is small compared to the dimensions of what will be required to realize the announced green hydrogen projects for 2030 and only covers a small part of the new green hydrogen value chain. Therefore, it is important to proactively identify and address potential labour shortages to mitigate cost and completion schedule risks for these projects.

Capacity building is crucial for both, to strengthen innovation and to provide a sufficiently large talent pool. A structured assessment of the capacity building requirements will provide a clear understanding of hydrogen careers and workforce transferability and will enable the development of the right training and educational offers for a hydrogen economy.

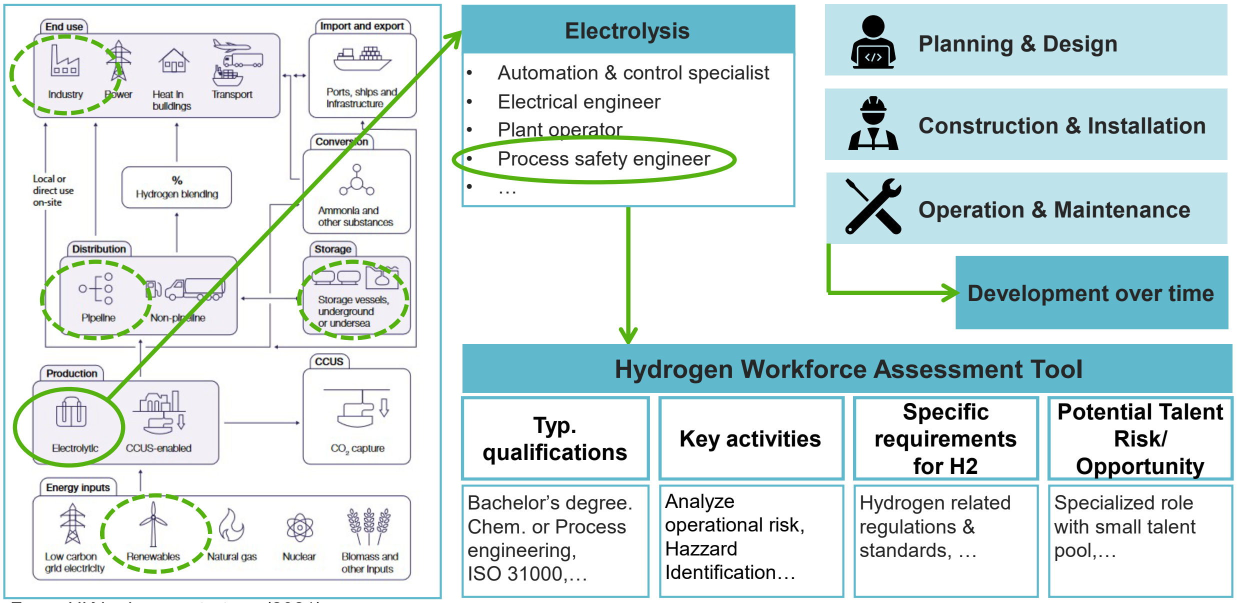
4.2.1 Identifying capacity building needs

To build up an adequate skill base, an inventory of the status quo provides a useful starting point. Stakeholders across the hydrogen value chain need to map their specific positions and roles along the value chain and identify a) the essential core occupations including their skill and knowledge requirements and b) skill and knowledge requirements for additional affected occupations. Based on this a gap analysis should be conducted, to identify opportunities to leverage the current skill pool and the requirements for additional hydrogen-specific training and workforce development. This assessment should be done per system component and for every project phase, to understand the pace at which an expanded hydrogen workforce will be required. Finally, potential risks and bottlenecks to meet the hydrogen economies talent requirements must be identified. An example for such a mapping procedure for a specific occupation, here a process safety engineer is shown in Figure 6.

