Support for the implementation of a research and development platform for Green Hydrogen in Morocco

Work Package 1 Report - Mapping of R&D framework in the PtX value chain

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Mapping of PtX R&D framework in Morocco

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List of abbreviations

AEL	Alkaline Electrolysis
AEM	Anion Exchange Membrane
BoP	Balancing of Plant
CC	Carbon Capture
CCUS	Carbon Capture Use and Storage
CfD	Contract for Difference
CSP	Concentrated Solar Power
DAC	Direct Air Capture
EC	European Commission
ED	Electro Dialysis
ESA-DAC	Electro-Swing Adsorption Direct Air Capture
IPP	Independent Power Producer
L-DAC	Liquid based Direct Air Capture
LCOE	Levelized Cost of Electricity
M-DAC	Membrane based Separation Direct Air capture
MSF	Multi Stage Flash
MED	Multi Effect Distillation
PtX	Power-to-X
PV	Photovoltaic
R&D	Research and Development
RES	Renewable Energy Sources
RO	Reverse Osmosis
S-DAC	Solid Based Direct Air Capture
SOEC	Solid Oxide Electrolysis Cell
TIS	Technological Innovation System
TRL	Technology Readiness Level
TVP	Thermal Vapor Compression

1 Introduction

1.1 Background - Green Hydrogen in Morocco

Decarbonization of energy systems as well as the creation of economic growth opportunities in sustainable and innovative sectors are **major drivers for the development of Green Hydrogen value chains** worldwide. Furthermore, against the background of recent global geopolitical developments and supply issues for natural gas in many countries worldwide, both the accelerated replacement of fossil fuels as well as reaching a higher degree of energy independence have gained importance. Morocco, as a current net fuel importer and with its vast renewable energy resources has very strong drivers and is in a favourable position for the production of Green Hydrogen for the countries' own demand as well as for export.

A wide range of **potential application fields for green hydrogen and its derivatives** exists of which some are considered as without alternative to achieve a deep or full decarbonisation of the energy system. This applies in particular to areas in which a direct use of material energy carriers is unavoidable and an electrification of the processes is thus not feasible. This applies, for example, to some industrial processes that require specific types of high temperature process heat (e.g. processes that use gas burners or steam), the production of certain chemical products as well as the air and sea transport sectors in which electric mobility concepts are not an option. In the industry sector, this applies in particular to the metallurgical industry and here specifically to steel production, but also to the production and processing of other types of metals, as well as to the highly energy and emission intensive cement, ceramic and glass industries. Another relevant use case for Green Hydrogen is the production of Green Ammonia, for the manufacturing of fertilizers, chemicals or for the direct use in fuel cells. For Morocco, as one of the leading producers of nitrogen fertilizers and one of the top four exporters of fertilizers worldwide, this is a particularly relevant field of application. The OCP group, Morocco's state-owned producer of phosphate, fertilizers and other chemicals, currently employs over 21,000 people and contributes to a major share of the countries' export revenues.

In other application fields, such as road and rail transport, both the use of synthetic fuels and direct electrification are feasible technological options and their applicability depends on the individual evaluation of the techno-economic and socio-political framework conditions in the specific case. In other sectors and application fields, such as private transport, provision of flexibility and stabilization of the electricity system or areas that require low-temperature process heat (e.g. district heating), direct electrification in most cases is the more cost efficient solution, however, this depends on the individual use case.

Against the background of the various drivers and the vast potential for the development of a national PtX value chain, the government of Morocco has defined a strategy and targets for the rollout of green hydrogen and PtX technologies (see chapter 2 for more details). As part of this strategy, to facilitate and accelerate the development of Moroccan capacities in the field of Green Hydrogen, it was decided that a national Green Hydrogen Research and Development (R&D) platform will be created. The purpose of this platform is to provide infrastructure and support for relevant stakeholders in the PtX value chain, facilitate networking and knowledge exchange in the research and industry sector and facilitate the development of specific technical capacities and local expertise in the PtX sector. The platform should further serve as an interface for international collaboration in the field, to further drive innovation.

1.2 Goal and structure of this report

Against the background of the above, the report on hand aims at providing an overview of the past and ongoing activities related to Green Hydrogen and Power-to-X (PtX) in Morocco and a mapping of the involved stakeholders and their roles in the PtX R&D landscape in Morocco to support the design of the PtX R&D Platform.

A consultation of selected stakeholders provides further insights into their perspectives and the focus of their interests regarding future PtX-related R&D activities in Morocco as well as the major barriers and drivers they perceive in the national framework for PtX R&D. These results can then serve as a basis for the development of a strategic PtX R&D roadmap that supports the implementation of Morocco's targets for the development of a sustainable and competitive national PtX economy which will be covered by a subsequent report.

In line with the above goals, this report is structured as follows:

Chapter 2 gives a brief **introduction to the national PtX strategy and strategic goals** to provide the strategic framing for the subsequent analysis of the respective R&D activities.

Chapter 3 provides the technical background and analytical structure for the following steps by giving an overview of the major technical **components in the PtX value chain and the latest technological developments**. This chapter is structured by activities in the upstream segment of the value chain, i.e. activities and components used as input for the production of Green Hydrogen and its derivatives; activities in the midstream of the PtX value chain, i.e. for production and transport of Green Hydrogen; and activities in the downstream segment, i.e. for the production of different derivatives of Green Hydrogen.

Chapter 4 then focuses on the activities related to the PtX value chain in Morocco by **mapping the relevant stakeholders and giving an overview over the past and ongoing activities in the field of PtX R&D in Morocco**. The Assessment is complemented by a stakeholder consultation process to gain deeper insights and understand the viewpoints and opinions of representatives of the most relevant stakeholder groups.

Chapter 5 presents the **analysis of the PtX framework in Morocco** based on the foregone steps. It includes an evaluation of the strengths and weaknesses in the Moroccan PtX framework and an identification of research areas that could be prioritized in order to address the needs and requirements of the local stakeholders in line with technological trends and the national PtX strategy.

Chapter 6 finally provides a **summary and first conclusions and recommendations** for the further development of the R&D landscape for PtX in Morocco. These will be further refined and elaborated in discourse with the concerned stakeholders in the later stages of this project.

2 National Strategy for Green Hydrogen and PtX

Between 2018 and 2022, Morocco has developed an ambitious strategy for the rollout of Green Hydrogen and PtX until 2050. The development of the strategy was, besides others, based on the following studies:

- Study on the Opportunities of Power-to-X in Morocco prepared by Fraunhofer (2018/2019)[1]
- Morocco's PtX 2050 Roadmap prepared by Frontier Economics (2020)

The above mentioned studies highlighted the great potential for the production and export of Green hydrogen and other PtX products in Morocco. In response, the National Commission of Hydrogen was created to develop a national strategy on green hydrogen production and for the establishment of a more detailed roadmap for the development until 2050. The following key milestones mark the development of the Moroccan green hydrogen strategy:

- The Creation of a National commission for Power to X by the Moroccan Energy Ministry on Feb.11, 2019
- Creation of a Green Hydrogen Cluster
- Morocco – EU partnership with Germany in June 2020 to develop a regional market for PtX
- Publication of "Roadmap for Green Hydrogen" in Aug. 2021

Morocco now aims at developing a strong local green hydrogen, green ammonia and liquid fuels sector, to cover the local industry demand as well as up to 4% of the global demand for green hydrogen until 2030. Until 2030, up to 162 TWh of green hydrogen could be exported assuming an optimistic scenario.

To further facilitate and accelerate the ambitious development of Moroccan capacities in the field of green hydrogen, the Moroccan government decided in 2021 to create a national Green Hydrogen Research and Development (R&D) platform. The platform aims at providing infrastructure and support for relevant stakeholders in the PtX value chain, facilitate networking and knowledge exchange in the research and industry sector and facilitate the development of specific technical capacities and local expertise in the PtX sector. The platform should further serve as an interface for international collaboration in the field, to further drive innovation.

Even though the Green Hydrogen R&D platform has not been launched yet, a number of applied research activities have already been initiated to support the development of local know-how and capacities for the production and use of green Hydrogen and downstream products, in particular ammonia, for meeting the local demand and for export.

The Green H2A R&D platform is further meant as a base for several other key activities: several platforms were started (Green Ammonia, Green Methanol, LOHC, etc.) which address different R&D work areas for PtX. A pilot project "Green Ammonia Pilot Plant" (4MW) was defined and initiated. Projects for different aspects of PtX like storage of Hydrogen were started (e.g. Project MELHY) as well as for "Power to Liquid" (1MW) (Project PtX Pathways). In parallel to the already

[1] https://www.isi.fraunhofer.de/en/presse/2019/presseinfo-24-klimaneutrale-energie-aus-power-to-x-marokko.html

planned pilot installation, a second Green Ammonia pilot project was announced in March 2022 (to be implemented by UM6P, OCP, Shell).

Most recently, the PtX Summit from June 22nd-24th 2022 in Morocco displayed the big support of PtX by the Moroccan government, local companies, and international partners. The event included presentations and discussion on a broad range of topics, most notably:

- The clear demonstration of the strong potential for Green Hydrogen in Morocco, based on both, wind and solar energy ("Morocco emerging … among top tier producers of green H2 by 2025").
- Discussions of the various innovation themes and the implementation of a semi-industrial scale to prove concepts and to test technologies (with OCP as one of the central stakeholders).
- The need for further cost reductions in electrolysis, which will depend on the scale up of the technology (e.g. JESA).
- Discussions about the transmission, distribution and storage aspects of the hydrogen value chain (e.g. JESA), thus addressing costs beyond electrolysis (e.g. for compression).
- Debating opportunities of modular setups to allow gradual expansion (e.g. Proton).
- Discussion of critical aspects of bankability ("market uncertainties delay investment") and entry barriers ("High investment cost and off-take risks at the start of market ramp-up", KfW).

A general consensus at the summit was that knowledge along the complete PtX value chain is essential for Morocco in order to be able to move forward in a sustainable manner.

3 The Green Hydrogen value chain

The following section gives a general description and overview of the Green Hydrogen value chain with its most relevant components and technologies in the Moroccan country context. This overview of technologies, trends and cost developments provides the background and analytical structure for the following analytical steps.

The value chain for green hydrogen comprises various segments, which can be divided into three parts: upstream, midstream and downstream. Upstream activities include all technologies for providing feedstock and energy for the production of Green Hydrogen and its derivatives. These are primarily electricity from renewable energies, water and CO_2. Midstream activities comprise the technologies for the actual generation of Green Hydrogen, namely the different types of electrolysis, while downstream activities, as the name suggests, cover all technologies for products derived from Green Hydrogen such as ammonia and methanol. An overview is given in Figure 1.

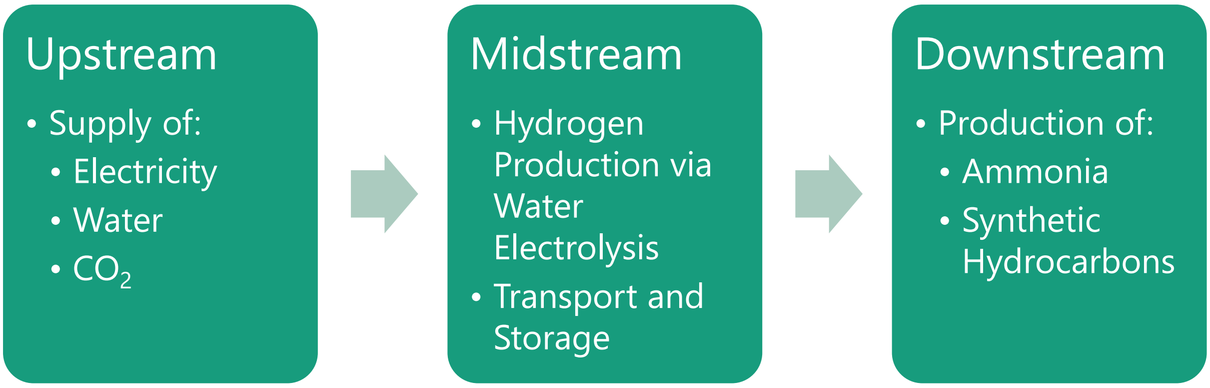


Figure 1 Overview of the segments of the Green Hydrogen value chain

3.1 Upstream activities

Power Generation from RES

There are several options for generating electricity from renewable energy sources (RES). The two types of power plants that have expanded the most worldwide in recent years are solar photovoltaics (PV) and onshore wind power (IRENA, 2022a). This is also reflected in the cost reductions in power generation. For both technologies, declines in installed cost per kW and increases in average capacity factors have led to global average cuts in levelized cost of electricity (LCOE) of 88 % (PV) and 68 % (onshore wind) between 2010 and 2021 (IRENA, 2022b). Solar PV, in particular, is a very good example of how technological innovation can reduce the cost and enhance the performance of a technology. R&D has led to a significant increase in module power output through the use of cells with higher efficiencies and better placement. New cutting techniques have additionally significantly reduced material losses per cell area. Furthermore, the consumption of silver in solar modules has been reduced in recent years, which has had a direct impact on costs. In the case of concentrating solar power (CSP), which besides solar PV also plays a relevant role in solar electricity generation, especially in Morocco, further developments in molten salt thermal energy storage have made it possible to achieve higher storage hours, which in turn has increased the capacity factors and thus reduced costs. CSP is attractive for Green Hydrogen generation as its combination with thermal storage allows for a steady electricity generation, also in the evening hours. For wind turbines, recent technological development has enabled larger rotor diameters and higher hub heights, resulting in better yields and lower costs (IRENA, 2022c).

For the use of power generation from renewable energy sources for the production of green hydrogen it is key to define the best technology configuration, i.e. to assess with which configuration of PV, CSP, wind and storage the optimal load factor for the green hydrogen generation can be achieved. In this context, detailed RES potential assessments with a high spatial resolution and in-depth simulations for potential sites are required to attain optimal cost effectiveness.

Seawater desalination

In addition to renewable electricity, the production of green hydrogen requires fresh water as an input. Especially in regions with high water stress levels and potential conflicts of use between drinking water demand, water for agricultural use and the production of industrial goods, water supply is an important issue to be considered for green hydrogen production. Since about 75% of the earth's surface is covered by oceans, seawater desalination offers a way to supply water without relying on groundwater, rivers, or lakes as natural freshwater reservoirs. In this process, the mineral components are separated from the seawater, resulting in two output streams: Salt brine and freshwater. Depending on whether the driving energy is thermal or mechanical, desalination processes are referred to as either thermal or membrane-based. Thermal processes such as thermal vapor compression (TVP), multi-stage flash (MSF) and multi-effect distillation (MED) are all based on the principle of distillation. This requires an external supply of heat, usually provided by the combustion of fossil fuels, which is why thermal processes are now most prevalent in the oil-rich countries of the Middle East. Membrane-based processes are dominated by reverse osmosis (RO). Here, salt water is forced against a semi-permeable membrane, which allows water molecules to pass through while salt remains on the input side. The advantage of this process is that, in comparison to thermal processes, less energy is required and the plants are lighter and smaller. Furthermore, since the energy is mainly used to pump the water through the membrane, the desalination process can be operated in a carbon neutral way if electricity from renewable sources is used. However, there is still room for improvement in terms of performance and costs of these technologies.

Another, less common membrane-based technology is electrodialysis (ED), which uses electrical potential differences to pass water through a membrane (Lotfy et al., 2022).

A further promising technology that could gain importance in the future is seawater electrolysis, which combines seawater desalination and electrolysis in one application. One of the biggest challenges here is to develop robust and efficient electrocatalysts that allow the splitting of seawater without being affected by chloride corrosion (Yu et al., 2019).

Carbon Capture

The last part of the upstream activities comprises the supply of CO_2 for the production of synthetic hydrocarbons based on Green Hydrogen. Three main groups of sources are available for carbon capture (CC): Exhaust gases from industrial processes, bioenergy, and direct air capture (DAC). In the short term, captured CO_2 from so-called hard-to-abate sectors, such as cement production, could be used due to its comparatively lower cost. In this case, however, CO_2 is only removed from the cycle until the synthetic fuel is burned, and in the long term it is still released into the atmosphere thus contributing to global warming. In the case of biogenic CO_2, the question arises as to what extent sufficient biomass will be available in the future and whether it would be more beneficial to use it in other areas. Hence, in the medium and long term, only DAC appears to be a truly sustainable carbon source for the production of synthetic hydrocarbons.

Direct Air Capture (DAC)

Overall, DAC is still not very widespread at the moment. Nevertheless, in recent years some companies have entered the market with the aim of commercial distribution. In all processes, as the name suggests, the CO_2 is captured directly from the air. Due to the comparatively low partial pressures of CO_2 in the air compared to, for example, the exhaust gases of a cement plant, this is associated with a high energy input and currently high costs. However, the method of energy supply and the process conditions differ depending on the technology. The most common technologies can be divided into two categories: solid-based (S-DAC) and liquid-based (L-DAC). S-DAC uses solid adsorbents to capture and release CO_2 in an adsorption/desorption cycle to separate it from the air. Adsorption takes place at ambient pressure and temperature, while desorption occurs at low pressures and moderate temperatures. The energy input is therefore used during the regeneration process to desorb the CO_2 from the adsorbent by lowering the pressure and increasing the temperature. L-DAC, on the other hand, is based on two closed chemical cycles, whereby CO_2 from the ambient air is bound in a basic solution in the first cycle and released at high temperatures in the second cycle (IEA, 2022). The main parameters of the two technologies are listed in Table 1 and the main advantages and disadvantages are shown in Figure 2.

