The Risks and Opportunities of

# Green Hydrogen Production and Export

## From the MENA Region to Europe

Dii Desert Energy | November 2020 | Study on behalf of the Friedrich-Ebert Stiftung

FRIEDRICH EBERT STIFTUNG | Climate and Energy Project مشروع الطاقة والمناخ | MENA Hydrogen Alliance An initiative of Dii Desert Energy


**Prepared by:**

Cornelius Matthes
Valeria Aruffo
Louis Retby-Pradeau

The Hashemite Kingdom of Jordan
The Deposit Number at The National Library
(2020/12/5362)

يتحمل المؤلف كامل المسؤولية القانونية عن محتوى مصنفه ولا يعبّر
هذا المصنف عن رأي المكتبة الوطنية أو أي جهة حكومية أخرى.

**Title:** Risks and Opportunities of Green Hydrogen Production and Export From the MENA Region to Europe

**Prepared by:** Cornelius Matthes (lead); Valeria Aruffo; Louis Retby-Pradeau

**Contributors:** Frank Beckers, Malcolm Cook, Shukri Halaby, Fadi Maalouf, Abdallah Alshamali, Samir Rachid and the Direction of Observation, Cooperation and Communication of the Ministry of Energy, Mines and Environment of Morocco, Damien Sage, Paul van Son, Frank Wouters, Alessandro Zampieri

**ISBN:** 978 - 9923 - 759 - 24 - 0

The Risks and Opportunities of

# Green Hydrogen Production and Export

From the MENA Region to Europe

## About Friedrich Ebert Stiftung:

Friedrich-Ebert-Stiftung is the oldest German political foundation and advocates for the advancement of social democracy. Through its Jordan based Regional Climate and Energy Project MENA, it brings together government representatives with civil society organizations, supports research and provides policy recommendations, to promote and achieve a socially just energy transition and climate justice for all in the MENA region.

## About Dii Desert Energy

Dii Desert Energy is an independent, non-profit, international public-private sector network operating from Dubai. By connecting the international industry active in the MENA region with authorities and institutions, Dii Desert Energy focuses on practical conditions for 'green electrons' and 'green molecules' along the energy value chains leading to tangible and profitable projects and other benefits for local and international stakeholders.

**Dii Desert Energy | November 2020 | Study on behalf of the Friedrich-Ebert Stiftung**

FRIEDRICH EBERT STIFTUNG

Climate and Energy Project

MENA Hydrogen Alliance
An initiative of Dii Desert Energy

**Prepared by:**
Cornelius Matthes
Valeria Aruffo
Louis Retby-Pradeau

# TABLE OF CONTENTS



## List of Figures:

| Acronym | Description |
|---|---|
| BNEF | Bloomberg New Energy Finance |
| CAPEX | Capital Expenditure |
| CCGT | Combined Cycle Gas Turbine |
| CCUS | Carbon Capture, Utilization, and Storage |
| CIS | Commonwealth of Independent States |
| $CH_4$ | Methane |
| $CO_2$ | Carbon Dioxide |
| CSP | Concentrated Solar Power |
| DEWA | Dubai Electricity and Water Authority |
| Dii | Dii Desert Energy |
| Desertec 1.0 | 2009 – 2014: Implementation of renewables in the deserts with a strong focus on export of power to Europe |
| Desertec 2.0 | 2015 – 2018: Overcoming practical hurdles for RE with a new office in Dubai |
| Desertec 3.0 | Since 2019: Green molecules alongside green electrons: MENA to become a Green Powerhouse' for itself & the world |
| EDO | Energy Development Oman |
| EU | European Union |
| EUMENA | Europe, MENA and North Africa |
| GDP | Gross Domestic Product |
| GHG | Green House Gases |
| GW | Gigawatt |
| HVDC | High Voltage Direct Current |
| $H_2$ | Hydrogen |
| IEA | International Energy Agency |
| IRESEN | Institut de Recherche en Energie Solaire et Energies Nouvelles |
| kWh | Kilowatt hour |
| LCoE | Levelized Cost of Electricity |
| LCoH | Levelized Cost of Hydrogen |
| LNG | Liquefied Natural Gas |
| LOHC | Liquid Organic Hydrogen Carriers |
| Masen | Moroccan Agency for Sustainable Energy |
| MEMR | Ministry for Electricity and Mineral Resources |
| MENA | Middle East North Africa |
| $M^3$ | Cubic meter |
| NEPCO | National Electricity Power Company |
| OPEX | Operating Expenditure |
| OCP | Office Chérifien des Phosphates |
| OPWP | Oman Power and Water Procurement Company |
| PDO | Petroleum Development Oman |
| PV | Photovoltaic |
| R&D | Research and Development |
| RE | Renewable Energy |
| SMR | Steam Methane Reforming |
| Solar PV | Solar Photovoltaic System |
| TPES | Total Primary Energy Supply |

# 1.0: EXECUTIVE SUMMARY

National governments worldwide, regional institutions and private sector businesses are concerned about climate change, international trade and markets with sustainable jobs and industries. In the context of a global pandemic and its social and economic implications, Europe has elaborated on a major green recovery plan to ensure the recovery is sustainable and inclusive. "The Next Generation EU" is the new recovery instrument, which aims at creating new jobs and mainstreaming climate actions.[1] The European Green Deal represents the core element of the recovery package, to ensure Europe will reach climate neutrality being the first climate neutral continent by 2050. Green hydrogen is also called "the missing link for the energy transition"due to its ability to decarbonize and couple different sectors where carbon dioxide ($CO_2$) cannot be abated or electrification is not possible. Furthermore, the development of a green hydrogen economy can also help to integrate more renewable energy (RE) in the energy system, provide seasonal storage and contribute to green growth and local job creation.

The MENA region is blessed with some of the world's best solar and wind resources, allowing a high combined capacity factor for solar photovoltaic and wind, which is crucial to achieving very low prices to produce green hydrogen. A regional partnership between Europe and the MENA region offers an obvious win-win situation: the production of green hydrogen in MENA will support local industrial and social-economic development with many new jobs. With Europe's zero emissions goal by 2050 becoming national law in all countries, potential off-takers are already lined up: among others the steel or heavy transport industries are evaluating where to source in the mid-and long term the big amounts of green molecules through market mechanisms. The MENA region is in the middle of a historic change in the role and position as a potentially dominant player from the huge and energy-rich deserts region. In the last few years, 'green molecules' have been included in the strategy of leading organizations like ACWA Power, NEOM, Siemens or Masen, alongside 'green electrons' to accelerate the transition towards a low carbon economy in the Arab World. Global initiatives with the focus on regional market developments such as Dii Desert Energy/Desertec 3.0 have therefore been expanded, in this case by the MENA Hydrogen Alliance. Green hydrogen is a promise to improved and sustained prosperity and stability in the region through the creation of a solid market place with local jobs and industries associated with the energy transition.