[57] Kolstad & Kinyondo (2017). Alternatives to local content requirements in resource-rich countries. Link

[58] WIPO (n.d.). Global Innovation Index 2022 Oman. Link

Figure 6: Exemplary mapping procedure to identify workforce requirements



From: UK hydrogen strategy (2021)

Besides the companies directly involved in hydrogen production, transportation or consumption, a wide range of additional organisations will require special training and knowledge (e.g., insurers, municipalities, fire brigades, etc.). Furthermore, many of these jobs do not currently exist, and therefore no corresponding job titles in the official classifications exist.[59]

Studies indicate that significant talent shortages in core occupations such as engineering could be a greater talent risk than a lack of hydrogen specific skills.[60] It is important to note, that even where individual training needs for occupations are modest, the scale of the overall roll-out required over a short time, will still be a significant challenge.[61]

4.2.2 Training and education to address the new capacity building needs

Capacity building for green hydrogen can occur through on the job training or in a more formalised setting, via structured education and training. An evaluation of the current training landscape across Europe[62] showed that currently Master programs and professional training courses are dominating the training landscape.

In the academic area, hydrogen was first addressed in Master's or PhD theses. Meanwhile many universities offer integrated elements e.g., individual modules or courses, within a technical or economical degree. Furthermore, the first dedicated Master's programs are evolving. **Interdisciplinarity** is key, due to the nature of hydrogen as the energy vector for

[59] itt perspektive (2020). Skills Development for Hydrogen Economies – Damit aus einer Wasserstoffstrategie eine Wasserstoff(weiter)bildungsstrategie wird. Available online (German). Link

[60] HYPOS e.V. (2022). Berufliche Qualifikationen in der Wasserstoffindustrie (English title: Job Qualification in the Hydrogen Industry). Available online (German). Link

[61] H2FCSupergen (2017). The Economic Impact of Hydrogen and Fuel Cells in the UK. Link

[62] Fuel Cells and Hydrogen Observatory (2022). Education & Training. Link

sector coupling, but also between technical and economic disciplines to successfully implement projects.

In the professional training area, the development of industry association certificated courses is important to provide quality assurance and comparable qualifications. However, the development of industry-endorsed technical standards is crucial in this regard, as a lack of such standards will impede the development of relevant trainings.

Pilot and demonstration projects are the most important source for real-time learning opportunities, for individuals for on-the-job training as well as for organisations. They also provide the basis for developing industry-endorsed technical standards. Pilots and demonstration projects will require public funding and should be characterised by a strong **cooperation** between universities, non-university research institutions and industry, and international cooperation. They need to be complemented with investments for equipping student **hydrogen laboratories for practical training** and some private sector funding for Bachelor's, Master's or PhD theses.

Finally, the government has a key role, in setting up **fast approval processes** for new courses and programs for universities and other training providers, to keep pace with the developments in the industry.

In the academic area, Oman is well positioned, with its strong technical universities such as Sultan Qaboos University (SQU) and German University of Technology in Oman (GUtech), and the Oman Hydrogen Centre (OHC). Programs set up in this area will benefit from international partners, like universities as the RWTH Aachen or the TU Munich as well as the Fraunhofer Institutes for R&D, who focus on applied research. The Fraunhofer Academy[63] for training, as well as others professional training providers like TÜV SÜD[64] or the Renewable Energy Academy (RENAC)[65] can support in the area of professional training.

4.2.3 General awareness creation

For public acceptance and capacity building, general awareness for climate change, energy transition and renewable energies needs to grow. Schools have a key role in this. They can raise the interest of young people in scientific and technical professions at an early age and lay a solid foundation in the so-called STEM (Science, Technology, Engineering and Mathematics) subjects. To fulfil this role, qualified teachers, and an educational concept for the integration of climate, energy, and hydrogen topics in the classroom is required. Providing schools with toolkits & platforms, for knowledge sharing are strong enablers.