Table 1 Main parameters of S-DAC and L-DAC technologies

Parameter	S-DAC	L-DAC
CO_2 separation	Solid adsorbent	Liquid sorbent
Specific energy consumption [GJ/t_{CO_2}]	7.2-9.5	5.5-8.8
Share of heat / electricity consumption [%]	75-80 / 20-25	80-100 / 0-20
Regeneration temperature [°C]	80-100	ca. 900
Regeneration pressure	Vacuum	Ambient
Capture capacity	Small-scale (modular design possible)	Large-scale
Net water requirement [t_{H_2O}/t_{CO_2}]	-2-0	0-50
Land requirement [km^2/Mt_{CO_2}]	1.2-1.7	0.4

Source: (own collection based on (IEA, 2022))

Currently, the high temperatures required for desorption in L-DAC processes cannot be generated entirely from renewable energy sources. Instead, natural gas is usually burned to supply the heat. In contrast, the more moderate process conditions at S-DAC allow the use of 100% renewable electricity and heat. Combined with the lower capital costs and the ability to use the technology for net water production, the S-DAC processes appear to be a more promising option for sustainable CO_2 capture from the air (Fasihi et al., 2019, IEA, 2022).

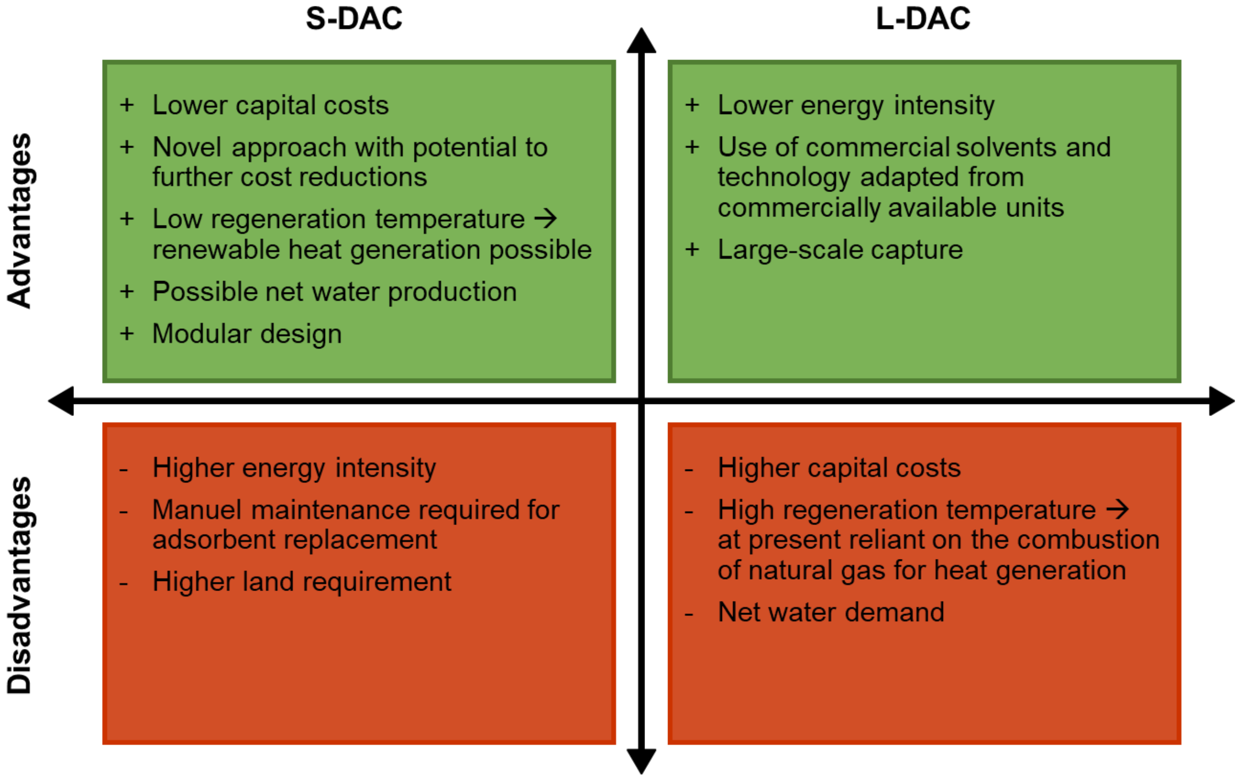


Figure 2 Main advantages and disadvantages of S-DAC and L-DAC technologies

Source: Own depiction based on (IEA, 2022)

Other emerging technologies for DAC include electro-swing adsorption (ESA-DAC) and membrane-based separation (M-DAC). However, these have a much lower level of maturity than S-DAC and L-DAC and require further research and development to assess their potential (IEA, 2022). Overall, the diffusion of DAC will depend primarily on future costs. Depending on the availability of low-cost renewable energy technologies, recent estimates suggest that the cost per ton of CO2 could decline to less than 100 USD by 2030 for the best locations (Fasihi et al., 2019, IEA, 2022).

3.2 Midstream activities

Electrolysers

The water electrolysis process uses electricity to split water into oxygen and hydrogen. The four major technologies and their main characteristics, advantages and disadvantages are summarized in Figure 3. Depending on the process temperature, a distinction is made between low-temperature and high-temperature electrolysis. The two most prevalent technologies with the highest technology readiness level (TRL) are both low-temperature technologies. While alkaline electrolysis (AEL) is characterized by its robust design and comparatively low cost, polymer exchange membrane (PEM) electrolysis is more compact and can be operated under more flexible process conditions. The solid oxide electrolysis cell (SOEC) provides the highest electrical efficiency, but as a high-temperature technology, it requires additional heat input, which reduces overall efficiency. This makes them particularly interesting when industrial waste heat is available at a high temperature level, which is the case, for instance, when producing synthetic hydrocarbons or ammonia. Compared to AEL and PEM, they currently still have a shorter lifetime and a lower TRL. The last technology with the lowest level of maturity so far is anion exchange membrane (AEM) electrolysis. AEL is said to have the potential to combine the advantages of AEL and PEM. However, this still requires substantial research and development to make them commercially available and, in particular, to increase the currently still very low lifetimes (IEA, 2021, IRENA, 2020).

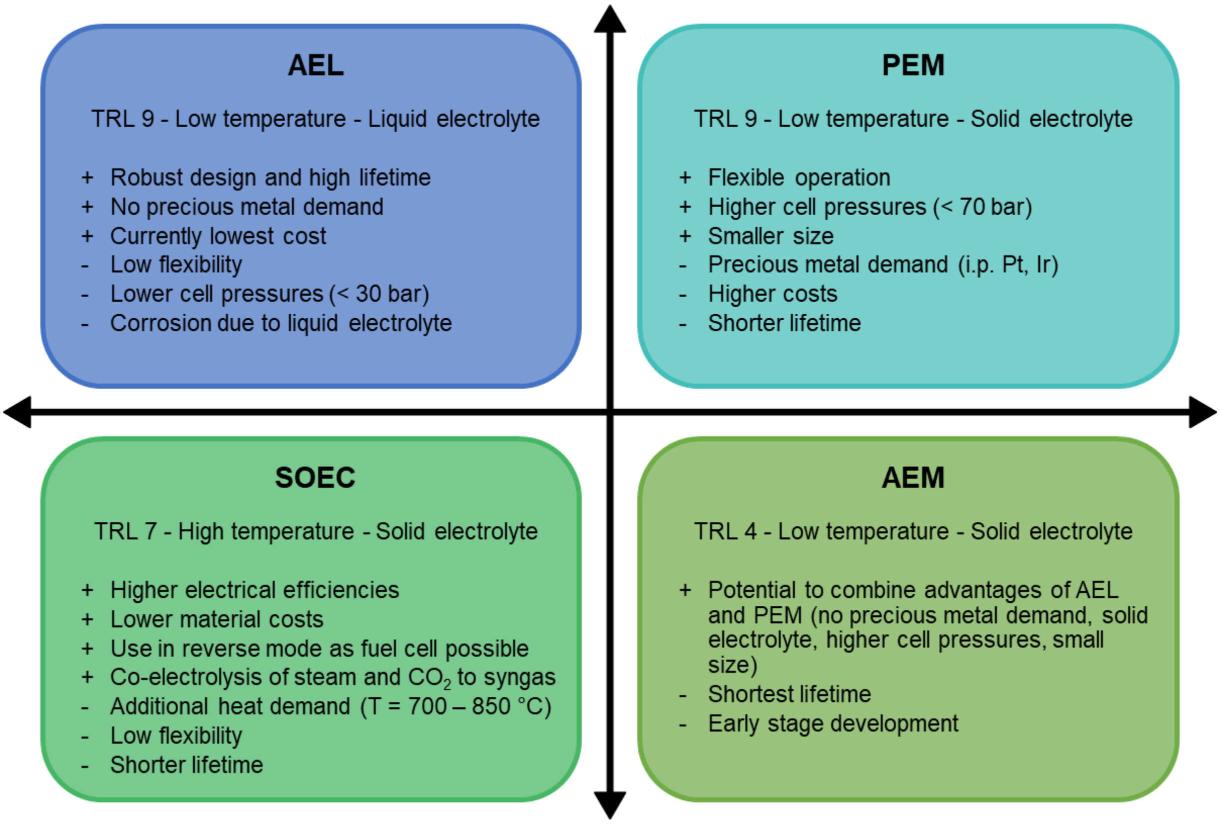


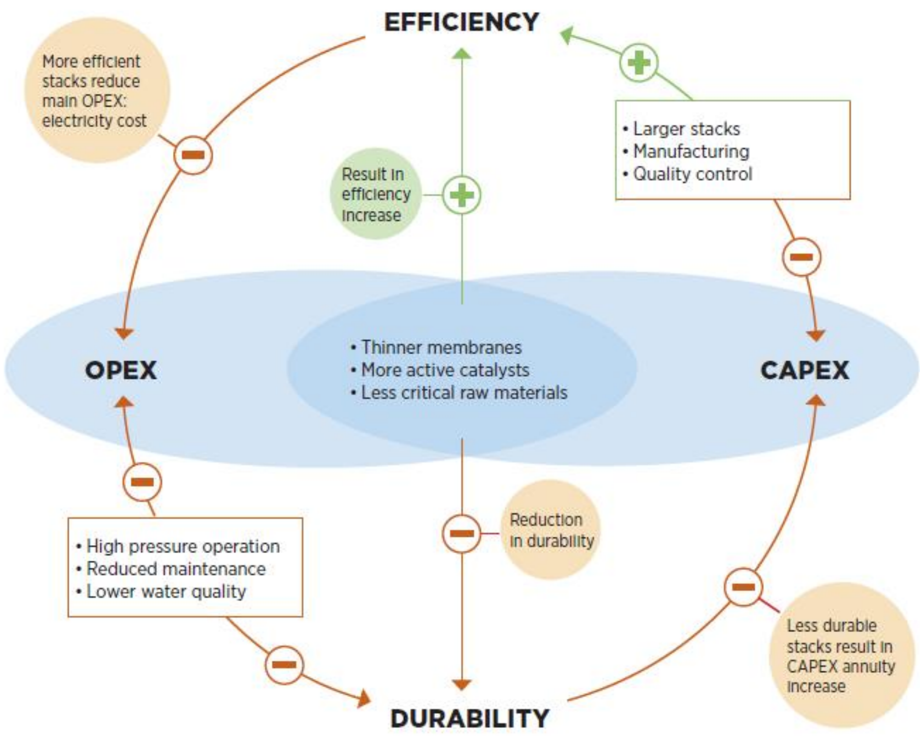
Figure 3 Main characteristics of the four major electrolysis technologies

Source: Own depiction based on (IRENA, 2020) and (IEA, 2021)

All of the described electrolysis technologies can be divided into the following levels (IRENA, 2020):

- Cell - Composed of two electrodes, solid or liquid electrolyte, two porous transport layers, bipolar plates providing mechanical support and distributing the flow.
- Stack - Composed of multiple cells connected in series (insulating) spacers, seals, frames (mechanical support) and end plates (avoiding leakage).
- System level including Balancing of Plant (BoP) - Composed of multiple stacks and equipment for cooling, processing, electronics and water supply.

There is potential for technology improvement at all levels. Each potential improvement relates to one of the three parameters efficiency, cost and durability. However, the individual aspects cannot be considered independently of each other. Figure 4 shows potential trade-offs of efficiency, durability and cost in the further development of electrolysis technologies.



Note: The arrows represent a direct impact or effect from the R&D of a given material or component over each relevant dimension. CAPEX = capital expenditure; OPEX = operational expenditure.

Figure 4 Trade-offs between efficiency, durability and costs for electrolysers

Source: (IRENA, 2020)

There are various areas in which technological improvements and cost reductions for electrolysis technologies can be expected in the future. A recently published study (EPO, IRENA, 2022) based on patent analyses has identified five areas in which R&D plays a particularly important role in relation to water electrolysis:

Cell operation conditions and structure

- → Operation at higher temperatures and pressure to increase energy efficiency and reduce costs without compromising durability and performance of membranes

Electrocatalyst materials

- → Substitution of scarce materials (such as platinum or iridium) with non-noble materials in order to reduce costs and facilitate scale-up of production

Separators (diaphragms, membranes)

- → Reducing membrane thickness to increase energy efficiency

Stackability of electrolysers (stacks)

- → Improvements in components such as electrodes bipolar plates and porous transport layers, including their manufacturing to reduce costs

Photoelectrolysis

- → Integration of electricity and hydrogen production in a single step to reduce costs

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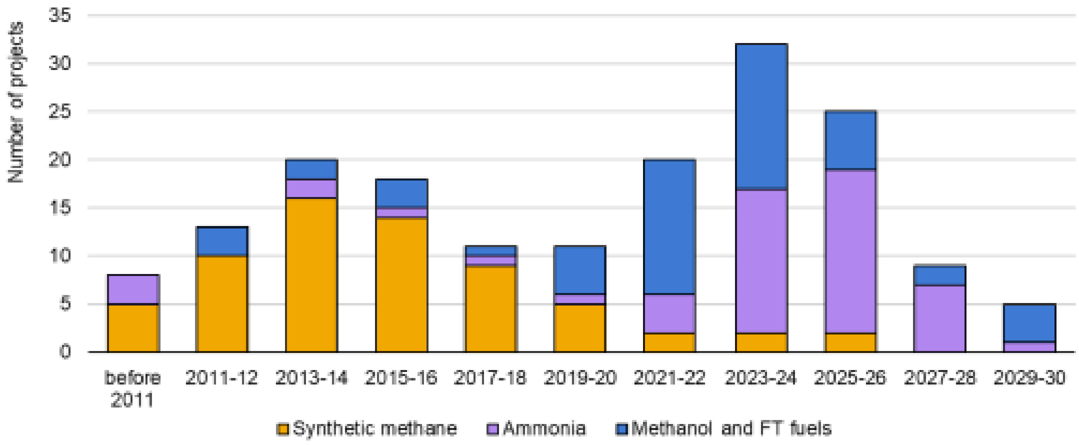
Additionally, at the system level, using the same inverter for a larger number of stacks could result in an increase in load, thereby reducing losses and increasing efficiency. In addition, increased module sizes could lead to further cost reductions through economies of scale (IRENA, 2020).

3.3 Downstream activities

With regard to technologies and activities in the downstream segment of the PtX value chain, a review by the International Energy Agency (IEA, 2021) shows that in recent years there has been a trend away from synthetic methane projects toward production of ammonia, methanol, and Fischer-Tropsch (FT) fuels (see Figure 5).



Notes: FT = Fischer-Tropsch. Figure includes eight synthetic methane and five FT fuel projects decommissioned before 2020. Ammonia includes projects in the chemical industry, where ammonia is used as a feedstock.

Figure 5 Number of green hydrogen downstream projects by end product and start year

Source: (IEA, 2021)

Green Ammonia

Ammonia is one of the most important chemicals in the world today, mainly used for the production of nitrogen fertilizers. Global production has therefore risen continuously in recent years due to the growing demand for food and the resulting increased use of fertilizers. Although ammonia is composed only of hydrogen and nitrogen atoms and thus contains no carbon itself, production is currently associated with high CO_2 emissions. This is due to the fact that hydrogen is currently produced almost exclusively from fossil fuels such as natural gas, coal and naphtha, and ammonia production alone accounts for approximately 45% of global hydrogen consumption. At the same time, this is also an opportunity, as it therefore makes ammonia easier to decarbonize compared to other chemicals. If electrolytically produced green hydrogen is used instead of fossil hydrogen, it is referred to as green ammonia.

The switch to green ammonia also enables new uses. While ammonia is currently seen primarily as a hydrogen consumer, in the future it could play an important role as a hydrogen carrier for the transport of green hydrogen as well as a carbon-free fuel, for example in maritime shipping. For example, projections by IRENA indicate that annual global demand could rise to 688 million metric tons in a scenario that limits global warming to below 1.5 °C. This is four times as much as today.

However, green ammonia is currently still more expensive than conventional ammonia. While the cost of renewable ammonia production is currently USD 720-1400 and could decline to USD 310-610 by 2050, fossil ammonia cost only between USD 110 and 340. However, with the rising gas prices due to the current energy crisis, the cost of ammonia has risen significantly since the first quarter of 2022. With only around 10% of the total global production being traded vs 90% being used as feed-stock at the production site, the cost of bulk Ammonia have risen to around 800 USD/t in the Asia Pacific region, 1180 USD/t in North America and 1550 USD/t in Europe during the quarter ending March 2022 (chemanalyst 2022).

The most important cost driver of green ammonia production is the cost of green hydrogen, which accounts for about 90%. In comparison, nitrogen purification and the actual Haber-Bosch synthesis process are almost negligible. Thus, to reduce cost differences, there are two major levers. On the one hand, the framework conditions should be created to lower the costs of green hydrogen and thus also green ammonia. On the other hand, a sufficiently high CO_2 price could ensure that the costs of conventional ammonia increase. In addition, clear policy and financial frameworks should also be put in place, for example through R&D support, quotas, tax incentives, Carbon Contracts for Difference (CfD), off-take guarantees or concessional loans (IRENA, AEA, 2022).