This paper shows that the MENA region has the potential to become Powerhouse for green hydrogen, in the first place for regional societies, but also for world markets. The opportunities will thus significantly outweigh the risks. We believe that carefully considering some environmental challenges like utilization of land and water, and more importantly the green and emission-free color of hydrogen will guarantee a very positive development. The emerging green molecules may be compared with the success story of RE over the last ten years, perhaps even in accelerated manner.

The world is facing a historic crisis in the oil & gas industry. However, the good news is that green hydrogen will reward leadership in this sector. While Morocco has already pushed towards the development of a green hydrogen economy, Oman is starting to recognize the potential. Its neighbour KSA/NEOM announced the world's largest green hydrogen/ammonia project in July 2020.[2] The UAE have launched a small demonstration project.

However not much has yet been happening until now in most other MENA countries. International partnerships with Europe and other geopolitical forces such as China will help to accelerate development.

Policy makers in MENA have a unique chance, in fact also responsibility, to move fast for the benefit of their economies, bringing down the cost of green hydrogen projects by establishing bold national action plans with clear milestones. As a prerequisite, a common standard to certify the green nature of hydrogen needs to be created which is crucial to build trust and start engaging successfully in international markets.

1 European Commission (2020). *Europe's moment: Repair and prepare for the next generation.* Brussels, Press Release, 27th of May.
Available at: https://ec.europa.eu/commission/presscorner/detail/en/ip_20_940

2 Air Products, ACWA Power and NEOM Sign Agreement for USD 5 Billion Production Facility in NEOM Powered by Renewable Energy for Production and Export of Green Hydrogen to Global Markets. Press release. 8th July 2020.
Available at: https://www.acwapower.com/news/air-products-acwa-power-and-neom-sign-agreement-for-5-billion--production-facility-in-neom-powered-by-renewable-energy-for-production-and-export-of-green-hydrogen-to-global-markets/

## 2.1 Hydrogen as Energy Carrier

Hydrogen is the first and the lightest chemical element of the periodic table. As the most abundant chemical substance in the universe, hydrogen is often called the missing link for the energy transition. This is thanks to its key role in the concept of sector coupling: hydrogen as an energy carrier can interconnect and integrate the energy-consuming sectors such as buildings (heating and cooling), transport, and industry with the power sector.[3]

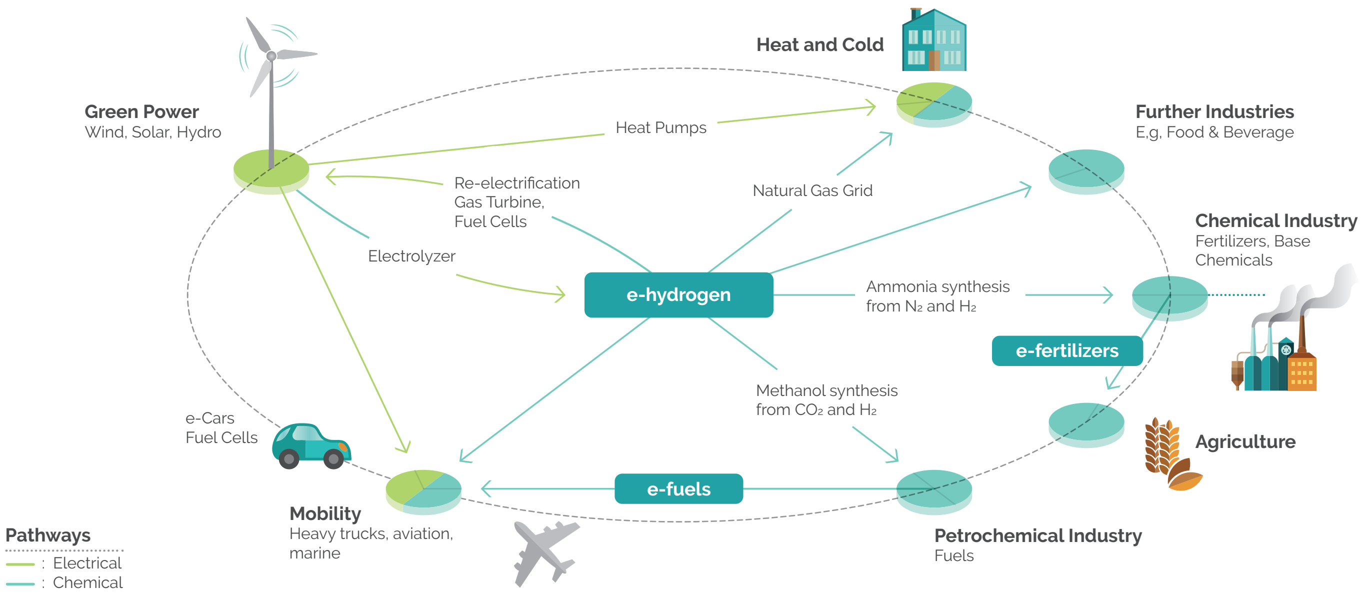



***Figure 1:** The role of hydrogen in sector coupling | **Source:** Siemens 2019.*

Carbon-rich fuels like petroleum, gas, and coal have had a success story due to several advantages: a wide range of use, high energy density, easy to transport and store,[4] but present a massive downside related to its impact on the environment as the main contributor the global warming. 2020 seems to be a turning point, with the most profound crisis in the history of the oil & gas industry and finally an accelerated drive towards zero-carbon solutions globally. This year we have seen a historic drop in oil & gas prices, even to a negative level, due to the geopolitical factors, combined with the global pandemic, which decreased the energy consumption globally in an unprecedented way. In the broader context of climate change incumbent targets, NOCs and IOCs have been facing the necessity to create a future proof business model by diversifying their portfolio, such as Total, Saipem or ENI Group, that have all created their renewable energy and hydrogen divisions ('New Energies'), most often as independent operational arms.

3 Appunn, K., "Sector coupling - Shaping an integrated renewable energy system." Clean Energy Wire. 25th April 2018. Available at: https://www.cleanenergywire.org/factsheets/sector-coupling-shaping-integrated-renewable-power-system.

4 Pflugmann, F., De Blasio, N., "Geopolitical and Market Implications of Renewable Hydrogen New Dependencies in a Low-Carbon Energy World." Environment and Natural Resources Program Belfer Center for Science and International Affairs Harvard Kennedy School. Report 2020. Available at: https://www.belfercenter.org/publication/geopolitical-and-market-implications-renewable-hydrogen new-dependencies-low-carbon.