[63] More information, see: https://www.academy.fraunhofer.de/en.html
[64] More information, see: https://www.tuvsud.com/en/services/training
[65] More information, see: https://www.renac.de/trainings-services

5 Conclusions and recommendations for policy makers

Oman's hydrogen plans are ambitious. If governed well, the emerging hydrogen sector can make a substantial contribution to local economic value creation, particularly around employment, and provide an alternative pathway of sustainable development beyond oil and gas.

The creation of a hydrogen economy as envisioned by Oman has a large potential for domestic job creation. In total, 291,000-381,800 employment opportunities (FTE) could be realized by 2050 based on the hydrogen production target of 8 Mt. 46-50% of the employment opportunities are expected to be created though the deployment of renewable energy as feedstock for hydrogen production. Major employment benefits are seen in the construction and industry sectors and to lesser extent in research and development, and non-technical services. A higher share of local manufacturing in the field of green hydrogen could lead to an increase of 31% of total employment potential. Depending on the price of green ammonia and green steel, the possible contribution of green hydrogen-related exports to GDP is expected to be at least as high as that of current oil and gas exports.

In addition, synergies between scaling up green hydrogen and renewables in Oman can be created. While grid-connected green hydrogen has an impact on the power system it can also offer flexibility for system integration. A fast scale-up of renewables on the other hand can support faster cost reductions and lower the cost of green hydrogen. By replacing fossil fuel-based industrial feedstocks locally, green hydrogen can moreover make an important contribution to reducing the country's emissions.

To support the nascent hydrogen economy and capitalize on those benefits, policy makers in Oman might consider the following recommendations:

- Further elaborate plans for the **energy transition** including for hydrogen to **spur local offtake demand,** e.g., a phased fuel-switch to hydrogen in energy intensive industry and manufacturing sectors, and consider the **introduction of carbon pricing**. These can make a vital contribution to reaching Oman's Net-Zero target.
- Consider **further elevating the 2030 and 2040** renewable energy targets and implementing **supporting policies to achieve strengthened targets**. This can unlock cost reductions for green hydrogen and infrastructure synergies while also giving a strong signal to investors of Oman's growing clean energy technology market.
- Recognize the importance of **pilot projects** for developing regulation, proof of concept and gaining insights on infrastructure and supply chain needs. Create supportive conditions for first-movers, including financial support, to kickstart the market run-up.
- Support the timely **build-out of necessary infrastructure** to enable domestic offtake and exports. Continue to engage in proactive infrastructure planning (pipeline networks and export facilities at ports), develop hydrogen infrastructure regulation, and consider infrastructure repurposing potential to reduce cost and lead times.
- Define **key offtake markets** and **align with international offtakers** regarding demand, and **(sustainability) requirements.** Support international efforts for mutual recognition of hydrogen certification processes.

- Clarify the **objectives behind local content requirements and evaluate alternative approaches** for achieving these objectives.
- If local content requirements (LCR) are taken into consideration, they should be focused on **capacity-building and value-added** (i.e., support domestic firms in acquiring capabilities to generate higher value-added in the future) rather than mere ownership. Any LCRs should be phased-in and -out again in a gradual and transparent manner.
- Provide **incentives for international consortia to support capacity building**, technology development and knowledge transfer, rather than setting strict requirements that compromise the cost-competitiveness of green hydrogen from Oman.
- **Identify capacity buildings needs** on a national level and encourage companies and organisations to do the same on their level.
- **Speed up approval processes** for universities and other **training providers** to set up dedicated programs for hydrogen related capacity building.
- Raise **public awareness** for environment, climate change, sustainability, and opportunities from renewable energy and hydrogen.