Green Methanol

Another important chemical that could be a potential downstream product of the green hydrogen value chain in the future is methanol. Like ammonia, methanol is currently produced almost exclusively from fossil fuels. While it is currently used mainly as a chemical feedstock for the production of other products such as formaldehyde, acetic acid or plastics, methanol, if produced based on renewable sources, is also considered a potential synthetic fuel for the future. Since methanol, unlike ammonia, is a hydrocarbon, a carbon source is needed for its production. So, in addition to hydrogen costs, CO_2 supply costs are also a factor when producing green methanol (IRENA, Methanol Institute, 2021). The development of future costs is thus strongly influenced by upstream and midstream technologies. With regard to the support of green methanol, similar aspects apply as those described above for green ammonia.

4 Green Hydrogen R&D activities in Morocco

4.1 Mapping of key stakeholders and support programs

To obtain an overview of the past and ongoing activities along PtX value chain in Morocco, the analysis starts with a mapping of the relevant stakeholders that already do or potentially could play a role in the planning, funding and implementation of R&D activities related to the PtX value chain in Morocco. This comprises various different types of stakeholders from research institutions, the industry, energy or policy sector, national and international financing institutions as well as present and potential future international cooperation partners.

4.1.1 Background: Stakeholders in technology innovation processes

An 'innovation ecosystem' in which different stakeholders or agents relevant for the development and market uptake of a new technology interact with each other, can be described using the Technical Innovation System (TIS) concept. The TIS concept was first described by Carlsson & Stankiewicz (1991) and defines a TIS as a *"dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion and utilization of technology"*. Hekkert et al (2011) define TIS further as systems composed of the four major components: actors, institutions, networks and technology. Thereby, the actors are the central stakeholders realizing and driving technical innovations, while institutions are defined as formal rules within the system (such as laws, regulations, norms and standards) and networks describe the resulting possible modes of interaction and collaboration between the actors.

This understanding of the concept of innovation systems for new technologies "… *stresses that the flow of technology and information among people, enterprises and institutions is key to an innovative process. It stresses the interaction between actors who are needed in order to turn an idea into a successful process, product or service in the marketplace.*" (Hekkert et al 2011). Thus, a careful design of support frameworks, regulations, laws and communication channels, which optimally addresses the relevant actors and their needs in a specific TIS, is key to the successful and fast development and uptake of an innovation into a market.

Figure 6 depicts the generic structure of a technical innovation system (TIS) with its framing institutions and policies (i.e. technology or innovation policies, regulations, norms and various support frameworks) and its actors in different areas that interact with each other in the process of technology innovation and its market diffusion. Here, the actors are grouped into supply and demand side and entities focused on research and education, respectively.

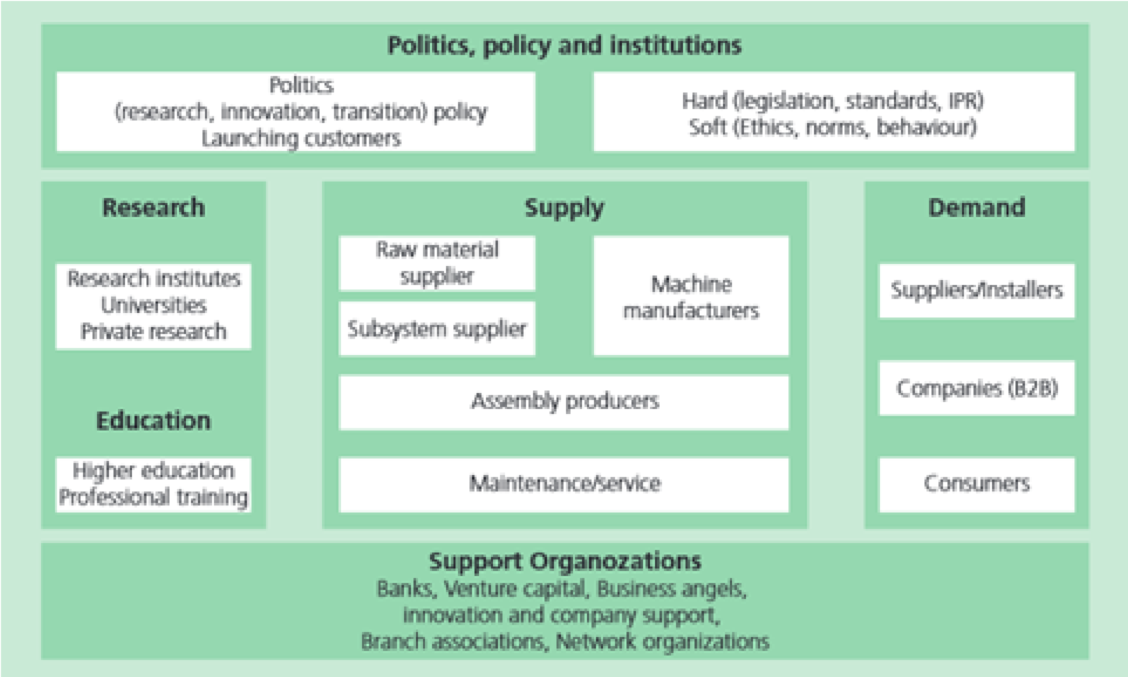


Figure 6 General structure of a technical innovation system (TIS) with institutions and actors that interact in the process of technology innovation and diffusion.

Source: Hekkert et al (2011)

4.1.2 Overview of stakeholders related to PtX R&D in Morocco

For the case of PtX in Morocco, an overview over the major stakeholder groups and actors relevant for the research, development and innovation ecosystem for PtX is provided in Figure 7 and briefly described in the subsequent section. A more detailed list of the identified institutions and stakeholders is provided in the Annex (A.2).

Policy sector and public institutions

The legal framework, regulations and strategic targets for the development of sustainable energy sources and green hydrogen and PtX in Morocco are in the field of responsibility of the Ministry of Energy Transition and Sustainable Development which, in cooperation with other key government agencies, notably MASEN (Moroccan Agency for Sustainable Energy) and IRESEN (Institut de Recherche en Energie Solaire et Energies Nouvelles), shapes the countries' energy strategy. ONEE (Office National de l'Electricité et de l'Eau Potable) as the state-owned utility for electricity and water supply in Morocco covering the major share of the electricity generation (together with MASEN), all of the transmission and partly also the distribution of electricity as well as ONHYM (Office Nationale des Hydrocarbures es des Mines) as the state-owned enterprise responsible for the exploration and development of fossil fuel and mineral resources are also relevant stakeholders for the strategic and institutional framework for the national PtX development.

Relevant for shaping the policy framework and strategies for scientific research, innovation and higher education are in particular the Ministry of Higher Education, Scientific Research and

Innovation, the Centre National pour la Recherche Scientifique et Technique (CNRST) and the Moroccan Foundation for Advanced Science, Innovation and Research (MAScIR) as well as IRESEN as the major coordinating entity for research activities related to sustainable energy sources.

In the context of policies and regulations framing industrial development and strategies for international trade, the Ministry of Industry and Trade as well as the Confédération Générale des Entreprises du Maroc (CGEM) are further relevant stakeholders. Other potential interest groups in this field comprise, for example, the Institut de Formation aux Métiers des Energies Renouvelables et de l'Efficacite Enérgétique (IFMEREE), the Institut Marocain de Normalisation (IMANOR), the Société Nationale d'Electrolyse et de Pétrochimie (SNEP) or the Fédération de l'Energie (FdE).

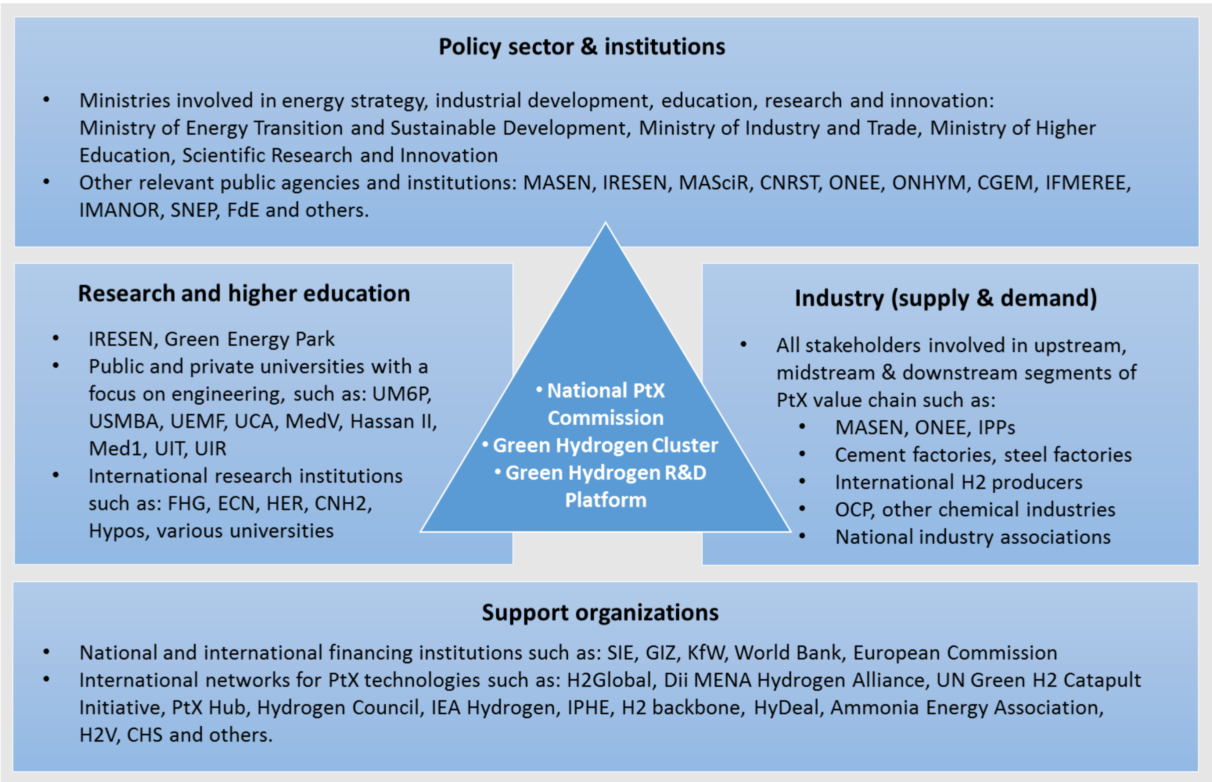


Figure 7 Overview of stakeholder groups relevant for the PtX R&D and innovation system in Morocco

Research institutions and universities

With regards to research relevant for the development of the PtX value chain, IRESEN is the main coordinating agency for research and development activities and a key actor for the distribution of national funds for R&D in line with the countries' sustainable energy targets.

Higher education institutions, namely national public and private universities with a focus on electrical and chemical engineering, are crucial stakeholders for the implementation of PtX related R&D activities as well as for the education and training of specialized workforce needed for the sustained development of the PtX value chain in the future. Some of the most relevant universities with a specific focus on relevant engineering topics (i.e. chemical and process engineering) are listed in the table below. Green Energy Park[2] as a cooperation platform between IRESEN, OCP and the Ministry of Energy, Mines and the Environment, is another relevant entity which forms an important interface between the policy, research and industry sector. In collaboration with various universities and international research institutions (such as Fraunhofer, DLR and Helmholtz), Green Energy Park focuses on various research areas related to the use of renewable energy sources.

Table 2 Universities with a focus on engineering relevant for PtX (non-exhaustive)

UM6P	Mohamed VI Polytechnic University
USMBA	Sidi Mohammed ben Abdellah University
UEMF	Euromed University of Fes
UCA	University Cadi Ayyad (Marrakech)
MedV	MedV University (Rabat)
Hassan II	Hassan II University (Casablanca)
Med 1	Med 1 Universityer (Oujda)
UIT	Ibn Tofail University (Kenitra)
UIR	International University of Rabat

Industry stakeholders and associations

Besides the above mentioned research institutions, industry stakeholders are the key actors when it comes to developing and implementing innovative, application oriented technologies. In the context of the different segments of the PtX value chain (cf. chapter 3), a wide range of national and international industries and industry associations could play a role in the development of the Moroccan PtX value chain.

Regarding upstream activities, besides the generation of electricity from RES (e.g. through MASEN, ONEE or independent power producers IPPs), especially CO_2-emission intensive industries, i.e. industries in which CO_2 is a process-based emission and cannot be avoided by direct electrification, are relevant stakeholders as in the context of ambitious decarbonization efforts, Carbon Capture and Use (CCUS) might be an interesting option for them. This applies in particular to the cement industry and steel industry. In Morocco, respective stakeholders could be, for example, Cemos Ciment, Lafarge Holcim, Ciments du Maroc / Heidelberg Zement or Ciments de l'Atlas (CIMAT) with factories in various locations along the coast and inland.

For midstream activities, i.e. all activities related to the actual generation, storage and transport of green hydrogen, a wide range of established international stakeholders can be mentioned, such as Nareva, Proton Ventures, Sunfire, Linde Engineering, Baker Hughes, and many others (cf. A.2). National parties that could play a role in this segment in the future are various stakeholders currently active in the transport and storage of gases and fossil fuels as well as companies involved in chemical, electrical and process engineering.

Regarding downstream activities of the PtX value chain, i.e. production of green ammonia or other derivatives and synthetic fuels, in particular OCP (Office Chérifien des Phosphates) as the

[2] https://www.greenenergypark.ma/

major producer of ammonia and fertilizers in the country is a highly relevant stakeholder. Other stakeholders interested in the production of synthetic fuels could also play a role in the future.

Relevant industry associations in Morocco that could further support the development of the national PtX value chain, for example, by sharing of knowledge among their members and by facilitating communication between their members and the policy sector, are among others, the Fédération des Industries Métallurgiques Mécaniques et Electromécaniques (FIMME), Fédération Nationale de l'Electricitéet de l'Electronique (FENELEC), Fédération de la Chimie et de la Parachimie (FCP) and others.

Interfaces and communication channels

The above mentioned stakeholders from the policy, research and industry sectors are further organized in three main institutional platforms for the exchange, coordination and facilitation of PtX development in Morocco:

- The National Green Hydrogen commission
- The National Green Hydrogen Cluster
- The Green Hydrogen R&D Platform

National Commission for PtX

The National Green Hydrogen Commission (CNH2) was founded in 2019 and includes stakeholders from the following entities: The Ministry of Energy, Mines and Environment (MEME), the Ministry of Economy and Finance (MEF), the Ministry of Industry, Trade and Investment and the Green and Digital Economy (MICEVN), Ministry of Education and Training, Higher Education and Scientific Research (ENSSUP), the OCP Group, the National Office for Electricity and Drinking Water (ONEE), Moroccan Agency for Sustainable Energy (MASEN) the National Office for Hydrocarbons and Mines (ONHYM), the Research Institute for Solar Energy and New Energies (IRESEN), National Higher School of Mines (ENSMR), General Confederation of Moroccan Enterprises (CGEM). It is an institutional body focusing on strategic goals, legal and regulatory framework and other formal aspects related to the development of PtX in Morocco.

Green Hydrogen Cluster

The Green Hydrogen Cluster comprises members from the major ministries involved in renewable energy and PtX as well as various associated stakeholders from the national and international industry sector (see Figure 8). The following ministries are members of the cluster: Ministry of Energy Transition and Sustainable Development (former Ministry of Energy, Mines and Environment), Ministry of Economy and Finance (former Ministry of Industry, Trade, Investment & Digital Economy), Ministry of Transport and Logistics, Ministry of Higher Education, Scientific Research and Innovation (former Ministry of National Education, Vocational Training, Higher Education & Scientific Research). The president of the Cluster is Mohammed

Yaha Zniber, the vice presidents Badr Ikken and Mehdi Tazi. The secretary general is Samir Rachidi.

The cluster is grouped into individual thematic committees on:

- Energy transport
- Renewable Energies
- Chemical Industry
- Projects
- R&D and Innovation
- International Partnerships

The Green Hydrogen Cluster is focused on supporting the exchange between various industry stakeholders and identifying potential needs for studies or support measures to accelerate the development of a competitive and innovative Moroccan PtX industry. Strategic focus areas of the cluster comprise capacity development, supporting innovation and collaboration, facilitation of networking and improving the development of a conducive regulatory framework for the development of the hydrogen industry.

Figure 8 Industry partners of the Green Hydrogen Cluster (non-exhaustive)[3]

Green Hydrogen R&D Platform

To further facilitate and accelerate the development of Moroccan capacities in the field of green hydrogen, the Moroccan government decided in 2021 to create a national Green Hydrogen Research and Development (R&D) platform. The platform aims in particular at facilitating networking and knowledge exchange between research institutions and the industry sector, providing infrastructure and support for joint R&D activities and to facilitate the buildup of specific technical capacities and local expertise required for the PtX sector. The platform further aims at serving as an interface for international collaboration in the field.

[3] Source: http://www.greenh2.ma/

Other support institutions

Besides the above mentioned types of actors that are driving the development and diffusion of technological innovations, **national and international financing institutions** are another important stakeholder group. In the case of Morocco these could comprise local banks and institutions specialized in financing sustainable energy investments, such as SIE, and international development banks such as the GIZ, KfW, or the World Bank. Also research funding provided by the European Commission (EC) plays a role for R&D activities in the field of RES and PtX.

Finally, various **international PtX initiatives** focus on different aspects related to green hydrogen and PtX, such as latest trends in technology development, best practices in regulation, questions relating to certification of green products or sustainability standards. Table 7 provides a non-exhaustive overview over some of the major initiatives.