Today, hydrogen is still largely produced by steam methane reforming (SMR) with the main users being in the petrochemical/fertilizer industry. Finally, it reveals its potential to fight climate change, where it could play a significant role as a sustainable energy carrier. Hydrogen is not an energy source but can deliver or store a large quantity of energy for extended periods at lower costs than electricity [5] but must be produced from another substance, water, fossil fuels or biomass among others,giving to hydrogen its color.

## 2.2 The Colors of Hydrogen and Applications

Currently, 96% of hydrogen is produced from fossil fuels via carbon-intensive processes either by Steam Methane Reforming (SMR) without Carbon Capture, Utilization, and Storage (grey hydrogen) or coal gasification (black hydrogen). The GHG emissions and approach in the production process give hydrogen its color.

**Green hydrogen** is produced through the electrolysis of water in an electrolyzer, powered by electricity produced from renewable sources such as hydro, wind or solar. Provided that the inputs of electricity only come from renewable energy sources (and if desalinated water needed, powered 100% by solar and wind), the GHG emissions during the production process are equal to zero.

**Grey hydrogen** production uses natural gas while **Black hydrogen** uses coal as a primary source. The transformation process, called Steam Methane Reforming (SMR) uses oxygen from water steam in a heat chamber to separate methane ($CH_4$) and produce $H_2$. However, the process remains highly pollutive as it generates >9kg of $CO_2$ for every kilogram of hydrogen produced.[6]

**Blue hydrogen** follows the same process as grey hydrogen, but the carbon emitted during production is captured with a CCUS process to reduce $CO_2$ emissions. The EU's framework refers to blue hydrogen as fossil-based hydrogen with carbon capture.

**Yellow hydrogen** is obtained by electrolysis from the electric energy of mixed origin that could be from nuclear or waste-to-hydrogen. Also, it could be via gasification of waste.

**Turquoise hydrogen** uses natural gas or biomass as energy input via pyrolysis to produce hydrogen in an endothermic process while solid carbon is obtained as a by-product. While pyrolysis for biomass is a relatively dirty process from an environmental point of view, the pyrolysis process via natural gas can be interesting, provided that the energy comes from renewable sources.[7]

*Green hydrogen*, in opposition to other colors, has a key role to play in the energy transition and can decarbonize hard-to-abate sectors. As an example with a big global impact for the steel production to replace coking coal in the direct reduction process;[8] it can be used in refineries as a main

5 F. Pflugmann, N. De Blasio, Geopolitical and Market Implications of Renewable Hydrogen New Dependencies in a Low-Carbon Energy World. Environment and Natural Resources Program Belfer Center for Science and International Affairs Harvard Kennedy School. Report 2020.

6 Duignan, A., Simonitsc, T. (2020). US Machinery Hydrogen 101. North America Equity Research. JP Morgan. According to other sources even 10-11kg of $CO_2$ for every kilogram of hydrogen produced.

7 Megret O., Hubert l., Calbrytrably M., Carrere, H., Garcia-Bernet D., Bernet, N., Production d'hydrogène à partir de déchets. État de l'art et potentiel d'émergence. Rapport Final 2015. Record.

8 Most of the leading steel producers, like thyssenkrupp, Salzgitter or Voest Alpine have successful pilot projects for this purpose.

consumer of hydrogen to replace step by step grey with green one, in the mobility sector for longer haul solutions like fuel cells buses,[9] trains,[10] or even ships. Industrial heat applications can also play an important role. The more long-term applications may concern sectors such as heating and cooling for residential use or power generation (to blend with gas in CCGTs or turbines running 100% on hydrogen). Today, about 55% of the hydrogen produced around the world is used for ammonia synthesis, 25% in refineries and about 10% for methanol production. The remaining applications worldwide account for only about 10% of global hydrogen production.[11] It has to be noted that approximately two thirds of hydrogen is produced on site for captive use, hence no transport is required and no market or transparency on prices existing.

Furthermore, hydrogen has a wide range of applications today and green hydrogen could take over completely in the long term to support the decarbonization process.

9 A large number of municipalities, particularly in Europe, already have fleets of fuel cell buses operating.

10 The first fuel cell train has been operating in Germany since 2019. Recently, a fuel cell train has been put in operation in Austria and the French national train group SNCF has placed orders for fuel cell trains.
Available at: https://www.cnbc.com/2020/09/14/in-austria-a-hydrogen-train-is-set-to-travel-on-challenging-routes-.html.

11 Hydrogen Europe. "Hydrogen in Industry".
Available at: https://hydrogeneurope.eu/hydrogen-industry.

## 3.1 The Role of Hydrogen in the Global Energy Transition

The main trends of the energy transition are the accelerated deployment of emission-free technologies, the digitalization of energy processes and the decentralization/democratization made possible by RE. What role can hydrogen play in the interdependent energy transition of the global economy? Green hydrogen is the missing link to the decarbonization of all sectors. Hydrogen has the potential to become the fuel molecule that powers a clean global economy . It can be used as a substitute for fossil fuels as clean industrial feedstock in a large variety of applications – from heavy transport to steel making – and produces no pollution at the point of consumption. Being a CO2-free energy carrier, H2 is clean, sustainable and flexible: it can be transported over long distances and it has high energy when compressed or liquefied; it produces clean power and fuel and it has safety similar to natural gas or petroleum . Hydrogen is expected to meet from 24% of the world energy needs by 2050 with an annual sale of H2 worth of USD 700 billion and billions more in sales of end-use equipment .More bullish and very recent estimates foresee an addressable global market of up to USD 11.7trillion, calling it a "once in a lifetime opportunity" (Goldman Sachs, September 2020).