Appendix A. Modelling assumptions

Parameter	Assumption	Source
Wages and salaries in Oman	-	Based on MEM and statistical yearbook 2022, Sultanate of Oman
Average FTE in Oman	2040 hours / year	MEM
Input/Output table	-	MEM
Green hydrogen production in Oman 2050	8 MTPA	MEM
Domestic hydrogen demand, 2050	1.75 MTPA	MEM
LCOH2	50 €/MWh	Guidehouse 2022
Share of export delivered as derivative	90%	Own assumption
OMR – EUR exchange rate	0.41:1	Stand April 2023
OMR – USD exchange rate	0.38:1	Stand April 2023
Credit periods	20 years	Own assumption
Loan interest rate	5%	Own assumption
Green hydrogen / ammonia supply chain		
Capital cost share	20%	Based on Guidehouse 2019
O&M cost share	13%	Based on Guidehouse 2019
Feedstock cost share	67%	Based on Guidehouse 2019
Green steel to power demand chain		
National green steel production	1.4 MTPA	Own assumption
Green steel capital cost share	9%	EPRS (2021). Carbon-free steel production
Green steel O&M cost share	1%	EPRS (2021). Carbon-free steel production
Green steel feedstock cost share	90%	EPRS (2021). Carbon-free steel production
Energy demand DRI steel production	16,6 t_{steel}/t_{H2}	Common futures (2023). Potential supply chains for hydrogen steelmaking in Europe
Cost for green steel facility	3 Bn USD for 5 MTPA	Based on Jindal presentation
Hydrogen to power demand chain (2050)		
National hydrogen demand for power generation	0.35 MTPA	Own assumption
Fuel Cell efficiency	60%	Own assumption
Full load hours	4,000	Own assumption
Specific capital cost	600 €/kW	Based on gas power plant data from Fraunhofer ISE (2018)
Specific O&M cost	20 €/kW	Based on gas power plant data from Fraunhofer ISE (2018)
Type of plant	Power generation only through new dedicated hydrogen power plants	Own assumption
Sensitivity analysis / investments & expense share		
Omani share in material expenses	90%	Own assumption
Omani share in services expenses (low local value)	10%	Own assumption
Omani share in services expenses (high local value)	30%	Own assumption
Hardware cost share of indirect feedstock costs	63%	Based on data from NREL (2021)

Appendix B. Germany's hydrogen solution providers

Field	Companies (product)
Project development	Eternal Power, Hydrogen Rise
Electrolyser and other manufacturing	AREVA H2Gen (PEM electrolysis), Borsig ZM (compression), Enapter (AEM electrolysis), Evonik (AEM electrolysis), GSR (Valves), Heraeus (catalysts), HEROSE (vavles), H-TEC SYSTEMS (PEM electrolysis), Linde Engineering (PEM), Neuman & Esser (compression), Robert Bosch (PEM), Sunfire, thyssenkrupp nucera (PEM electrolysis)
Transport	Hydrogenious (LOHC), Max Streicher (pipelines)
Application	Aspens (fuel cell), AVL List (powertrain solution), BASF (chemistry), F.Laeisz (transportation applications), H2-Mobility (mobility),IAV (fuel cell), Ineratec (E-Fuels, PtX), Lufthansa (aviation), MAN Energy Solutions (turbines), Neuman & Esser piston (compressors, PtX, mobility), Robert Bosch (comprehensive hydrogen technology, fuel cells), Siemens Energy (hydrogen turbines), thyssenkrupp nucera (chlor-alkali), Tractebel (PtX)
Certification, Standards	DIN, TÜV Nord, TÜV Rheinland, TÜV SÜD
Research	Fraunhofer Institutes (e.g., IEG, ISC, ISE, IST)
Other	Boreal Light (water desalination), Carbonauten (CO_2-sink), Next Kraftwerke (virtual power plants), SPG Steiner (ammonia plants), SMA (solar PV systems), Viessmann
Solutions along various parts of the value chain	Aspens, BASF, IAV, Linde Engineering, Ludwig Bölkow Systemtechnik, Lufthansa, MAN Energy Solutions, MTU Middle East, Robert Bosch, RWE, Sunfire, thyssenkrupp Engineering, Tractebel, Uniper, Wago, Wenge