Table 3 International initiatives focusing on green hydrogen or PtX

Dii	Dii - MENA Hydrogen Alliance
UN	UN - Green Hydrogen Catapult initiative
AEA	Ammonia Energy Association
HyDeal	HyDeal Initiative
PtX Hub	PtX Hub
H2 Backbone	European Hydrogen Backbone
Hydrogen Council	Hydrogen Council
IEA	IEA Hydrogen
CEM	Clean Energy Ministerial Hydrogen Initiative
IPHE	International Partnership for Hydrogen and Fuel Cells in the Economy
CHS	Center for Hydrogen Safety
H2Global	H2 Global
H2V	Mission Innovation Hydrogen Valley

4.2 Overview of past and ongoing PtX R&D activities

This section provides a brief description of the current and planned activities and framing R&D measures along the PtX value chain in Morocco.

PtX R&D in Morocco can rely on established partnerships, studies on PtX, pilot projects, R&D projects:

PtX R&D activities in Morocco (current and planned)

International partnerships:

- Morocco – Germany Energy Partnership Parema (2021-2022), MoU between German Federal Ministry of the Economy and Moroccan Ministry of Energy and Mines[4]
- Morocco-EU partnership (6/2021)[5]
- Morocco – Portugal agreement on green hydrogen cooperation (2/2021), aiming at forming a joint working group and developing a joint roadmap for hydrogen and ammonia
- Morocco – Germany Green Hydrogen cooperation Agreement (6/2020), goal: support green hydrogen production, R&D and investments
- IRENA – Ministry of Energy, Mines and Environment (MEME) Strategic Partnership (6/2021), supporting the energy transition with a focus on green hydrogen, goal: developing local expertise and sharing it globally[6]

Various Studies on potential and market opportunities:

- **Study on the Opportunities of Power-to-X in Morocco**, Fraunhofer (2018-2019)[7]
- **Morocco's PtX 2050 Roadmap**, frontier economics (12/2020)
- **Green H2A Research Platform** (12/2021), between IRESEN, UM6P and OCP Group, goals: support R&D and innovation, implement pilot projects, provide know-how transfer, promote development of standards and certification
- First **pilot project** under H2A at industrial site (owned by OCP Group) **Jorf Lasfar** (Casablanca) planned with 4MW/4tpd Ammonia, Jorf Lasfar includes an industrial port (sulphur, ammonia and coal imports, fertilizer exports), a steel factory, a coal power plant as CO2 source, and a phosphate chemical complex of a desalination plant with electricity surplus
- Several studies financed and launched by Masen with support from KfW development bank on the Moroccan hydrogen market and in the context of a large scale green hydrogen project

Various pilot projects (current and planned):

[4] https://www.energypartnership.ma/home/ https://www.giz.de/en/worldwide/57157.html

[5] https://ec.europa.eu/clima/news-your-voice/news/eu-and-morocco-form-green-partnership-energy-climate-and-environment-ahead-cop-26-2021-06-28_en ; https://competitivite-pacc.ma/partenaires/

[6] https://www.irena.org/newsroom/pressreleases/2021/Jun/Morocco-and-IRENA-Partner-to-Boost-Renewables-and-Green-Hydrogen-Development

[7] https://www.isi.fraunhofer.de/en/presse/2019/presseinfo-24-klimaneutrale-energie-aus-power-to-x-marokko.html

- Green Ammonia demonstration plant (by FH-IGB with OCP Group and Green Energy Park GEP), capacity ca. 4MWe/4tpd, assessing technology and export options, in chemical complex Jorf Lasfar
- MELHY, exploration of storage of green H2 in salt caverns
- PtX pathways, PtL pilot project, capacity ca. 1MWe/100kg-1tpd, assessing technology potential and scale-up potential
- Green Methanol production
- PtL platform (by 2024/2025)
- PtX Infrastructure (pilot fueling stations)
- UM6P, small pilot at Mohammed VI University
- Green H2A R&D pilots (size ca. 1MW/1tpd)
- A 100 MW green hydrogen electrolysis project under development by Masen with support from KfW development bank using green electricity from additional wind and solar plants (potential sites under investigation)

Based on the R&D and pilot projects already several proposals for "Roll-outs" to larger installations, as part of so called 'Green Hydrogen valleys', are under discussion:

Planned "**Green Hydrogen Valleys**"

- 10-20 MW scale projects
- Drivers: Co-localization of industry and innovation, push for local R&D, capacity building (international companies to use platform for capacity building for their subcontractors), agreements with universities, certification services for local companies, becoming a regional PtX R&D hub
- Locations:
  - Tangiers
  - Casablanca (industry, sector coupling)
  - Jorf Lasfar (industry, chemical complex, ammonia port)
  - Laayoune
  - Dakhla

4.3 Stakeholder consultation

The stakeholder consultation aims at getting a deeper insight into the status quo and the strengths and weaknesses of the current R&D framework for PtX technologies in Morocco. Further, the direct exchange with stakeholders aims at obtaining a better understanding of the perspectives that different stakeholders have on the development of PtX in Morocco in general, the major drivers and barriers to the market rollout as well as key potentials for future research activities. These findings are of key relevance for the development of recommendations for the setup of the PtX R&D platform, ideas for the design of related services and possible business models as well as potential future pilot projects.

The identification and selection of the stakeholders to be consulted was based on the stakeholder mapping conducted before (see section 4.1). The stakeholders were then listed and grouped and prioritized based on the client's feedback. The full list of stakeholders is provided in the Annex (A.2). The stakeholders identified as the most relevant in each group and value chain segment were then contacted via email.

The interviews were conducted via video calls with an average duration of ca. 90 minutes. The interview language was either English or French based on the preference of the respective interviewee.

To facilitate and structure the interviews, an interview guideline was developed which provided an overview of the questions grouped into four sections:

- Part A – Information about the institution the interviewee is representing to gain a solid understanding of the background and focus of the respective entity
- Part B – General outlook on the development of Green Hydrogen technologies in Morocco to understand the interviewee's views on key drivers, barriers, potentials, etc.
- Part C – Activities of the institution related to the Green Hydrogen value chain (past, present and planned)
- Part D – Perspectives and ideas regarding options for the design of the Green Hydrogen R&D platform to gain insights into needs and ideas for targeted support for Green Hydrogen R&D

The document was sent to the stakeholders prior to the interview. It was further used as a questionnaire that was sent to additional stakeholders who were not interviewed. The document is included in the Annex (A.1).

A total number of seven expert interviews was conducted comprising stakeholders from different groups, i.e. academic research institutions, industry sector and government institutions.

4.3.1 Rating of barriers for the development of a PtX value chain in Morocco

The graphs in Figure 9 to Figure 12 present the rating of barriers for the development of green hydrogen along the PtX value chain segments in Morocco that the stakeholders provided. In the graphs the relevance of each barrier is specified based on a 5 point scale ranging from 1 = *not relevant* to 5 = *very relevant*. A zero indicates that no answer was given or the barrier was not applicable for the respective respondent.

0 - No answer / not applicable
1 - Not relevant
2 - Slightly relevant
3 - Moderately relevant
4 - Relevant
5 - Very relevant

In summary, the results of the questionnaire survey indicate the following key points:

With regard to **upstream activities**, the scarcity of drinking water and potential conflicts of use with the production of green hydrogen are considered as a highly relevant factor that should thus be addressed by future R&D activities with priority. In this context, also the high cost of seawater desalination and purification should be addressed in order to allow for the implementation of sustainable and economically competitive technical solutions in the future.

Only individual stakeholders had an opinion about the relevance of the cost and availability of CO_2 sources as a barrier for methanol production, as this aspect was not in the focus of expertise of most of the respondents. However, also for this aspect the currently high costs (for both direct CO_2 air capture and purification from industrial exhaust gases) are seen as a very relevant barrier by individual stakeholders. Similarly, only individual stakeholders see the spatial distribution of RES generation sites and industrial production sites (as CO_2 sources) as a very important barrier. More in-depth assessments of the research needs related to this issue could be useful if CO_2 capture plays a relevant role in Morocco's PtX strategy.

The potential competition of electricity generation for residential and industrial demand with the production of green hydrogen was seen as a critical barrier by only one respondent.

Regarding **midstream activities** in the PtX value chain (i.e. production and transport), respondents see both the transport of gaseous products (H2, CO2, N2, NH3) as well as liquefied gases/products as relevant or even very relevant barriers to the development of a PtX industry in Morocco. A clear strategy addressing the cost and technical options for PtX product transport is thus central. Also the lack of the suitable export infrastructure for PtX products is seen as a relevant barrier that needs to be addressed. The cost of a potential transport of purified seawater through pipelines is seen as a barrier by some of the stakeholders.

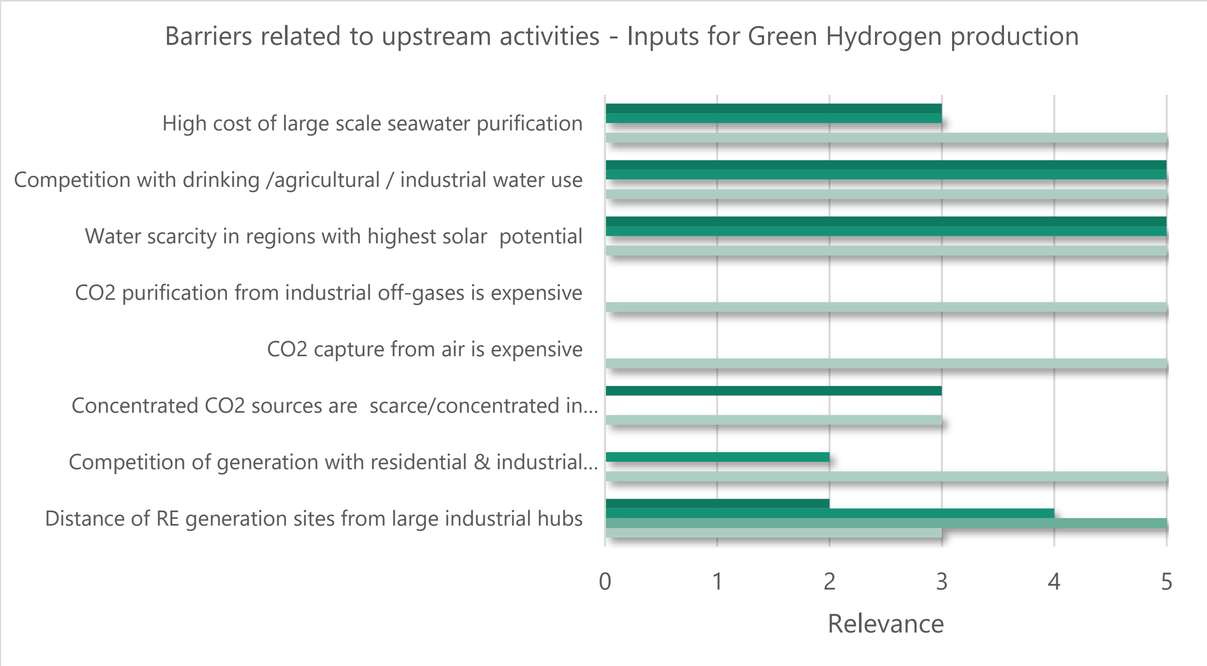


Figure 9 Rating of barriers related to upstream activities, i.e. inputs for Green Hydrogen production

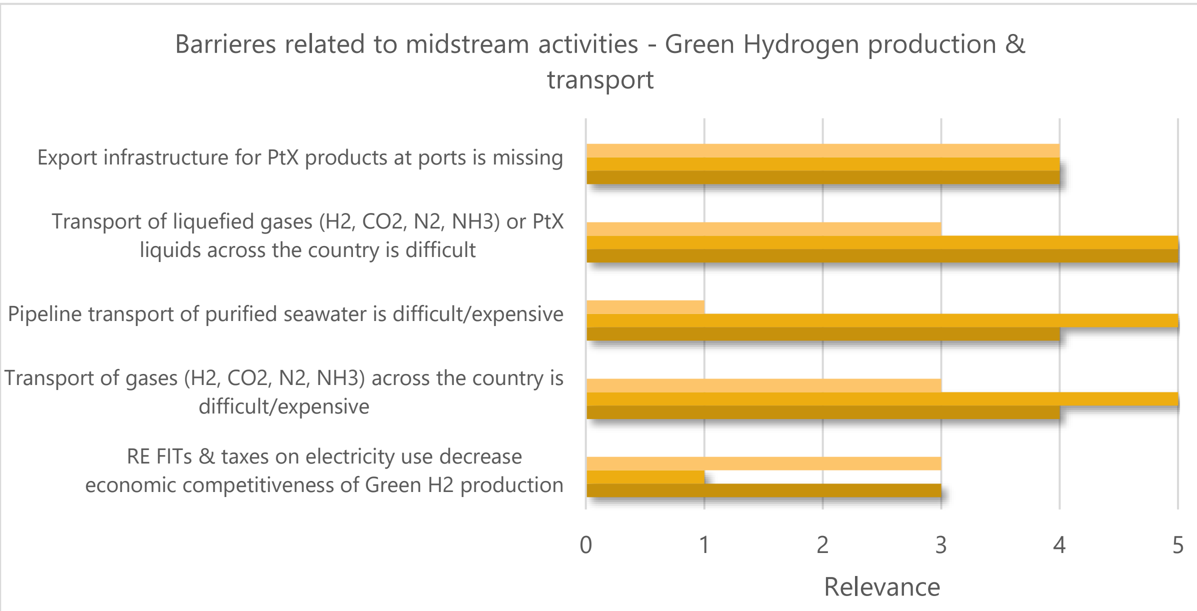


Figure 10 Rating of barriers related to midstream activities, i.e. green hydrogen production and transport

Concerning **downstream activities** (i.e. the production of green hydrogen derivatives), most respondents see the high cost of conversion infrastructure as well as the high cost of electrolytic generation as the main barriers for the PtX sector development. Also the technical integration of different technologies in one PtX synthesis platform can be a relevant barrier according to the majority of the respondents. R&D activities should thus emphasize future cost-reductions and include the identification of pilot projects demonstrating optimal integration of PtX technologies.

Barriers related to **competencies and capacities** relevant for the development of the PtX sector are mainly associated with a lack of training facilities (both lab scale and pilot scale) as well as with the lack of highly skilled workers experienced in PtX technologies. Also a lack of holistic know-how in the field of PtX was seen as a relevant barrier by the majority of respondents. The results emphasize that a focus on specific PtX related trainings, on both lab and pilot scale, should be focus areas in the national R&D strategy.

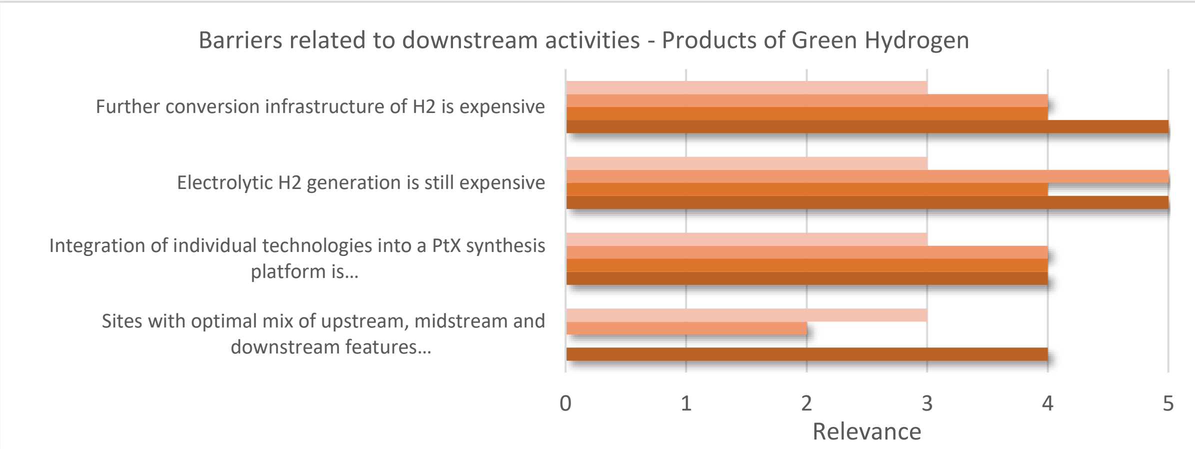


Figure 11 Rating of barriers related to downstream products of green hydrogen

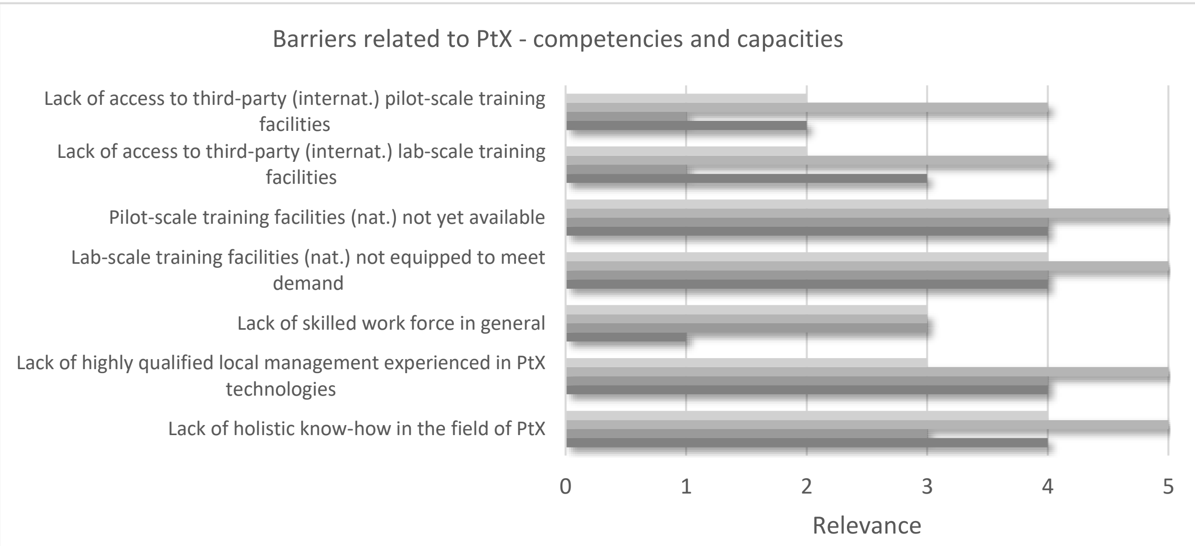


Figure 12 Rating of barriers related to PtX competencies and capacities

With regard to the **political and regulatory framework for PtX**, a lack of a clear long-term perspective and attractive financing options as well as a lack of regulations for the export of PtX products were rated as relevant barriers by part of the stakeholders. However, the political support for PtX in general is not seen as a critical barrier by most of the respondents.