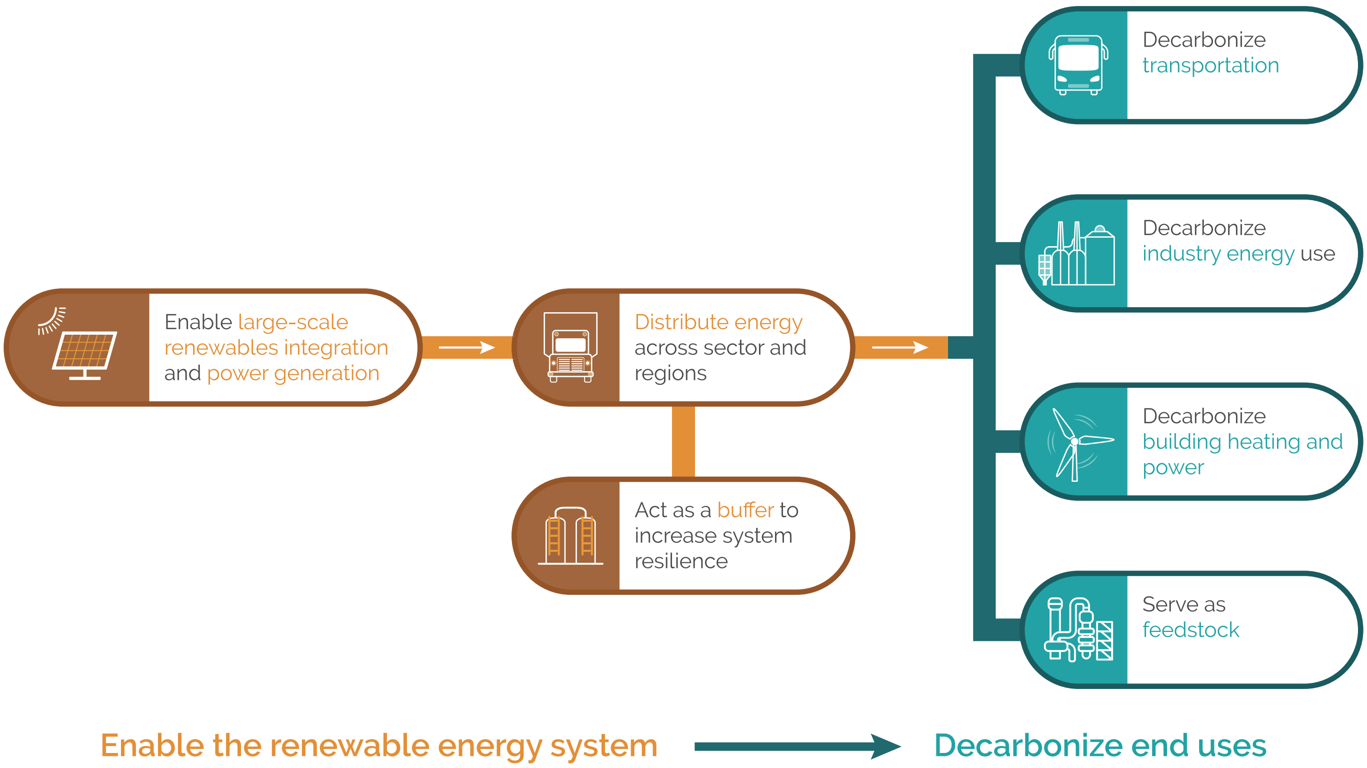



*Figure 2: Hydrogen applications and decarbonization | Source: Hydrogen Council*

12 Dii Desert Energy (2020). Corporate presentation.

13 Dii Desert Energy (2020). Corporate presentation.

14 Bloomberg New Energy Finance (2020). Hydrogen Economy Outlook. Available at: https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf.

15 https://www.barrons.com/articles/goldman-sachs-says-so-called-green-hydrogen-will-become-a-12-trillion-market-heres-how-to-play-it-51600860476.

However, the path towards a global market for green hydrogen is not only dependent on the evolution of technical and economic factors - hydrogen's source, handling, shipping, the overall cost/kg- but also political choices along the value chain. From each alternative, both winners and losers [16] will emerge and re-shuffle the balance of power's cards by creating new dependencies between states. Countries with very cheap solar and wind sources might well emerge as global hubs for production, storage and transport of green molecules, and arbitrage between other markets, somehow similar to the LNG.

In its recent report, The Belfer Center [17], scales countries' renewable hydrogen potential considering three parameters and classifies them in key players categories based on their availabilities of resources (wind, solar, water) and the quality of their infrastructures to produce, transport and distribute hydrogen.[18] The report highlights the position of Morocco and Australia as potential export champions as they are rich in water and renewable energy resources and possess the clear capacity to deploy the required infrastructure.[19]

Along with Morocco and Australia, MENA countries in general and Gulf countries in particular, could emerge as well, as main key players in the transition. In fact, even though most gulf countries are already planning to shift from fossil to a green economy via different governmental plans, only too few projects are emerging, and the plans could be bolder and quicker in certain countries. In case the big oil & gas producers do not embrace big change in this historic crisis of the energy sector, their relevance and stability might be at stake.

In the eastern Mediterranean, Cyprus and Greece could be the potential winners, if not for production, but hydrogen transit. Indeed, the East-Med pipeline deal signed in January 2020 between Israel, Cyprus and Greece [20] could decrease the role of Turkey and CIS countries and place e.g. southern Mediterranean countries higher up on the energy's power scale.

## 3.2 International Partnerships: EU, Germany, France

National hydrogen strategies have been flourishing worldwide. Japan was the first country in 2017, followed by South Korea, New Zealand, and Australia in 2019. Japan has already developed some international partnerships on green hydrogen, e.g. with Australia or Brunei. The Netherlands, Austria, Norway, Portugal, Germany,and France made their announcements throughout 2020. In June 2020,

16 Van de Graaf, T., Overland I., Scholten D., Westphal, K., The new oil? The geopolitics and international governance of hydrogen. Energy Research & Social Science 2020 Dec; 70: 101667. Published online 2020 Jun 30. doi: 10.1016/j.erss.2020.101667.

17 Pflugmann, F., De Blasio, N., "Geopolitical and Market Implications of Renewable Hydrogen New Dependencies in a Low-Carbon Energy World." Environment and Natural Resources Program Belfer Center for Science and International Affairs Harvard Kennedy School. Report 2020.
Available at: https://www.belfercenter.org/publication/geopolitical-and-market-implications-renewable-hydrogen-new-dependencies-low-carbon.

18 The five key players categories: 1. Export champions with high resources and infrastructures, 2. Renewable rich but water constrained with high infrastructures; 3. Renewable constrained with high infrastructures; 4. Resources rich with high infrastructures; 5. Resources rich with poor infrastructures.
Available at: https://www.belfercenter.org/publication/geopolitical-and-market-implications-renewable-hydrogen-new-dependencies-low-carbon.

19 Ibid.

20 "Israel, Greece and Cyprus sign deal for EastMed gas pipeline". Euronews. 2 January 2020.
Available at: https://www.euronews.com/2020/01/02/israel-greece-and-cyprus-sign-deal-for-eastmed-gas-pipeline.

the German Federal government has adopted a EUR 9 billion National Hydrogen Strategy, of which EUR 7 billion are dedicated to the market ramp-up of hydrogen technologies in Germany and a further EUR 2 billion allocation for international partnerships. The construction of projects in Morocco and other developing economies as well as helping with required studies to lay the foundation for first projects are the key pillars of this strategy. On 14th September 2020, the French government presented its national hydrogen strategy, providing an investment of EUR 7.4 billion by 2030 with an investment of EUR 1.5 billion in electrolysis plants and a targeted electrolyzer capacity of 6.5 GW by 2030. Only with the German and the French strategy together, EUR 16 billion are earmarked for hydrogen projects, and both countries look at the MENA region as 'natural' partner.