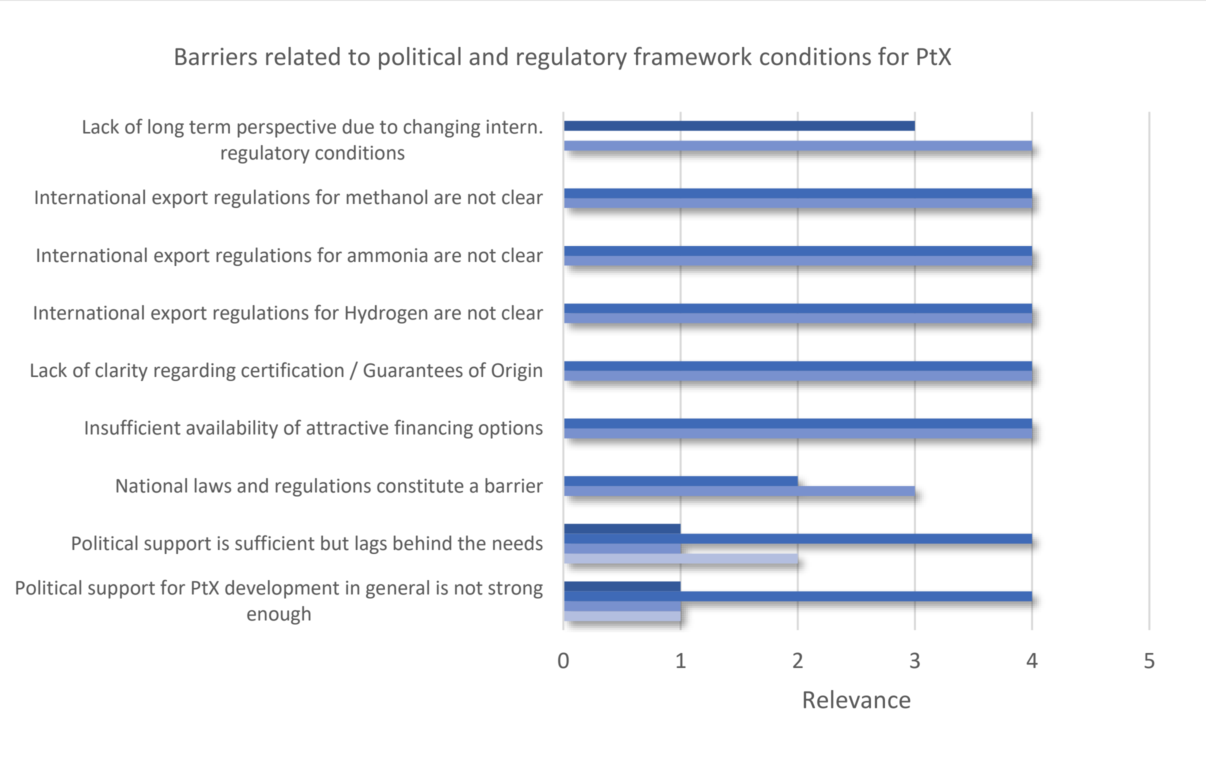


Figure 13 rating of barriers related to the political and regulatory framework conditions for PtX

Potential support measures and focus areas for future R&D activities

Finally, **Figure 14** shows the results of the rating of the relevance of services or activities that could be provided to support the development of the Moroccan PtX value chain, for example through the planned PtX R&D platform.

In line with the barriers discussed in the section above, this graph shows that in particular capacity building services (in person and online trainings) are of high relevance in order to build specialized know-how and ensure that skilled workforce for the PtX sector is available.

Even more relevant, according to the stakeholders' responses, is, however, the development of framework conditions (i.e. an 'ecosystem') that is more conducive to innovations and fosters the collaboration of various different stakeholders (e.g. trough targeted R&D programs and funding). In this regard, also matchmaking services between national and international stake-holders from the research and industry sector, but also among national stakeholders, are seen as a highly relevant service that could be provided or facilitated through the R&D platform. Testing and lab facilities for technical components and PtX systems would also be relevant services, according to the respondents.

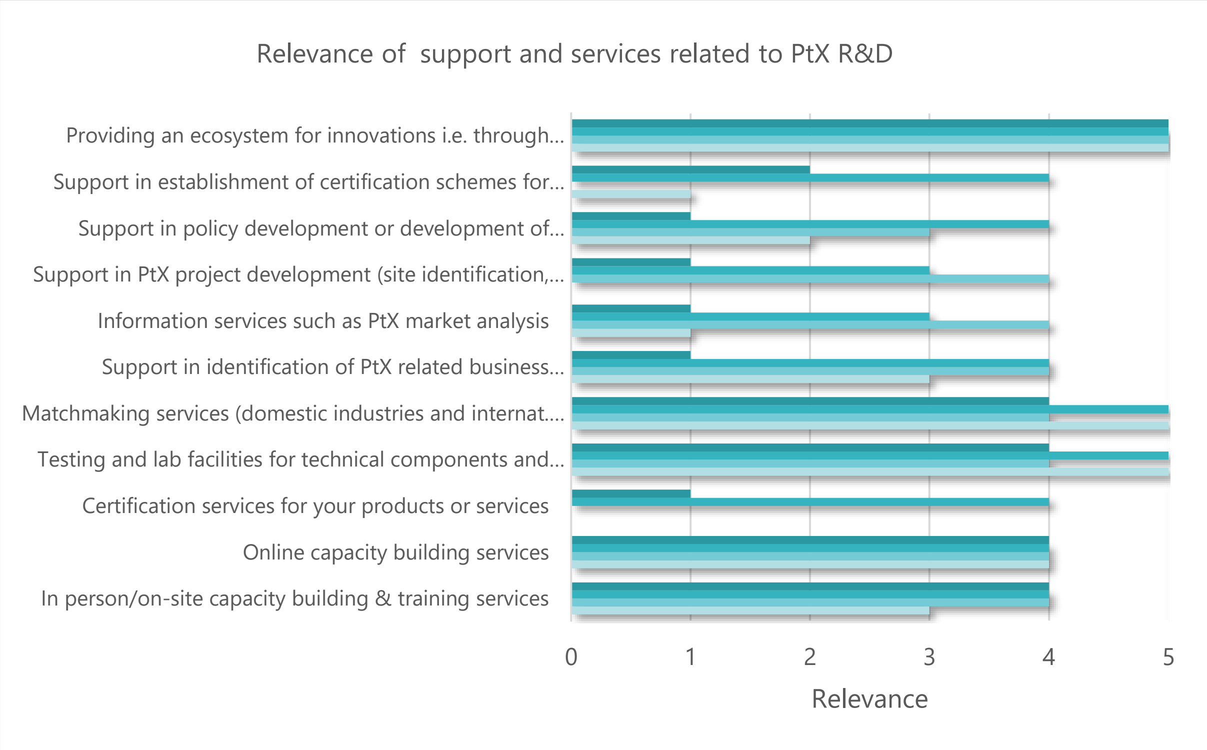


Figure 14 Rating of relevance of services and activities to support the development of the PtX value chain (potential services of the R&D platform)

4.3.2 In-depth insights from the stakeholder interviews

Universities and research institutions

The **Euro-Mediterranean (EUROMED) University of Fes**, with its strong focus on engineering and industrial innovations, well established collaborations with industrial companies in the field of process engineering and a long-standing experience in R&D projects in the field of renewable energy, is a relevant player for the development of a PtX R&D framework in Morocco.

EUROMED already implemented several research projects over the past 10 years in relevant fields such as RE generation, solar desalination and enhancing efficiency and innovative technologies for water purification, Carbon Capture and Use (CCU) from cement plants or implementation of innovative process technologies in various industrial sectors (industry 4.0 / smart factories). Latest initiatives under the Moroccan – US cooperation on industrial zones (millennium challenge), focus on supporting companies to identify and introduce innovative and smart process technologies. PtX-related technologies in industrial processes could be part of such activities in the future. Research activities on PtX at the university are also integrated in various ongoing PhD theses.

Perspectives on the H2 R&D platform

In general, the support through and the collaboration with IRESEN is perceived as very positive and helpful. However, higher funding volumes and more targeted programs for R&D activities related to PtX would be important to support the steady development of expertise in the field and to create a conducive framework for universities to build fruitful and sustainable connections with relevant industries. To this end, sufficient long-term funding perspectives for PtX relevant topics are crucial to enable the academic staff to establish and maintain collaborations with industry stakeholders, which at the same time, provide benefits for their academic research activities and serve higher education purposes (i.e. generation of publications and embedding PhD Theses in R&D activities). Developing Masters Curricula (building on bachelor studies of Chemical Engineering) that incorporate practical trainings, apprenticeships or writing of Master Theses in industrial companies (as already done in the past in cooperation with OCP) could further help in the medium to long term, to ensure that engineers with specific technical expertise for PtX technologies will be available for the future development of the national PtX value chain.

Besides supporting the establishment of cooperation between the industry and academic research sector, in particular the nationwide coordination of PtX R&D activities is seen as crucial to avoid redundancies. This is relevant, for example, regarding investments for PtX-specific lab equipment and for sharing the research results among research stakeholders. In this regard, IRESEN, the Green H2 Cluster and the H2 R&D platform could play a pivotal role to facilitate the exchange and coordination among the different actors of the PtX innovation system in Morocco. For the R&D platform a business model in which universities would get access through the IRESEN-funded projects while industry stakeholders pay for access to the services, is suggested.

A further axis of support could be provided by facilitating more international research cooperation.

Pilot project ideas

In particular the water supply for a future PtX industry in Morocco is seen as a highly relevant topic that should be reflected in potential future pilot projects. A pilot project combining green hydrogen production with sustainable water desalination or water purification technologies could be an option to address the important issue of water scarcity and PtX water demand. For example, renewable energy based and more energy efficient treatment options for brackish water, such as the application of waste heat to increase the efficiency of desalination or membrane distillation processes for water purification, could support the development of technological expertise and capacities in the field of sustainable concepts for water use for PtX in Morocco.

Secondly, R&D is recommended to focus on CCUS and the production of downstream PtX products, such as ammonia, methane and methanol, and their potential application in different sectors. Research related to green ammonia is generally associated with OCP and UMP6 and is not necessarily in the focus of EUROMED. Topics related to certification and standards are seen as relevant more in the longer term, i.e. at a later development stage of the PtX value chain.

The **Ibn Tofail University** (Kenitra) is working on questions related to the stability of the subsoil and earth quakes as well as on topics related to oil exploration activities. The work is based on methods such as: Seismic Reflection, Geophysical exploration, Seismic Sequence Stratigraphy, etc). The last project focused on the stabilization of the TGV platform (high-speed train). Based on their background, the university is interested to work more on storage of hydrogen in salt caverns. They investigate the stability of the subsoil (effect of temperature, great depth subsoil) and address the stability of cavities (affecting the durability of storage). Thereby, they can propose ways for less interventions in cavities and assure long-term stability. Findings show varying stability of salt deposits in Morocco (Agadir less stable, South of the country more stable / horizontal deposits, tectonically stable).

Markets: Main markets for their services are Morocco and, more, generally the MENA region. They did contribute to projects in collaboration with Manchester, Senegal and Tunisia. The work occurs through research agreements and common research strands.

Outlook on the development of Green Hydrogen in Morocco: Morocco had a good start with renewable energy sources and the hydrogen economy is the natural continuation of these efforts. The trend to sustainable development is also seen with the present development of electric cars.

View on the potential for local use of green hydrogen: Application of PtX in Morocco is seen as very useful, especially in the phosphate industry. In transport applications may focus on goods transport, while application for other cases is more doubtful. However, at present there is a phase of defining more precisely which will be the first markets for hydrogen in Morocco.

The major drivers for green hydrogen in Morocco are climate neutrality and industrial development. Major barriers include notably water scarcity in regions with high solar potentials, the distance of renewable energy generation from major industrial hubs, as well as more generally, the fact that the questions related to green hydrogen are not yet sufficiently in the public focus.

Cooperation with other entities may include Green H2 Cluster, IRESEN, and the collaborations with Manchester and Tunisia (on H2 storage). In any case, a good potential of the university is perceived to participate in research on green H2, in particular related to storage options.

The **International University of Rabat (UIR)** is a privately managed public university with one of its focus areas on engineering and, in this context, an emphasis on renewable energy technologies. Teaching activities at the university cover a wide range of topics relevant to the PtX value chain, as the university already offers a Master program specialized on renewable energy engineering (with 60 students per year) and has teaching and research activities relating to renewable energy generation, solar desalination as well as green hydrogen production, storage, transport and use applications. Currently there is an active project on hydrogen storage based on metal hydride. Past projects covered, for example, the development of solar devices (CSP, PV, CPV), pilot scale wind turbines and desalination based on solar heat. For the future it is planned to implement laboratory-scale test facilities covering the whole green hydrogen value chain (including PV and wind generation, desalination, electrolysis, pressure storages and metal hydride storage as well as fuel cells for heating and transport).

Beyond the above mentioned comprehensive R&D activities, the university is also planning on implementing a **Master program specifically focused on green hydrogen** from 2023 on. The program is foreseen to begin with a number of ca. 50 students per year and a study duration of 5 years with the potential for the students to continue with a PhD program afterwards.

Further, the university has recently (5/2022) launched an initiative for a **regional green hydrogen institute** through pooling with three other universities (Mohammed V, Ibn Tofail Kenitra and Université Internationale Abdulcasis UIASS) to develop joint research activities, such as research and pilot projects in the field of green hydrogen.

These initiatives already started to address some of the major barriers that were mentioned regarding the development of the PtX value chain in Morocco, namely, the lack of specialized training relevant for the PtX sector at the engineering level and the coordination of R&D activities among national research stakeholders. However, there is still a shortage of funding targeted specifically at activities promoting education and research in the PtX sector.

Further barriers that were discussed and that should be prioritized in the national R&D strategy for PtX are the need for the development of more research platforms on laboratory scale as well as industrial pilot scale to evaluate and compare different competing technical solutions as well as the establishment of closer connections with the industry sector. Here, the national PtX R&D platform will play an important role and the activities of the platform should be closely coordinated and designed complimentary to the ongoing initiatives of the regional green hydrogen institute in order to maximize synergies. The development of stronger networks to national and international industry stakeholders in PtX-related sectors could be addressed both through the PtX R&D platform and through the Green Hydrogen Cluster. In this context, more regular activities in the Cluster (i.e. 3-4 meetings a year) would be helpful to establish a lively exchange and to foster a better mutual understanding of opportunities and needs among all stakeholders.

Another, more specific barrier mentioned with regard to the implementation of PtX pilot projects is the limited availability of local suppliers for technical components, i.e. electronic equipment, for small-scale pilot plants (<10MW). Here, the PtX R&D platform could help to facilitate an exchange on supplier options (nationally and internationally).

CNRST is the major funding agency for scientific research and supporting technology transfer and innovation in line with the government strategies. The funding channeled through CNRST is, however, not specifically focused on renewable energy or PtX topics and CNRST is not involved in research and development activities or pilot projects directly.

In the context of R&D for PtX rollout in Morocco, some **key issues to be addressed** comprise: The innovation ecosystem including in general should be supported and the absorptive capacity of the market for innovative technologies needs to be strengthened more, in order to facilitate not only the development but also the sustained market diffusion of innovations. This implies that gaps of skills for innovation and commercialization of new technologies need to be addressed in a targeted manner.

So far, R&D activities driven by private sector stakeholders are still rather weakly developed. This is partly due to a lack of incentives for private sector R&D activities. A clearer policy framework and measures (e.g. fiscal measures or investment support) driving the development and market uptake of innovations would help to stimulate innovation activities and create an entrepreneurial environment in general. In the context of PtX R&D in particular, more detailed market studies would help to identify and address private sector stakeholders that could be interested in the production and/or use of PtX products. To this end a targeted dialogue with the respective industry stakeholders (such as energy- and emission-intensive industries, ports, etc.) will be needed to assess their interests and needs as well as to raise awareness about the opportunities of the PtX value chain. The gathered information, together with the government strategies for PtX, should form the basis for a clear and transparent roadmap for private sector involvement in the PtX value chain development which would provide a higher level of certainty for all concerned stakeholders. Here IRESEN plays a key role to coordinate activities and bridge the gap between public and private stakeholders.

In the higher education and research sector, i.e. public and private universities, play a relevant role in the national R&D activities, however, they partly lack the resources, flexibility and critical mass to appropriately address emerging R&D demands and requirements in cooperation with the private sector. As they also play a crucial role in the development of skilled workforce for the emerging PtX industry, the development of curricula should be aligned with the sector targets based on a close cooperation between IRESEN, the Ministry of Higher Education and Research and the Ministry of Industry.

Also international cooperation should be developed and further strengthened strategically, to further catalyze the innovation process and identify the most relevant technologies and developments relevant for the country context.

Industry stakeholders

ONEE as the only utility for electricity and water supply in Morocco that covers the major share of the generation (together with MASEN), all of the transmission and partly also the distribution of electricity, is aiming at the diversification of the energy supply and increasing the national energy security in line with the countries' targets for the implementation of a sustainable energy supply (based on Law 13-09 as of 2010).

ONEE is a member of the Green Hydrogen Cluster and National Hydrogen Commission and therefore actively participates in the development of the national hydrogen strategy. The utility sees itself as an active stakeholder, not only for the development of a strategic vision but also for the implementation of R&D activities and PtX (pilot) projects in Morocco.

In particular against the background of globally rising prices for fossil fuels and shortages in the natural gas supply due to political conflicts (i.e. recent diplomatic issues with Algeria) and the resulting need to diversify sources for gas supply, the development of Green Hydrogen for replacement of fossil gases gains importance in the country. Further, the stabilization of the energy system with rising shares of fluctuating renewable energy generation and the exploration of energy storage options (such as batteries and Green Hydrogen) are focus areas of the utilities' strategy. ONEE employs 9000 people of which 3000 are engineers working in electricity and water supply and provides training services through their training center in Casablanca.

Pilot project ideas

ONEE is mainly interested in pilot projects related to the generation, storage and use of Green Hydrogen to increase power system flexibility. Green Ammonia or other PtX downstream products are not in the focus of interest of ONEE and should be covered in separate pilot projects.

In the near term, a pilot project would be useful in a location in the south of Morocco where both, wind and solar potentials, are excellent and also gas turbines are located, so that a pilot project could target Green Hydrogen generation as well as testing of a fuel switch in the existing gas turbines.

A second idea for a pilot project, potentially more in the medium term, could be focused on the training needs of ONEE's engineers working with gas turbines. In proximity to the ONEE training centre in Casablanca and major gas turbines located in Mohammedia, a pilot activity could focus on building-up knowledge and expertise for the use of Green Hydrogen in gas turbines.

MASEN as the major stakeholder for the development of renewable energy projects in Morocco is also a key stakeholder in the PtX landscape. MASENs R&D department is active in all segments of the PtX value chain from RE generation, electrolysis, storage to the production of downstream products and use applications. MASEN also hosts PhD students working on renewable energy related topics. Further, the R&D platform in Ouarzazate covers a wide range of training and testing activities focused on CSP and PV. In the future, also activities related to green hydrogen will be integrated in the platform. Here, coordination with the planned activities associated with the PtX R&D platform will be important to be able to avoid redundancies and maximize synergies between the platforms.

Regarding R&D networks, various cooperations exist in particular with researchers and institutions from Europe (through European-funded research projects, e.g. Horizon). However, ties to the national industry and academic research sector are still rather loose. More targeted, national funding programs particularly fostering applied research and industrial integration would be helpful in this regard. Relevant industry stakeholders should, besides large-scale players like OCP or steel manufacturers, also include auxiliary industries, to maximize local value chain integration. Facilitating national and international collaboration could further help to enhance the availability of research equipment which is still largely missing due to a lack of funding. Here joint research activities with international institutions could facilitate the acquisition and sharing of equipment.

The Green Hydrogen Cluster could play a more central role to facilitate exchange and collaboration on national and international level by organizing joint meetings and conferences where stakeholders have the chance to discuss and establish connections.

Another general issue is that the vision for the development of individual technologies and products (for local use and export) is still not sufficiently clear. A clearer and more detailed roadmap would also be relevant to be able to get a better understanding of the required infrastructure for both local applications and export of PtX products. Regarding exports of green hydrogen, also Sub-Saharan countries should be considered in strategic considerations.

One major barrier that should be addressed with priority by any future R&D activities and should be included in pilot projects is, however, water scarcity and the need to develop economical desalination and waste water treatment technologies and to properly integrate them spatially with green hydrogen production.

Also missing competencies, in particular regarding specialized engineers, but also researchers and managers, constitute a significant bottleneck for the development of the PtX sector in Morocco. To address this, a specific green hydrogen Master program would be helpful.

Pilot projects should cover a broad range of potential technologies (AEL, PEM, SOEC) in order to be able to evaluate and compare technological options, reduce costs and to be flexible in the future. Also different scales/sizes should be covered, to evaluate, for example, the applicability of small-scale plants for off-grid rural zones. R&D efforts and pilot projects should first focus on green hydrogen in the near term and then at green ammonia. Methanol might be interesting in the long term. Water treatment and desalination, however, should always be included in the pilot projects.

ONHYM as a public institution overseeing the mining, oil and gas sectors in Morocco is a central stakeholder in the countries' energy system and responsible for strategic considerations regarding the transport of energy carriers within the country and across borders. Even though ONHYM is not directly involved in the production of green hydrogen or any of its downstream products, the development of gas pipeline projects implies relevant linkages to the PtX value chain. Currently ONHYM investigates options for developing new pipelines (Morocco - Nigeria and Morocco – Europe) which allow for blending of hydrogen with natural gas (up to 10%) as well as pipelines for pure hydrogen.

Activities of the PtX R&D platform that could be relevant to ONHYM include research on gas pipeline materials and components as well as on storage options for hydrogen (e.g. in salt caverns). Also training facilities for engineers working specifically with hydrogen could be relevant for ONHYM as their own training facilities currently do not cover this aspect.

5 Analysis of the Moroccan PtX R&D framework

The results of the previous mapping and stakeholder consultation are analyzed with regard to potential gaps and obstacles in the R&D landscape for PtX in Morocco. In a first step, a SWOT analysis is carried out to highlight critical gaps or obstacles that need to be addressed by policy measures. In a second step, this analysis is used for a prioritization of activities and identification of research areas in the Moroccan context that are particularly relevant to address the most critical segments of the PtX value chain and to promote the most relevant framing R&D measures.

5.1 SWOT Analysis

The following analysis of strengths, opportunities, weaknesses and threats summarizes the analysis of the Moroccan PtX R&D framework.

Strengths	Weaknesses
• Clear vision for promoting RE in Morocco • Excellent, low-cost RE potentials • Ambitious long-term targets for the rollout of green H2 and NH3 production • IRESEN well established and accepted in PtX community as coordinating agent • Strong interest in green NH3 development with OCP as key stakeholder • Several H2 pilot projects already implemented and in preparation • Strong interest in pilot projects in various universities • Existing knowledge on various key topics in local universities • Relevant initiatives focusing on green hydrogen in higher education (Green Hydrogen Master Program) and research (Green Hydrogen regional research institute) • Various possible pilot projects with different technology foci (such as H2 production, ammonia production, combination with water purification, etc.)	• R&D and innovation framework for PtX in Morocco still weak • Weak links between public and private research sector and local industry • Lack of incentives for public-private R&D cooperation • Lack of financing for PtX-specific research activities • Small number of stakeholders involved in PtX R&D so far • Low level of awareness about PtX in industry sector • Clear vision/ roadmap for role of private sector in PtX rollout still missing • Insufficient coordination among different PtX R&D stakeholders • Insufficient vision for development of infrastructure for local use and export of PtX products • Skilled workforce for PtX sector (specialized engineers and managers) is scarce • Water demand for electrolysis is critical in the context of water scarcity

Opportunities	Threats
• High potential for production of H2 and PtX downstream products • Rising demand for H2 globally • High demand for fertilizers globally • Potentially high global demand for green NH3 in the future • Existing transport infrastructure for fossil fuels • Proximity to European markets • Established energy partnerships • Established international research partnerships	• Strong competition in PtX R&D and trade of PtX products globally • Uncertainty about global PtX market development • Uncertainty about cost development of various PtX technology options • High cost of PtX technologies might hinder market diffusion • Redundancies and lack of coordination between national R&D initiatives might cause inefficiencies in R&D spending • Lack of skilled workforce might become bottleneck for PtX development • Water scarcity and use conflicts could become an issue for H2 production if not addressed appropriately • Certification of PtX products may be critical for market success in the future

5.2 Prioritization of research areas and framing measures

Based on the analysis of the relevance of barriers for the development of the PtX value chain (section 4.3.1) and the in-depth discussions with representatives from different stakeholder groups (i.e. research, industry, government) in Morocco, the following focus topics for future R&D activities can be identified:

→ Cost reductions and optimal technology integration

Lab-scale and pilot-scale testing infrastructure should be developed quickly, to gain more experience with various technology options along the PtX value chain and to evaluate their applicability in the Moroccan context. Emphasis should thereby be on cost reductions, as the high cost of electrolytic generation as well as of conversion infrastructure for downstream products are still perceived as strong barriers for the PtX sector development. R&D activities should thus emphasize future cost-reductions and include the identification of pilot projects demonstrating cost-optimal integration of different PtX technologies, also including CCU.

→ Water supply and water treatment

The **scarcity of drinking water and potential conflicts of use with the production of green hydrogen** should be addressed by any future R&D activities with a high priority. Activities should include the techno-economic evaluation of the applicability of different technologies for seawater desalination and waste water purification and aim at cost reductions as well as optimized spatial planning and infrastructure development for water supply (i.e. optimal localization of water treatment plants and hydrogen production sites).

→ Energy system planning and spatial optimization

Generally, a **clear idea of the development of the national electricity demand and the demand of renewable electricity for future green hydrogen production** in the context of Morocco’s climate targets is crucial. Green hydrogen production should neither endanger the national sustainable energy transition, nor should the electricity demand for electrolysis compete with electricity generation for residential, industrial or mobility purposes. In this context, **in-depth studies analyzing pathways for the development of the overall energy system, also considering spatial planning** (i.e. the location of industrial hubs, renewable energy sources, CO_2 sources and PtX generation sites) will be highly relevant.

→ Infrastructure development

The above need for spatial optimization also highlights the relevance of a **clear strategy for infrastructure development addressing the cost and technical options for the transport of different PtX products as well as the logistics related to upstream inputs** (i.e. renewable electricity, water, CO_2). Currently, both the transport of gaseous products (H_2, CO_2, N_2, NH_3) as well as liquefied products constitute relevant barriers and stakeholders are largely missing a clear vision for the development of both domestic and export infrastructures for PtX products. Studies should thus be focused on developing a holistic understanding of infrastructure needs under different technology development pathways as a basis for strategic political decisions and the development of a transparent infrastructure roadmap.

→ Certification schemes

Certification of green hydrogen and the **implementation of transparent guarantee of origin schemes for green Ammonia or other hydrogen derivatives or products** will become crucial in the mid- and longer term, when large-scale exports of these products are to be realized. Therefore, this issue should be addressed timely through participation in global initiatives for the development of standards and certification systems and through participation in joint programs with partners from MENA and Europe.

In addition to the above mentioned focus areas for R&D activities, a number of framing measures will be crucial to facilitate the development of the national PtX R&D landscape and PtX value chain:

→ Capacity building and training

The **development of local capacities and specialized know-how, especially regarding engineering and management expertise** for the green hydrogen sector will be crucial to allow for a sustained development of the PtX sector in Morocco. This implies a stronger focus on green hydrogen in the national higher education system (e.g. as through the planned Green Hydrogen Master Program at UIR) as well as the participation in international training and exchange programs, for example through European development projects and through cooperation with research institutions like Fraunhofer and their pilot projects. The strategic, long-term capacity development should receive a high priority in the national PtX strategy in order to build a solid foundation of specialized know-how and to ensure that skilled workforce for the PtX sector will not become a bottleneck in the future.

→ Matchmaking and strengthening of R&D networks

Another crucial framing measure to facilitate the development of the PtX R&D ecosystem in Morocco is the **strengthening of networks between national and international research institutions as well as between research and industry stakeholders**. A close cooperation and mutual understanding of needs and interests among national industry and research stakeholders will be a pivotal precondition for technological innovation and technology adoption. Missing links between industry and research should be addressed by **establishing platforms for stakeholder exchange** (e.g. through conferences and seminars and activities organized through the Green Hydrogen Cluster) as well as through **creating incentives through funding schemes specifically targeted at applied, cooperative R&D activities**.

→ Coordination of PtX R&D activities

As the PtX research, development and innovation system in Morocco is continuing to grow, the **coordination of activities and efforts undertaken by the various stakeholders** becomes increasingly crucial to be able to use synergies and avoid redundancies in research activities and R&D spending. In this context the conception of roles and responsibilities of the different stakeholders and institutions, in particular IRESEN and MASEN, as well as the functions and aims of the institutional interfaces, i.e. the National PtX Commission, the Green Hydrogen Cluster and the H2 R&D Platform, should be defined and communicated clearly.

5.3 Assessment of funding needs

This section provides a general approach for planning and an estimate of funding requirements for potential activities in the context of the implementation of the PtX R&D platform as a basis for more specific discussions with IRESEN. For more in-depth assessments, the actual setups and sizes of activities and potential pilot projects need to be discussed and specified in detail in coordination with the concerned stakeholders and decision makers.

Generally, the funding needs for the implementation and operation of a PtX R&D platform can be broken down to:

- Initial investments for the construction of a hardware platform providing the necessary infrastructures including buildings, laboratories for a range of electrolyser and synthesis technologies
- Establishment (hiring, training etc.) of a technical team i.e. as permanent technical staff under IRESEN consisting of technicians and engineers
- An annual operational budget for the operation and maintenance of the R&D facilities
- R&D project specific budgets for the implementation and execution of specific research activities in collaboration with universities and international research organizations

To identify the necessary investments for the test facilities, further discussions and analyses with IRESEN and the relevant stakeholders are required in order to identify the scale of the plants and the scope of the supply chain to be implemented i.e. with regard to:

- power rating of the different electrolysis technologies
- hydrogen quality and pressure to be supplied
- demand for hydrogen storage
- synthesis plants component specifications
    - Ammonia: Haber Bosch Reactor and air separation unit, balance of plant (compressors etc.)
    - Methanol: Synthesis reactor, distillation unit, balance of plant (compressors, separators etc.)
- major interfaces and facility infrastructure
    - Water supply and treatment
    - Grid connection
    - Waste water treatment

Such investments will also depend on the existing infrastructure, i.e. in the context of an industrial site at the chosen facility site.

Typical investments for small scale PtX R&D facilities in Germany are ranging from 2- to 5 M€ for a single technology pathway. In addition, these installations will cause O&M cost in the range of 5% of the initial EPC cost per annum. Further operating cost such as the supply of electricity, water and heat will depend on the actual operation hours of the system

The technical team for one such PtX R&D path will typically consist of 5-7 technicians and engineers and further 3-5 researchers executing the actual R&D activities.

Several of such R&D research facilities exist at different scales operated by industry, universities and research organizations (i.e. in Germany by Fraunhofer, Max Planck, etc.). As part of improving the international networking, it would be very useful for IRESEN to engage with these existing lab facilities and to take on board their experience for the design of the Moroccan facilities planned.

Recommendations on investments and infrastructure

For the establishment of the platform, significant investments into R&D and test infrastructure as well as pilot and demonstration installations are necessary which are expected to serve multiple objectives, i.e. R&D as well as educational and training purposes at the same time. In order to ensure the effective use of the available resources and avoid stranded investments during the initial phase, such investments should be selected carefully through a well informed decision making process. Therefore, it is recommended to involve international experts (i.e. from the already established network) as well as industrial stakeholders to develop and approve such an investment strategy. Most likely, a phased approach will be the most suitable, where investments are placed in accordance with a prioritization agreed among the stakeholders and platform management. Not spending the entire budget right from the start will allow to make use of a learning curve and adjust the plan based on the experience from the initial phase (to allow for adequate risk management)

Due to the combined use of the infrastructure and pilots, access to the technical details and performance data should be defined upfront and negotiated with the suppliers in order to maximize the benefit for the platform and its stakeholders and objectives.

The management of the IP generated and its commercialization are critical for the economic success of the platform in the medium to long term and should be given particular attention. Therefor a separate committee is recommended above; these aspects should also be reflected in the KPIs (i.e. patents, licenses etc.)

Potential sources of funding

To fund the activities of the Green Hydrogen R&D platform, besides national funds, a range of international funding programs and initiatives could be relevant. For joint R&D work Fraunhofer may support the Moroccan partners to find suitable funding opportunities for PtX research and development activities. Focus should thereby be on the funding of pilot projects, as these constitute essential milestones in the development of the Moroccan PtX R&D framework.

In principle the following options for funding can be considered:

1. Funding of PtX pilot

The PtX pilot is the key R&D activity to advance PtX development in Morocco. Presently funding of the PtX pilot is considered by KfW.

2. Funding opportunities by BMBF

Here, especially the continuation of the program PMARS (Programme Marocco-Allemand de Recherche Scientifique) has to be observed.

Link: https://www.bmbf.de/bmbf/shareddocs/bekanntmachungen/de/2020/09/3139_bekanntmachung.html

3. BMWK/BMBF International hydrogen projects (GIZ and KfW involved)

Within this program, the continuation of previous projects has to be observed.

Link: https://www.ptj.de/projektfoerderung/internationale-wasserstoffprojekte-bmwk-modul-1

4. Calls by EU (Clean Hydrogen Partnership and EU Horizon)

Again the continuation of existing programs needs attention

Link: https://www.clean-hydrogen.europa.eu/index_en

5. IKI program (Internationale Klimaschutz Initiative / International Climate Initiative)

IRESEN, UM6P and Fraunhofer IMWS/IGB submitted a proposal in the previous IKI program in 2020/21. Presently the calls are closed, but continuation is expected.