In Europe, building a hydrogen economy has been started with the "Green Deal" launched by the new EU Commission in place since December 2019, pledging to become the first carbon-neutral continent by 2050. The plan sets up an ambitious target to be reached already by 2030: at least a 50% cut in greenhouse gas emissions (from 1990 levels), boosting the share of renewable energy and deployment of a wide range of energy efficiency measures. To reach this goal, the EU counts on strong partnerships with neighbouring countries to build a sustainable market for hydrogen with a breadth of applications and path: elaborating a legal framework, scaling up the technology, re-purposing existing gas pipelines and developing the required infrastructure. On 8th July 2020, Frans Timmermans, the Executive Vice-President of the European Commission in charge of the European Green Deal, and Kadri Simson, Commissioner for Energy, have announced the EU Hydrogen Strategy. Green hydrogen is one of the top priorities in the energy transition, as it will help to reach faster and more complete decarbonization of our economies. International partnerships, especially with North Africa, have been declared as crucial to make this vision a reality.

As an example, member States must require fuel suppliers to supply a minimum of 14% of the energy consumed in road and rail transport by 2030 as renewable energy.[21] As this will translate into national law, unprecedented pressure is building in identifying all possible opportunities to reduce the carbon footprint. Steel plants already show with pilot projects how coking coal could be eventually completely substituted by hydrogen. Eventually, climate-neutral steel could be produced with green hydrogen from the MENA region, with every steel plant along requiring GW equivalent capacity. Refineries could substitute more and more grey with green hydrogen.[22] The chemicals industry could use green molecules to replace 'grey' with 'green' ammonia for fertilizers. Many other opportunities outlined in the first part about different hydrogen applications would in any case present a huge opportunity to forge a close partnership with Europe as a major off taker of green molecules. The European Hydrogen Strategy published on 8th July 2020[23] outlines that a significant part of Europe's hydrogen needs will need to be imported and that MENA could be an important partner for this.[24]

The hydrogen diplomacy already started with success since both Morocco and Oman are already partnering with European countries in the production of green hydrogen. Morocco and Germany

**21** European Commission (2019). Renewable Energy – Recast to 2030 (RED II).
Available at: https://ec.europa.eu/jrc/en/jec/renewable-energy-recast-2030-red-ii.

**22** An example for this is the Westkueste 100 Project
Available at: https://www.westkueste100.de/en/.

**23** European Commission, "A hydrogen strategy for a climate-neutral Europe", Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Brussels, 8 July 2020, COM (2020) 301 final.
Available at: https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf.

**24** See also 2X40 GW Initiative by Hydrogen Europe and Dii Desert Energy, whose core concept was adopted in the European Hydrogen Strategy.
Available at: https://dii-desertenergy.org/wp-content/uploads/2020/04/2020-04-01_Dii_Hydrogen_Studie2020_v13_SP.pdf.

have particularly close ties and they announced in June 2020 the "Power to X project of 100 MW electrolyzer capacity",[25] while different stakeholders in Oman and the Belgian leader DEME, are developing "Hyport Duqm",[26] a large scale green hydrogen plant in Oman. (Further detailed under the chapter on Morocco and Oman).The most advanced project is clearly the mega project announced by NEOM, ACWA Power and Air Products in July 2020 (for more details, see annex III).

The combination of Europe being a large potential buyer of green molecules from MENA and the availability to support first projects financially, which is needed to bridge the gap between the today still more expensive green and conventionally produced hydrogen, provides an opportunity for the MENA region to start developing first green hydrogen projects. The opportunity is not only to generate new export revenues, but also for local markets green molecules will be in high demand. While many jobs have already been created for solar and wind projects - and this will grow even more with green hydrogen projects - the value chain for the production, storage and conversion of green hydrogen is much longer and more complex. In addition, on a variety of applications, there will be a chance to create many new jobs, creating increased growth and prosperity in the MENA region.

**25** "Project «Power to X» : La mise en œuvre s'accélère ». Finances News. 23 June 2020.
Available at: https://fnh.ma/article/developpement-durable/projet-power-to-x-la-mise-en-oeuvre-s-accelere.

**26** "Deme and partners present Hyport®duqm, a large-scale green hydrogen project in Oman".
Available at: https://www.deme-group.com/news/deme-and-partners-present-hyportrduqm-large-scale-green-hydrogen-project-oman-1.

Following a massive boom over the last decade, we have seen a huge increase in the installed capacity of solar and wind projects in the MENA region of over 10 GW.[27] Most importantly, the tariffs for solar PV and wind projects for utility-scale projects are in the range of 1-3 USD cents/kWh,[28] thus significantly outperforming fossil/conventional generation. High capacity factors for wind projects in countries such as Morocco, Egypt, Saudi Arabia or Oman present interesting business cases even for wind only green hydrogen projects. The conditions are similar to off-shore wind in Europe, just with the difference that here we speak about much cheaper onshore projects with sites often well located close to the sea. This is complemented by proximity to Europe, including existing infrastructure, such as gas pipelines or HVDC lines under the Mediterranean. Particularly with the recent momentum in installations, it is safe to say the energy transition in the MENA region is already in full force. Would green hydrogen projects potentially detract the countries from their core mission to boost the installed capacity of renewable energy?

Dii believes that green molecules are an opportunity to even accelerate the energy transition. Provided that the hydrogen is green, installed capacities of solar and wind will rise further. Green hydrogen from a system point of view can be seen as a tool to integrate a larger percentage of RE. Curtailed electricity, such as of wind parks with weak grid connection or solar PV, could be made use of and seasonal storage - best in underground rock formations [29] - and could help to bridge gaps between winter and summer local power demand. For storage, hydrogen does not compete with batteries, but rather complements with longer-term applications and very large amounts of energy to be stored. Indeed, with utility-scale off-grid green hydrogen projects, an entirely new and potentially very large market segment could develop next to on-grid RE projects.[30]

## 4.1 Ecological Implications

### 4.1.1 Water, Land Use for Renewables, Infrastructure and Others

Electrolysis typically requires approx. 4m$^3$/day (24h) of purified water or 6m$^3$/day of raw, unpurified water per 1 MW of electrolysis.[31] Generally, the options to source water are from existing desalination,[32] ground water (not viable for public acceptance and scarcity), sewage water (according to manufacturers, generally possible, but likely more costly to treat than produce newly desalinated water). There is the possibility to use seawater directly without desalination, but this is only in R&D stage today.[33] Smaller reverse osmosis desalination plants flexibly close to the generation

27 Dii Desert Energy Project Database.

28 Dii Desert Energy database with tenders. Lower end countries like UAE or KSA, higher end Egypt, Jordan, Tunisia, Morocco. Tariffs in Oman not public.