Link: https://www.international-climate-initiative.com/foerderung-finden/

6. Tools for search of funding programs

Further funding options can be found using search tools such as this funding database:

https://www.foerderdatenbank.de/SiteGlobals/FDB/Forms/Suche/Startseitensuche_Formular.html?resourceId=86eabea6-8d08-40e7-a272-b337e51c6613&input_=285abce9-4339-43b9-9e4d-b1cac15665f4&pageLocale=de&filterCategories=FundingProgram&templateQueryString=marokko&submit=Suchen

In this context, especially programs with focus on Africa need to be considered:

https://www.foerderdatenbank.de/SiteGlobals/FDB/Forms/Suche/Expertensuche_Formular.html?resourceId=c4b4dbf3-4c29-4e70-9465-1f1783a8f117&input_=bd101467-e52a-4850-931d-5e2a691629e5&pageLocale=de&filterCategories=FundingProgram&filterCategories.GROUP=1&templateQueryString=afrika&submit=Suchen

6 Summary and first conclusions

Between 2018 and 2022, Morocco has developed an ambitious strategy for the rollout of Green Hydrogen and PtX until 2050. The National Commission of Hydrogen was created to develop a national strategy on green hydrogen production and for the establishment of a more detailed roadmap for the development until 2050. The following key milestones mark the development of the Moroccan green hydrogen strategy:

- The Creation of a National commission for Power to X by the Moroccan Energy Ministry on Feb.11, 2019
- Creation of a Green Hydrogen Cluster
- Morocco – EU partnership with Germany in June 2020 to develop a regional market for PtX
- Publication of "Roadmap for Green Hydrogen" in Aug. 2021
- Decision in 2021 to create a national Green Hydrogen Research and Development (R&D) platform. The platform aims at providing infrastructure and support for relevant stakeholders in the PtX value chain, facilitate networking and knowledge exchange in the research and industry sector and facilitate the development of specific technical capacities and local expertise in the PtX sector. The platform should further serve as an interface for international collaboration in the field, to further drive innovation.

This report aims at providing an overview of the past and ongoing activities related to Green Hydrogen and Power-to-X (PtX) in Morocco and a mapping of the involved stakeholders and their roles in the PtX R&D landscape in Morocco to support the design of the PtX R&D Platform. In addition, a consultation of selected stakeholders provided further insights into their perspectives and the focus of their interests regarding future PtX-related R&D activities in Morocco as well as the major barriers and drivers they perceive in the national framework for PtX R&D. These results can then serve as a basis for the development of a strategic PtX R&D roadmap that supports the implementation of Morocco's targets for the development of a sustainable and competitive national PtX economy which will be covered by a subsequent report.

The following table of strengths, opportunities, weaknesses and threats summarizes the analysis of the Moroccan PtX R&D framework.

Strengths	Weaknesses
• Clear vision for promoting RE in Morocco • Excellent, low-cost RE potentials • Ambitious long-term targets for the rollout of green H2 and NH3 production • IRESEN well established and accepted in PtX community as coordinating agent • Strong interest in green NH3 development with OCP as key stakeholder • Several H2 pilot projects already implemented and in preparation • Strong interest in pilot projects in various universities • Existing knowledge on various key topics in local universities • Relevant initiatives focusing on green hydrogen in higher education (Green Hydrogen Master Program) and research (Green Hydrogen regional research institute) • Various possible pilot projects with different technology foci (such as H2 production, ammonia production, combination with water purification, etc.)	• R&D and innovation framework for PtX in Morocco still weak • Weak links between public and private research sector and local industry • Lack of incentives for public-private R&D cooperation • Lack of financing for PtX-specific research activities • Small number of stakeholders involved in PtX R&D so far • Low level of awareness about PtX in industry sector • Clear vision/ roadmap for role of private sector in PtX rollout still missing • Insufficient coordination among different PtX R&D stakeholders • Insufficient vision for development of infrastructure for local use and export of PtX products • Skilled workforce for PtX sector (specialized engineers and managers) is scarce • Water demand for electrolysis is critical in the context of water scarcity

Opportunities	Threats
• High potential for production of H2 and PtX downstream products • Rising demand for H2 globally • High demand for fertilizers globally • Potentially high global demand for green NH3 in the future • Existing transport infrastructure for fossil fuels • Proximity to European markets • Established energy partnerships • Established international research partnerships	• Strong competition in PtX R&D and trade of PtX products globally • Uncertainty about global PtX market development • Uncertainty about cost development of various PtX technology options • High cost of PtX technologies might hinder market diffusion • Redundancies and lack of coordination between national R&D initiatives might cause inefficiencies in R&D spending • Lack of skilled workforce might become bottleneck for PtX development • Water scarcity and use conflicts could become an issue for H2 production if not addressed appropriately • Certification of PtX products may be critical for market success in the future

The study identified potential barriers for the development of green hydrogen along the PtX value chain segments in Morocco and assessed the relevance of these barriers based on ratings provided by different stakeholders. In summary, the results of the questionnaire survey indicate the following key points on barriers:

- With regard to **upstream activities** (i.e. inputs for green hydrogen production), the scarcity of drinking water and potential conflicts of use with the production of green hydrogen are considered as a highly relevant factor that should thus be addressed by future R&D activities with priority. In this context, also the high cost of seawater desalination and purification should be addressed in order to allow for the implementation of sustainable and economically competitive technical solutions in the future. Only individual stakeholders had an opinion about the relevance of the cost and availability of CO_2 sources as a barrier for methanol production, as this aspect was not in the focus of expertise of most of the respondents. However, also for this aspect the currently high costs (for both direct CO_2 air capture and purification from industrial exhaust gases) are seen as a very relevant barrier by individual stakeholders. Similarly, only individual stakeholders see the spatial distribution of RES generation sites and industrial production sites (as CO_2 sources) as a very important barrier. More in-depth assessments of the research needs related to this issue could be useful if CO_2 capture plays a relevant role in Morocco's PtX strategy. The potential competition of electricity generation for residential and industrial demand with the production of green hydrogen was seen as a critical barrier by only one respondent.
- Regarding **midstream activities** in the PtX value chain (i.e. production and transport of green hydrogen), respondents see both the transport of gaseous products (H2, CO2, N2, NH3) as well as liquefied gases/products as relevant or even very relevant barriers to the development of a PtX industry in Morocco. A clear strategy addressing the cost and technical options for PtX product transport is thus central. Also the lack of the suitable export infrastructure for PtX products is seen as a relevant barrier that needs to be addressed. The cost of a potential transport of purified seawater through pipelines is seen as a barrier by some of the stakeholders.
- Concerning **downstream activities** (i.e. the production green hydrogen derivatives), most respondents see the high cost of conversion infrastructure as well as the high cost of electrolytic generation as the main barriers for the PtX sector development. Also, the technical integration of different technologies in one PtX synthesis platform can be a relevant barrier according to the majority of the respondents. R&D activities should thus emphasize future cost-reductions and include the identification of pilot projects demonstrating optimal integration of PtX technologies.
- Barriers related to **competencies and capacities** relevant for the development of the PtX sector are mainly associated with a lack of training facilities (both lab scale and pilot scale) as well as with the lack of highly skilled workers experienced in PtX technologies. Also, a lack of holistic know-how in the field of PtX was seen as a relevant barrier by the majority of respondents. The results emphasize that a focus on specific PtX related trainings, on both lab and pilot scale, should be focus areas in the national R&D strategy.

- With regard to the **political and regulatory framework for PtX**, mainly the lack of a clear long-term perspective and attractive financing options as well as a lack of regulations for the export of PtX products were rated as relevant barriers. However, the political support for PtX in general is not seen as a critical barrier by most of the respondents and shortcomings mainly relate to the long-term vision for the market development.

Based on the analysis of the relevance of these barriers for the development of the PtX value chain and the in-depth discussions with representatives from different stakeholder groups in Morocco, focus topics for future R&D activities have been identified in particular in the following areas:

→ Cost reductions and optimal technology integration
→ Water supply and water treatment
→ Energy system planning and spatial optimization
→ Infrastructure development
→ Certification schemes for green hydrogen
→ Capacity building and training
→ Matchmaking and strengthening of national and international R&D networks
→ Coordination of national PtX R&D activities

In addition to the suggested research focus areas, described in detail in section 5.2, we provide first recommendations for the short- and longer term perspective, based on the analyses conducted so far. Thereby, the need for a stronger cooperation and coordination between national and international R&D activities along the whole PtX value chain is one of the most central measures to ensure the effectiveness and efficiency of all other measures.

Short term perspective – To support the successful realization of PtX pilot projects and allow stakeholders to gain in experience and expand cooperations in the next 2-5 years:

- To reflect the needs of various different stakeholders in the PtX R&D sector in Morocco, pilot projects should be carefully chosen to address different technological challenges, such as H2 production and storage, production of downstream products (in particular Ammonia) and the use of hydrogen in turbines to replace fossil gases.
- Water supply for hydrogen production and related sustainability issues due to water scarcity and potential conflicts of use should be addressed early on. Pilot projects could focus on combining efficient water treatment technologies with green hydrogen production (desalination and use of alternative water sources). Hydrogen storage in the subsoil, e.g. in salt caverns, and their stability, can be another interesting R&D field, building on existing competences.
- Industry stakeholders should be addressed and supported in identifying business opportunities related to PtX to allow for a steady and sustainable development of the sector. Market studies and evaluation of different business cases could help in this regard and should be developed in cooperation with and shared with relevant stakeholders. Networks and interfaces for the exchange of stakeholders should be strengthened (e.g. through conferences and regular activities in the Green Hydrogen Cluster).

Longer term perspective - To facilitate the development of a sustainable local PtX sector and to develop economic opportunities and sustainable jobs in the longer term (5-10 years and beyond):

- The development of a stronger national "innovation ecosystem" should be promoted in particular with a focus on the absorptive capacity of the market (i.e. adoption of innovative technologies by end users in particular in the industry sector) by creating incentives to assess and deploy innovative technologies (e.g. through offering tax incentives or subsidized loan programs).
- Links between universities and industry stakeholders need to be strengthened in order to allow for research and development activities to be application oriented. Approaches that incentivize the cooperation between research institutions and industry stakeholders (e.g. through funding specifications or quotas) could help to combine competences so that technical innovations can be designed to optimally address the needs and requirements of the industry.
- The coordination of national R&D efforts on PtX should be supported to avoid fragmentation and redundancy in R&D efforts and investments in equipment. IRESEN could take a major role in this regard, providing an information platform and facilitating exchange of knowledge between research institutes to enhance the efficiency of research efforts. A clear understanding of the roles and responsibilities of the various stakeholders in the PtX innovation system will be a crucial element in this regard.
- Stronger development of general engineering capacities in higher education with a focus on chemical engineering and implementing more Master programs specifically focused on PtX technologies will be important to avoid bottlenecks in the future.
- Based on past experiences, development of dual study courses with industry and universities which provide students with higher education on chemical engineering supplemented by specialized practical training (e.g. through the PtX R&D platform) would help to develop specific skills which are directly applicable for the developing PtX industry. The program could be co-funded by industrial companies seeking specialized workers in this field. It would also help to further strengthen the links between academic research and the industry.

The report provides an estimate of funding requirements for potential activities in the context of the implementation of the PtX R&D platform as a basis for more specific discussions with IRESEN. For more in-depth assessments, the actual setups and sizes of activities and potential pilot projects need to be discussed and specified in detail in coordination with the concerned stakeholders and decision makers.

More specific recommendations will be part of the R&D roadmap to be developed in a second step of this project. A workshop with relevant stakeholders in Morocco will help to define future R&D activities in more detail based on a discussion of the activities proposed in this report (see 4.3.1., and 5.2, 5.3). Here we also intend to discuss how to strengthen work with international partners, and in which way the funding situation can be improved.

7 References

Carlsson, B., Stankiewicz, R. (1991): On the nature, function and composition of technological systems. J Evol Econ 1, 93–118 (1991). https://doi.org/10.1007/BF01224915

Chemanalyst (2022): Weblink: https://www.chemanalyst.com/Pricing-data/ammonia-37

EPO and IRENA (2022), Patent insight report. Innovation trends in electrolysers for hydrogen production, EPO, Vienna

European Patent Office (EPO), International Renewable Energy Agency (IRENA). Innovation trends in electrolysers for hydrogen production: Patent insight report, 2022.

Fasihi, M.; Efimova, O.; Breyer, C. Techno-economic assessment of CO2 direct air capture plants. Journal of Cleaner Production 2019, 224, 957–980. DOI: 10.1016/j.jclepro.2019.03.086.

Fraunhofer ISI (2019): Study on the Opportunities of Power-to-X in Morocco - 10 Hypotheses for Discussion. Karlsruhe, February 2019.

Frontier Economics (2020): PtX Roadmap for Morocco. Study prepared for the Moroccan Ministry of Energy, Mines and Environment.

Hekkert, M., Negro, S., Heimeriks, G., & Harmsen, R. (2011). Technological Innovation System Analysis: A manual for analysts. Utrecht.

International Energy Agency (IEA). Global Hydrogen Review 2021, 2021.

International Energy Agency (IEA). Direct Air Capture: A key technology for net zero, 2022.

International Renewable Energy Agency (IRENA). Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5oC Climate Goal: Abu Dhabi, 2020.

International Renewable Energy Agency (IRENA). Renewable Energy Capacity Statistics 2022, 2022a.

International Renewable Energy Agency (IRENA). Renewable power generation costs in 2021: Abu Dhabi, 2022b.

International Renewable Energy Agency (IRENA). Renewable technology innovation indicators: Mapping progress in costs, patents and standards, 2022c.

Lotfy, H. R.; Staš, J.; Roubík, H. Renewable energy powered membrane desalination - review of recent development. Environmental science and pollution research international 2022, 29 (31), 46552–46568. DOI: 10.1007/s11356-022-20480-y.

Yu, L.; Zhu, Q.; Song, S.; McElhenny, B.; Wang, D.; Wu, C.; Qin, Z.; Bao, J.; Yu, Y.; Chen, S.; Ren, Z. Non-noble metal-nitride based electrocatalysts for high-performance alkaline seawater electrolysis. Nature communications 2019, 10 (1), 5106. DOI: 10.1038/s41467-019-13092-7.

8 Annex

A.1 Annex 1 - Questionnaire for expert interviews

Support for the implementation of a research and development platform for Green Hydrogen in Morocco – Interview Guideline

Fraunhofer

Introduction

This questionnaire/interview guideline is associated with a project supporting the implementation of a research and development (R&D) platform for Green Hydrogen in Morocco. The **main objective of this R&D platform** is to support stakeholders to assess, improve, test and develop technologies for Green Hydrogen and related products (Power-to-X) towards the cost-effective rollout required in their respective markets. The R&D platform further aims to serve as a hub for training and capacity building in the field of PtX in Morocco and beyond and to link the academic and research world with stakeholders from the industry and service sector. The platform will thus provide a space for national and international collaboration and innovative business activities in the field of PtX.

The project "Support for the implementation of a research and development platform for Green Hydrogen in Morocco" is funded by the German agency for international cooperation GIZ and carried out by a consortium of researchers from the Fraunhofer Institute for Energy Economics and Energy System Technology IEE, the Fraunhofer Institute for Systems and Innovation research ISI, the Fraunhofer Institute for Microstructure of Materials and Systems IMWS and the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB. The project aims to support the design of the Green Hydrogen R&D platform in Morocco so it meets the needs of relevant stakeholders and generates the maximum benefits for business development, innovation and technology rollout in the field of green Hydrogen in Morocco.

In this context, your input on the Status Quo, the perspectives and the requirements for the development of a successful Green Hydrogen value chain in Morocco is highly valuable. Based on your feedback, we will be able to identify potential obstacles and derive targeted recommendations on how to optimally support Morocco's industry and research sectors along the Green hydrogen value chain and how to provide favourable framework conditions for international cooperation in the field.

We will ensure **data protection**. Your responses during the interview will be treated confidentially and discussed only within the project team and with the GIZ. In project reports and publications, we will never mention your name or the name of your institution associated with specific quotes without your permission[8]. Please let us know if you have further requirements regarding the confidentiality of your answers.

Part A: Your institution/company profile

1. **Name of institution/company*:** *Click or tap here to enter text.*
2. **Type of Institution/company (please select)*:**
   a. ☐ Government agency
   b. ☐ Industry
   c. ☐ Industry association

[8] Results will be anonymized and displayed aggregated by institution type / sector.

   d. ☐ Finance
   e. ☐ Academic research
   f. ☐ Other research
   g. ☐ Other (please specify): *Click or tap here to enter text.*
3. **Major products/services*:** *Click or tap here to enter text.*
4. **PtX value chain segment(s) mainly relevant*:** *Click or tap here to enter text.*
5. Company size (No. of employees, annual turnover): *Click or tap here to enter text.*
6. **Main target market*:**
   a. Morocco
   b. MENA
   c. EU
   d. Other (please specify): *Click or tap here to enter text.*
7. Estimated market share: *Click or tap here to enter text.*
8. **Confidentiality requirements for interview***: *Click or tap here to enter text.*
9. Other issues: *Click or tap here to enter text.*

Part B – Your outlook on the development of Green Hydrogen in Morocco

1. What is your perspective on the future development of the green hydrogen / PtX sector in Morocco in general? Please explain: *Click or tap here to enter text.*
2. Do you see a potential for local use of green hydrogen or related products in Morocco (in the short, medium and long term)? Please explain: *Click or tap here to enter text.*
3. How do you evaluate the potential for export of green hydrogen or related products (in the short, medium and long term)? Please explain: *Click or tap here to enter text.*
4. For which products do you see the most potential (e.g. green Hydrogen, green Ammonia, green Methanol, synthetic fuels)? Please explain: *Click or tap here to enter text.*
5. What do you think are the major drivers for the development of a green hydrogen value chain in Morocco? Please share your views: *Click or tap here to enter text.*
6. In the following, we have listed some potential barriers for the development of green hydrogen along the segments of the technology value chain.
   Please rate how relevant these barriers are in the Moroccan context by selecting the drop down menu. If you do not have an opinion on individual items, please select the respective option. You can add barriers or leave comments at the bottom of each table.