29 Van Wijk, A., Wouters, F., Rachidi, S., & Ikken, B. (2019, November). A North Africa - Europe Hydrogen Manifesto. Available at: https://dii-desertenergy.org/wp-content/uploads/2019/12/Dii-hydrogen-study-November-2019.pdf.

30 According to some experts, in certain countries, off-grid RE projects for green hydrogen could be larger than all on-grid projects combined.

31 ILF Consulting Engineers.

32 In practice not viable as discussed with ACWA Power due to existing supply agreements and limits in capacity as most desalination plants rather need to expand further.

33 Dresp, S., Dionigi, F., Klingenhof, M., Strasser, P. Direct Electrolytic Splitting of Seawater: Opportunities and Challenges (2019). Available at: https://pubs.acs.org/doi/abs/10.1021/acsenergylett.9b00220.

site, provided close to the sea in our view provide the most suitable and realistic pathway. Some overcapacity might even benefit local communities, which could be seen as an important factor for socio-economic development. It must be noted that the cost of water ranges from less than 1% to a maximum of less than 2% (under unfavorable conditions with very expensive water) in the overall business case. Hence, it is not a key factor from an economic point of view, but an important consideration for site selection and for green hydrogen, the energy for the reverse osmosis plants shall come from renewable sources.

Apart from water, other environmental implications need to be considered carefully, e.g. the typical challenges with land use as for solar and wind generation projects (land use is an important challenge, both from an environmental and social point of view, but given the vast, uninhabited deserts, less of an issue than in other countries – however topography can be a limit particularly in Oman), the challenges for new infrastructure like pipelines and in general the explosive nature of hydrogen as well as hazardous effects of green molecules such as ammonia or methanol. However, given that e.g. ammonia is transported around the world already today, there are well-established international health & safety standards in place. The general problematic for producing hydrogen (all other than green colors) shall be mentioned as well. Specifically, the long-term implications of storing huge amounts of $CO_2$ underground seem a point to put adequate emphasis during CCUS projects. In addition, the use of $CO_2$ for enhanced oil recovery cannot be considered a viable means of storage, as a significant amount of $CO_2$ is again released. Other forms than green hydrogen shall also not be taken as an excuse to delay the core energy transition towards emission-free technologies.[34]

## 4.2 Opportunities: The Costs of Green Hydrogen, Local Value Chain and Social Stabilities

### 4.2.1 MENA to Become a Cost Leader and Global Powerhouse

According to Bloomberg New Energy Finance (BNEF), green hydrogen for large projects costs between USD 2.5-4.5 per kg today.[35] The IEA estimates the price of grey $H_2$ production at USD 1-1.80/kg and blue hydrogen at USD 1.40-2.40 per kg [36] (note that these estimates were before the drop of the gas prices in March/April 2020, hence today's prices are probably significantly lower due to the sensitivity to the gas prices). Dii has also researched the levelized cost of producing green hydrogen (LCoH). Dii worked on the development of an innovative financial model toolkit to support stakeholders in understanding LCoH calculations and more importantly its sensitivity to various capex and opex scenarios foreseen in MENA region. Such toolkit is a valuable means for studying the competitiveness of green hydrogen production opportunities in MENA in a qualitative and quantitative approach (please refer to Section 8.0 for LCOH financial model toolkit description).

Based on an assumed electricity cost of 2 USD cents per kWh and an assumed plant capacity factor of 60%, then approximately half of the hydrogen production cost is the cost of electricity, while one third comes from the CAPEX and less than one fifth from OPEX for the electrolyzer plant. As for CAPEX, a significant cost reduction is expected over the next years. A sufficient capacity factor of

34 E.g. for blue hydrogen, methane leakage when producing natural gas is still a huge problem, as well as the unknown long term effects of injecting and storing $CO_2$ underground.

35 Bloomberg New Energy Finance (2020). Hydrogen Economy Outlook. Available at: https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf.

36 International Energy Agency (2019). The Future of Hydrogen. Seizing today's opportunities.

best >50% is an important factor for the business case. With a high combined capacity factor of solar and wind generation and among the world's lowest LCoE, the MENA region today can potentially produce a kg of green hydrogen at below USD2 per kg.

**NEOM's mega project for green ammonia** [37] targets to produce green hydrogen at even around USD 1.5 per kg, once it will be operational in 2025 (for more details, see annex III). A flexibly designed facility to convert hydrogen to ammonia via the Haber-Bosch Process can contribute to bring down the capex for storage facilities. This bold and pioneering project announced in July 2020 can well be seen as a catalyst for more green hydrogen projects not only regionally but globally. This shows that MENA could well emerge as a global cost leader in the production of green hydrogen, following a series of world record low wind and solar prices over the last years. Apart from the production cost, the cost of transport to international markets needs to be considered. In case e.g. hydrogen will be transported to Europe, a very rough USD2.00 per kg needs to be added. However, this cost is more derived from the conversion (and back for ammonia and LOHC), e.g. from hydrogen to ammonia, LOHC or to liquefy, rather than the pure cost of transport. Depending on geographic locations, transport route type and total distance, transport by pipeline is expected to be the winner, costing a fraction of this. Indeed, existing gas pipelines could be reused/repurposed (e.g. with new compressors) from natural gas to hydrogen use at limited costs.13% of Europe's gas imports come via the already existing infrastructure under the Mediterranean Sea.[38] Mid-term, conversion to ammonia via the Haber Bosch Process seems to be the choice for now. Other forms like liquefying the hydrogen, using liquid organic hydrogen carriers (LOHC) or converting to e-fuels are also considered. We believe the question of the right option and form of transport will be among the key issues to be resolved – together with the creation of the right conditions in Europe for import (legal and regulatory framework).

While all MENA countries could generate significant amounts of export revenues for the sale of green molecules to world markets, fossil fuel importers have an additional chance to reduce their import bill much more than they could have dreamt of just some years ago.

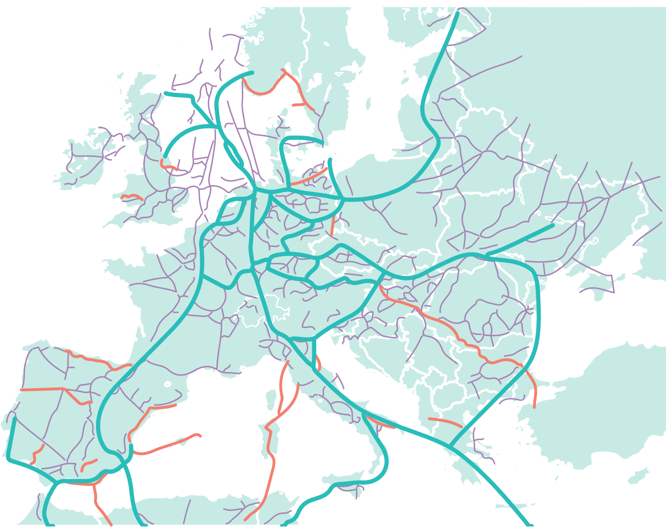


*Figure 3: European Transnational Hydrogen Backbone*

The red and purple lines refer to the existing natural gas infrastructure in Europe, whilst the teal lines outline the future hydrogen backbone infrastructure connecting the Iberian Peninsula, Italy, Greece and the Black Sea.

*Source: Van Wijk, A., Chatzimarkakis, J., (2020). Green Hydrogen for a European Green Deal. A 2x40 GW Initiative, page 15.*

37 "Air Products, ACWA Power and NEOM sign agreement for USD5 billion production facility in NEOM powered by renewable energy for production and export of green hydrogen to global markets", ACWA Power, 8th July 2020 Available at: https://www.acwapower.com/news/air-products-acwa-power-and-neom-sign-agreement-for-5-billion--production-facility-in-neom-powered-by-renewable-energy-for-production-and-export-of-green-hydrogen-to-global-markets/.

38 Wijk, A., Wouters, F., Rachidi, S., & Ikken, B. (2019, November). A North Africa - Europe Hydrogen Manifesto. Available at: https://dii-desertenergy.org/wp-content/uploads/2019/12/Dii-hydrogen-study-November-2019.pdf.

### 4.2.2 Local Value Chain

Apart from the value of green hydrogen to integrate more renewable energy into the power system, the variety of applications offers interesting possibilities to create local hydrogen economies. The successful concept of Hydrogen Valleys [39] in Europe might well serve to transfer and test some of these ideas in the MENA region. On different parts of the value chain, there might be synergies with existing industries on the manufacturing side and to create a significant amount of new jobs in future industries. Given the breadth of the value chain and applications, the potential for new jobs is certainly much higher than for all renewable technologies and could rival the number of jobs in the oil & gas industry long term and help to mitigate job losses of this industry that will decline necessarily in time. Like for RE 5-10 years ago, it must be ensured that there is a level playing field to enable business cases for local off-take as well (i.e. eliminating fossil fuel subsidies and pointing on the value of green hydrogen).

### 4.2.3 Hydrogen as the Bridge Between Africa and Europe

The opportunity for MENA to become a much closer partner for Europe is unique and the current setting could not be more favorable. Frans Timmermans made supportive statements in speeches before to taking his current role: "In my dreams, I would create a partnership with North-Africa and we would help and store huge capacity of solar energy in Africa and transform that energy into hydrogen and transport that hydrogen to other parts of the world and Europe through existing means we already have. (..) This is my dream of the future energy".

In Europe only, the hydrogen strategy plans to reach at least 6 GW of electrolyzers by 2024 and 40 GW of electrolyzer capacity by 2030. Simultaneously, the 2x40 GW Initiative policy orientation paper anticipates a roadmap for 40 GW electrolyzed capacity in North Africa and Ukraine by 2030, including 7.5 GW electrolyzer capacity for the domestic market and 32.5 GW for export. The North Africa-Europe Hydrogen Manifesto foresees that the future final energy mix in Europe could have a 50% - 50% share split of green electricity and green hydrogen for all sectors: industry, transport, commercial and households. By 2030, the EU Commission estimates that EUR 13-15 billion could be invested in electrolyzers across the EU, in addition to EUR 50-150 billion for a dedicated wind and solar capacity of 50-75 GW.

Green molecule trade will benefit both regions: in Europe, it will help meeting the decarbonization targets, improve energy security and support technology leadership. In North Africa, it will drive forward economic development, boost export, create green jobs and support social stability.[40] With hydrogen potentially being the new oil, a broad diversification of supply will of course still be imperative from a geopolitical point of view.

39 This concept has been promoted by the EU and has been successfully integrated in countries like Germany, the Netherlands or France.

40 Van Wijk, A., Wouters, F.,(2019). "Hydrogen: the bridge between Africa and Europe." Available at: http://profadvanwijk.com/wp-content/uploads/2019/09/Hydrogen-the-bridge-between-Africa-and-Europe-5-9-2019.pdf.

## 5.1 Morocco

Morocco has an outstanding RE track record with world-class wind and solar sources in optimal locations, robust existing infrastructure, electrical interconnections and even a gas pipeline to Europe. Nonetheless, the country is North Africa's largest energy importer.[41] Green hydrogen is an opportunity for Morocco to achieve a low carbon economy with many new jobs and at the same time strengthen energy security, reducing the import bill. The country has already taken some important steps to kick-start a green hydrogen economy- for the domestic market as well as for export to Europe - in terms of policy development and pilot projects.

Morocco is the only North African country with almost no oil and gas resources and therefore, the Kingdom heavily relies on the import of fossil fuels. The dependence on energy imports has important implications in terms of energy security and its economy. Referring to the energy balance of Morocco for the year 2018, fossil fuels (coal, oil and natural gas) accounts for almost 88% of total primary energy supply (TPES)[42] and around 80% in electricity production.[43] The energy import bill is evaluated to around EUR 7.58 billion in 2018 and to EUR7.03 billion in 2019.[44] In terms of petroleum products, the subsidies are estimated around EUR 0.92 billion in 2019.[45] The country's energy import bill has been reduced for two factors over the last years: lower prices of fossil fuel and higher share of renewable energy in the energy mix.

Morocco is the only country in MENA relying heavily on coal for power generation, which currently accounts for 38.5% installed capacity in 2019.[46] It represented 67%of electricity generation in 2019.[47] Ten years ago, Morocco started a cross-sectoral renewable energy and energy efficiency program to meet the growing energy demand and the climate change targets, whilst reducing the expensive fuel import bill and secure energy independence. By 2030, Morocco is set to increase its share of renewable energy installed capacity from 42% to 52%. In the frame of an ambitious energy transition strategy, Morocco has undertaken RE projects worth USD 30 billion and committed to developing the energy sector to a value of USD 40 billion.[48]

Larger opportunities are needed to accelerate the energy transition and decarbonize the industrial and mobility sectors. Green hydrogen is a technological solution, which will enable the Kingdom to

41 "Installed capacity rising to meet Morocco's growing energy demand", Oxford Business Group. Available at: https://oxfordbusinessgroup.com/overview/installed-capacity-rising-meet-moroccos-growing-energy-demand.