Upstream – Inputs for Green Hydrogen production	
Distance of Renewable Energy generation sites from large industrial hubs	Choose an item.
Competition of generation with residential and other industrial energy demand	Choose an item.
Concentrated CO_2 sources are relatively scarce/concentrated in large hubs	Choose an item.
CO_2 capture from air is expensive	Choose an item.
CO_2 purification from industrial off-gases is expensive	Choose an item.

Water scarcity in the regions with the highest solar power potential	Choose an item.
Competition with drinking water, agricultural or other industrial usage of water	Choose an item.
High cost of largescale seawater purification	Choose an item.
Other barriers not mentioned above: *Click or tap here to enter text.*	
Comments: *Click or tap here to enter text.*	

Midstream – Green Hydrogen production & transport	
Renewable Energy feed-in tariffs and taxes on electricity use decrease the economic competitiveness of Green Hydrogen production	Choose an item.
Transport of gases (H_2, CO_2, N_2, NH_3) across the country is difficult/expensive	Choose an item.
Pipeline transport of purified seawater is difficult/expensive	Choose an item.
Transport of liquefied gases (H_2, CO_2, N2, NH_3) or liquids (methanol, synthetic hydrocarbons) across the country is difficult	Choose an item.
Export infrastructure for PtX products at ports is missing	Choose an item.
Other barriers not mentioned above: *Click or tap here to enter text.*	
Comments: *Click or tap here to enter text.*	

Downstream products of Green Hydrogen	
Sites with optimal mix of upstream, midstream and downstream features are scarce	Choose an item.
Integration of individual technologies into a PtX synthesis platform is difficult (e.g. electrolysis and further processing technologies)	Choose an item.
Electrolytic H_2 generation is still expensive	Choose an item.
Further conversion infrastructure of H_2 is expensive	Choose an item.
Other barriers not mentioned above: *Click or tap here to enter text.*	
Comments: *Click or tap here to enter text.*	

PtX Competences	
Lack of holistic know-how in the field of PtX	Choose an item.
Lack of highly qualified local management experienced in PtX technologies	Choose an item.
Lack of skilled work force in general	Choose an item.
Lab-scale training facilities (national) are not yet fully equipped to meet the demand	Choose an item.

Pilot-scale training facilities (national) are not yet available	Choose an item.
Lack of access to third-party (international) lab-scale training facilities	Choose an item.
Lack of access to third-party (international) pilot-scale training facilities	Choose an item.
Other barriers not mentioned above: *Click or tap here to enter text.*	
Comments: *Click or tap here to enter text.*	

Political and regulatory framework conditions for PtX	
Political support for PtX development in general is not strong enough	Choose an item.
Political support is sufficient, yet in time it lags behind the needs	Choose an item.
National laws and regulations constitute a barrier	Choose an item.
Lack of clarity regarding certification / Guarantees of Origin	Choose an item.
International export regulations for Hydrogen are not clear	Choose an item.
International export regulations for ammonia are not clear	Choose an item.
International export regulations for methanol are not clear	Choose an item.
Lack of long term perspective due to changing international regulatory conditions	Choose an item.
Other barriers not mentioned above: *Click or tap here to enter text.*	
Comments: *Click or tap here to enter text.*	

Part C - Your activities related to the PtX value chain

1. **Has your institution/company been involved in any activities in the context of green Hydrogen production, transport, storage or downstream products or in research and development activities related to any of those fields in the past?**
   a. ☐ Yes
   b. ☐ No
2. If yes, please specify for each of the activities: *Click or tap here to enter text.*
3. **If no, do you foresee activities for your institution/company in any of these areas in the near/mid/long-term future?** Please specify: *Click or tap here to enter text.*
4. Are there any specific barriers or obstacles that keep your institution/company from engaging in activities related to the green hydrogen or PtX value chain? Please specify: *Click or tap here to enter text.*
5. Are there any specific support measures or instruments that could help your institution/company to address these barriers (if any)? Please specify: *Click or tap here to enter text.*

6. Do you make use of any R&D collaborations in your field and do you expect to collaborate with R&D organisations along your hydrogen related value chain in the future? Please specify: *Click or tap here to enter text.*

Part D – Your view on the design of the green Hydrogen R&D platform

1. **In general, do you see a potential for your institution/company to get involved with a future green Hydrogen R&D platform in Morocco?**
   a. ☐ Yes
   b. ☐ No
2. If no, please explain: *Click or tap here to enter text.*
3. **Please rate how relevant the following services/activities related to the PtX value chain are or could be for your institution/company by choosing from the drop down menu.** If you do not have an opinion on individual items or if they do not apply, please select the respective option. You can add or leave comments at the bottom of the table.

In person/on-site capacity building & training services	Choose an item.
Online capacity building services	Choose an item.
Certification services for your products or services	Choose an item.
Testing and lab facilities for technical components and systems	Choose an item.
Matchmaking services (domestic industries and internationally – R&D + industry)	Choose an item.
Support in identification of PtX related business opportunities	Choose an item.
Information services such as PtX market analysis	Choose an item.
Support in PtX project development (site identification, techno-economic analysis, etc.)	Choose an item.
Support in policy development or development of regulations and standards	Choose an item.
Support in establishment of certification schemes for green hydrogen production (Guarantees of Origin)	Choose an item.
Providing an ecosystem for innovations i.e. through joint R&D programs including public support	Choose an item.
Comments: *Click or tap here to enter text.*	

4. **For the above services/activities that you see as potentially relevant for your institution/company, please specify how the services would ideally be designed to address your company's needs best:** *Click or tap here to enter text.*

5. **Which other services/activities (not mentioned in the list above) could be relevant in the short/medium/long-term from the perspective of your institution/company?** Please share your views: *Click or tap here to enter text.*
6. **For PtX pilot projects in Morocco: Which design would you see as most beneficial and valuable to promote PtX development (e.g. regarding plant size, applied technologies or technology combinations, site selection, etc.)?** Please share your views: *Click or tap here to enter text.*

A.2 Annex 2 – Stakeholder list

Table 4 Policy sector and institutional bodies

Abbreviation	Name	Description	Website	Regional focus
IRESEN	Institut de Recherche en Energie Solaire et Energies Nouvelles	Coordinating national research in renewable energies	https://iresen.org/	MO
MASEN	Moroccan Agency for Sustainable Energy	Development and implementation of national RES strategy	https://www.masen.ma/en/	MO
MASciR	Moroccan Foundation for Advanced Science, Innovation and Research	Associated with UM6P, non-profit for promotio of technological research in material-, nano-, biotechnology- and life sciences.	https://www.mascir.com/en/home/	MO
CNRST	Centre National pour la Recherche Scientifique et Technique	Implementation of R&D programs in line with the government strategy, support R&D infrastructure	https://www.cnrst.ma/index.php/fr	MO
	Ministry of Energy Transition and Sustainable Development		https://www.mem.gov.ma/pages/index.aspx	MO
	Ministry of Industry and Trade			MO
	Ministry of Higher Education, Scientific Research and Innovation			MO
	Ministry of Economic Inclusion, Small Business, Employment and Skills?			MO
ONEE	Office National de l'Electricité et de l'Eau Potable		http://www.one.org.ma/	MO
ONDA	Office National des aéroports		https://www.onda.ma/en/I-discover-ONDA	MO
ONHYM	Office Nationale des hydrocarbures es des mines	Established 2005, public institution overseeing mining, oil and gas sectors. Provision of training and research services related to mining and hydrocarbons.	http://www.onhym.com/en/the-office/who-we-are2/presentation.html	MO

Abbreviation	Name	Description	Website	Regional focus
CGEM	Confédération Générale des Entreprises du Maroc	Representation of private sector companies to improve business climate on national, regional and international level.	https://www.cgem.ma/	MO
SNEP	Société Nationale d'Electrolyse et de Pétrochimie	Production and marketing of PVC/vinyl products, electrolysis products (soda, chlorine, bleach) and hydrochloric acid. Market leader for these products in Morocco.	https://www.snep.ma/	MO
SIE	Société d'Ingénierie Énergétique	Consultancy services for energy effieciency	https://www.sie.co.ma/	MO
AMEE	Agence Marocaine pour l'Éfficacité Energétique / Moroccan Agency for Energy Efficiency	Implementation of government strategy for energy efficiency through implementation of measures, norms and financing tools	https://www.amee.ma/	MO
FdE	Fédération de l'Energie	Contributing to national energy strategy debate, organizations of annual conferences	https://www.fedenerg.ma/	MO
IMANOR	Institut Marocain de Normalisation		https://www.imanor.gov.ma/	MO
OFPPT	L'Office de la formation professionnelle et de promotion du travail	Main provider of vocational training in Morocco	https://www.ofppt.ma/	MO
IFMEREE	Instutut de Formation aux Métiers des Energies Renouvelables et de l'Efficacite Enérgétique	Provider of technical training courses for technicians specialized in RES and EE, technical advice and assistance	https://ifmeree.ac.ma/	MO
CERIMME	Centre d'études et de recherches des industries métallurgiques, mécaniques, électriques et électroniques		http://www.cerimme.ma/	MO

Table 5 Research institutions and capacity building

Abbreviation	Name	Description	Website	Regional focus
UM6P	Mohamed VI Polytechnic University			MO
USMBA	Sidi Mohammed ben Abdellah University			MO
UEMF	Euromed University of Fes			MO
UCA	University Cadi Ayyad (Marrakech)			MO
MedV	MedV University (Rabat)			MO
Hassan II	Hassan II University (Casablanca)			MO
Med 1	Med 1 Universityer (Oujda)			MO
UIT	Ibn Tofail University (Kenitra)			MO
UIR	International University of Rabat			MO
FHG	Fraunhofer IMWS/ IGB/ CBP			D/international
	ECN-TNO			NL/international
	Cea-Tech			international
	University Halle Leipzig			D/international
	University of Jülich			D/international
	University of Offenburg			D/international
	University of Freiburg			D/international
Hypos	Hypos			international
HER	Hydrogen Europe Research			international
CNH2	Centro National de Hidrogeno			international

Table 6 Industry and industry associations

Abbreviation	Name	Description	Website	Regional focus
FIMME	Fédération des Industries Métallurgiques Mécaniques et Electromécaniques		https://fimme.org	MO
FENELEC	Fédération Nationale de l'Electricitéet de l'Electronique		https://www.fenelec.com/ds.htm	MO
FCP	Fédération de la Chimie et de la Parachimie		http://www.fcpmaroc.org/	MO
JESA	Jacobs Engineering S.A.	EPC & Consultancy services for Mining, Industry/Chemical, Energy, Infrastructure projects (e.g. fertilizer production, RES projects)	https://www.jesagroup.com/	Africa (MO)
CID	Conseil Ingénierie et développement	Engineering firm (civil engineering, buildings, transportation and hydraulic projects)	https://cid.co.ma/en/	MO/global
Afriquia		Fuel distribution, gas		MO
Somas	SOCIETE MAROCAINE DE STOCKAGE	Storage and distribution of butane gas to major oild and gas groups	https://somas.ma/	MO
Mahgreb Oxygen	Mahgreb Oxygen MA	Distribution of medical gases (oxygen, nitrous oxide, carbon dioxide, synthetic air)	https://www.maghreboxygene.ma	MO
SNTL	Société Nationale des Transports et de la Logistique	Transport sector	https://sntl.ma/	MO
Royal Air Maroc	Royal Air Maroc	Transport sector, air		MO
ONCF	Office National des Chemins de Fer du Maroc	Transport sector, rail		MO
Port Tangier	Major import, export hub	Transport sector, ship	https://www.tmpa.ma/en/	MO
OCP	Office Chérifien des Phosphates	Phosphate mining, fertilizer production, animal feed additives	https://www.ocpgroup.ma/about-us	MO
Green Energy Park	Green Energy Park	Partnership between IRESEN and UM6P for RES R&D (research, training, testing)		MO

Abbreviation	Name	Description	Website	Regional focus
	Nareva	Renewable energy / Wind	https://www.nareva.ma/en/	
	Heidelberg Zement	Local representation of HZ in Morocco since 2016, second largest cement manufacturer in MO, operating 3 cement plants in Aït Baha, Safi, and Marrakech, 2 grinding centers in Laâyoune and 1 in Jorf Lasfar, 5 quarries, and 23 concrete batching plants.	https://www.heidelbergcement.com/en/morocco	D/global (incl. MO)
	Sunfire	Eletrolyzers (hydrogen, Syngas, e-fuels), Alkaline electrolyzers and SOEC Electrolyzers (using industrial heat).	https://www.sunfire.de/en/	D
Linde	Linde Engineering	Services/technologies covering the whole hydrogen value chain	https://www.linde-engineering.com/en/index.html	D/global
	CALORIC Anlagenbau	Technologies for hydrogen production and gas refining, project development and implementation of pilot projects	https://www.caloric.com/de/	D
	Kraftanlagen GmbH			
	Baker Hughes	Provision of a wide range of technologies (Hydrogen, CCS, LNG, industrial processing technologies, etc)	https://www.bakerhughes.com/	global
	Advisian	Consultancy and engineering services in energy and water sector (incl. hydrogen and CCUS)	https://www.advisian.com/en-gb	global
	Air Liquide	Specialized on technology for gases, various H2 projects worldwide	https://www.airliquide.com/ https://www.airliquide.com/group/morocco	global (incl. MO)
	GP Joule	EPC and O&M services for Renewables , PV installations	https://www.gp-joule.com/	USA/Canada/D
	Haldor Topsoe	Production of Ammonia, hydrogen and methanol, catalysts and process technologies for fuel production, fertilizer production and other applications. Global representations (but not in MO).	https://www.topsoe.com/?hsLang=en	DK/global
	Enagás	Spains major natural gas company and operator of gas network, also active in green hydrogen	https://enagas.es/portal/site/enagas	ESP/global
	Thyssen Krupp	Metals, chemicals, engineering and construction	https://www.thyssenkrupp.com/en/home	global
	Proton Ventures	Ammonia production (technologies, project development, storage, R&D)	https://protonventures.com/	NL/global

Abbreviation	Name	Description	Website	Regional focus
MAN	MAN Energy Solutions (DE Deggendorf)	Wide range of services and technologies (engines and turbines) including PtG, PtL and PtC	https://man-es.com/company	D/global
NEL	NEL Hydrogen	Electrolyzers and fuelling stations for H2	https://nelhydrogen.com/	NO/global
	Mahgreb Steel	Steel production at two sites (Casablanca)	http://www.maghrebsteel.ma/	MO
AKWA	AKWA Group	Company group focused on oil and cas industry (and other business sectors) based in Casablanca	https://www.akwagroup.com	MO
EDF	EDF Energy	Energy supply, representation in Morocco	https://www.edfenergy.com/	FR/global (MO)
ACWA	ACWA Power	Energy project development and services, desalination and water purification	https://acwapower.com/	SA/MENA
Enel	Enel			
BASF	BASF			
ENGIE	ENGIE			
	John Cockerill			
	Siemens energy (MA)			
	Hy2Dev			
	Hydrogenics	Hydrogen, fuel cell and battery technology	http://hydrogenics.eu/	USA
McPhy	McPhy Energy SA	Developing hydrogen storage, production, fuelling solutions. various industry partners.	https://mcphy.com/en/?cn-reloaded=1	FR/global
	Total			
	Climeworks			
	Alrbus			
	Lufthansa			
	PSA			
	Port of Rotterdam			
	Vopak			
	Tractebel			
	VDA			
	Siemens Energy			

Table 7 International associations and initiatives

Abbreviation	Name	Description	Website	Regional focus
UN	UN - Green Hydrogen Catapult initiative		https://greenh2catapult.com/	
	Ammonia Energy Association		https://www.ammoniaenergy.org/	
HyDeal	HyDeal Initiative		https://www.hydeal.com/	
PtX Hub	PtX Hub		https://ptx-hub.org/about-us/	
	European Hydrogen Backbone	Development of a European hydrogen infrastructure (repurposed gas pipelines and hydrogen pipelines) for inner European transport and import of hydrogen until 2040.	https://gasforclimate2050.eu/ehb/	Europe
Hydrogen Council	Hydrogen Council	CEO-led initiative bringing together energy companies in order to promote hydrogen technology innovation and deployment worldwide, provide guidance to governments and support networking between companies, investors and governments.	https://hydrogencouncil.com/en/	
IEA	IEA Hydrogen	Research and innovation collaboration	https://www.ieahydrogen.org/	global
CEM	Clean Energy Ministerial Hydrogen Initiative	Initiative that aims to advance policies, programs and projects that accelerate the commercialization and deployment of hydrogen and fuel cell technologies across all aspects of the economy. Supporting international collaboration.	Clean Energy Ministerial Hydrogen Initiative	global
IPHE	International Partnership for Hydrogen and Fuel Cells in the Economy	Inititive to support clean energy traansition using hydrogen fuel cells by providing information, promoting collaboration and inform government RD&D	https://www.iphe.net/	global
CHS	Center for Hydrogen Safety	Global non-profit dedicated to promoting hydrogen safety and best practices worldwide. Platform for exchange, education, eLearning and other resources.	https://www.aiche.org/chs	global
H2Global	H2 Global	Foundation aiming to promote the production and use of green hydrogen and other climate-neutral energy carriers within Europe and its import.	https://www.h2-global.de/	global / EU
H2V	Mission Innovation Hydrogen Valley	Platform for project developers to showcase projects, promote matchmaking and support distribution of best practices	https://www.h2v.eu/	global