42 According to the International Energy Agency energy balance format, TPES refers to the total primary energy supply, i.e. gross domestic consumption excluding international bunkers (international maritime bunkers and international air transport)..

43 Direction of Observation, Cooperation and Communication, Ministry of Energy Mines and Environment of Morocco.

44 Provisional data of statistics exchanges, source: calculation based on data of Exchange Office in Morocco. Direction of Observation, Cooperation and Communication, Ministry of Energy Mines and Environment of Morocco.

45 Data of national accounts, High Commissioning for Planning.Direction of Observation, Cooperation and Communication, Ministry of Energy Mines and Environment of Morocco.

46 Source: calculation based on Electricity activity Data of Office National de Electricité et de l'Eau Potable (ONEE).

47 Ibidem.

48 Official website of the 'Observatory' of the Ministry of Energy, Mines and Environment. Available at: https://www.observatoirenergie.ma/en/.

decarbonize the production of fertilizers, substituting the current imports of around 2 million tons [49] of grey ammonia per year with green ammonia, or approximately USD 500 million equivalent of ammonia imports per year.[50] To produce 2 million tons of ammonia, via a mix of solar and wind energy, it would require an installed capacity of approximately 6 GW and local stakeholders suggest that subsidies or a premium on green ammonia may help to make the local production of green ammonia viable. The Kingdom has strong industrial assets, particularly OCP Group: one of the leading exporters of phosphate rock, phosphoric acid and phosphate fertilizers in the world, that currently accounts for 20% of the national energy consumption [51] and around 5% of total GDP. Also, an interesting synergy refers to the hydrogen application in the mobility sector. Over the last ten years, the automotive sector in Morocco grew exponentially to become today one of the main automotive markets in Africa with a turnover of around EUR 7 billion. In fact, approximately only 10% of the production is used in the domestic market and 90% exported to Europe and the MENA region. The largest manufacturing plant on the continent with a capacity of 400,000 cars per year was built by Renault in Morocco [52] and the second largest player is Peugeot that has been active in Morocco since 2018. Another example is the aircraft industry, which developed from zero to approximately EUR 1.5-1.6 billion last year. These trends had a positive impact in terms of local job creation, industrial development and socio-economic growth.

Morocco has the perfect conditions for renewable energy deployment in terms of wind and solar resources with sites close to the sea. Some experts of the local ecosystem estimate a very high combined capacity factor up to 70% from wind in some of the optimal locations and 25-30% from solar PV only. The ideal location of these resources allows to deploying facilities to desalinate the water required for electrolysis. Desalination is also an opportunity as local communities can benefit from the higher availability of drinking water. The Southern regions where the good wind and solar site are located, face water scarcity more than the North. As of today, there is only one water desalination plant in operation and a second plant is under construction in Agadir region;[53] hence, further development of desalination capacities would be a crucial element of socio-economic development in the country.

The Government of Morocco has been undertaking actions to elaborate and finalize the "Hydrogen Roadmap" for the Kingdom. This initiative has been steered by the National Commission on Green Hydrogen [54] from the Minister of Energy, Mines and Environment, Aziz Rabbah. Within this National Commission, there will be efforts and further studies to improve the legal framework and regulation, which are considered a prerequisite in order to make Morocco more attractive for national and foreign investments in the hydrogen sector. The priority is currently to finalize the roadmap and as second step, there will be in-depth studies carried out by the relevant working groups.[55] Thanks to a stable political environment, a vibrant clean energy strategy and a transparent legal framework, the country

49 Engelhardt, M., "Morocco-to-X: Badr Ikken and his team at IRESEN plan to transform the country into a hub for e-Fuels", Siemens Energy, 23rd April 2020. Available at: https://www.siemens-energy.com/global/en/news/magazine/2020/power-to-x-morocco.html.

50 Morocco is among the top importers and in 2018 imported USD 424 million. Available at: https://trendeconomy.com/data/h2/Morocco/0810.

51 International Energy Agency, Morocco Outlook, 2019, p. 56.

52 Black, A., Makundi, B., McLennan T., Africa's Automotive Industry: Potential and Challenges. African Development Bank. Available at: https://www.afdb.org/fileadmin/uploads/afdb/Documents/Publications/WPS_No_282_Africa%E2%80%99s_Automotive_Industry_Potential_and_Challenges.pdf.

53 Coukri, J. Station de dessalement d'Agadir: voici où en est ce méga projet, 20 February 2020, Media24. Available at: https://www.medias24.com/station-de-dessalement-d-agadir-voici-ou-en-est-ce-mega-projet-7768.html.

54 The National Commission was originally called 'National Commission on Power to X', the denomination was then changed end of summer 2020.

55 See Annex II for further information.

is widely qualified to play an important role in the green hydrogen market. Furthermore, the country's vision is to become a regional hub for power trading and potentially also for green molecules.[56] Once local needs are satisfied, Morocco's ambition is to become a key player in the export of different forms of green energy, thanks to its geographic position as the crossroads between Europe, Africa and the Middle East, as well as the existing logistics and energy infrastructures that link Morocco to Europe. Morocco is indeed connected to Spain via the Maghreb-Europe gas pipeline from Algeria. The long-term gas supply agreements will expire by 2021, which may open new opportunities as this pipeline could be converted and used for the export of green hydrogen blended with gas up to 15%.[57] The Tangier-Mediterranean port (Tangier-Med) is strategically located at the entrance to the Mediterranean with direct sea connections to 186 ports and seventy-four countries.[58] In 2019, it was ranked in the top 40 well connected ports worldwide, hence a perfect logistics hub to ship hydrogen at the gateway to Europe.[59] Jorf Lasfar is the port where OCP imports its ammonia and exports fertilizers, and therefore already operational, whilst Agadir may also consider set up chemical port facilities. However, the best sites for high-capacity factor for hydrogen production will be in the South of the country, and therefore ports and new logistics infrastructures may be required to be developed in the Southern regions.

In terms of pilot projects, as stated by the Direction of Observation, Cooperation and Communication of the Ministry of Energy Mines and Environment of Morocco *"An important step is the signing of the declaration of intention for the development of the Power To X sector in Morocco with the Federal Ministry of Economic Cooperation and Development of Germany (BMZ). The first Moroccan project requests have been submitted, the feasibility of which will have to be examined in detail in consultation between the partners. A project request concerns the "Power to X" reference project proposed by the Moroccan Agency for Sustainable Energy (MASEN) in order to produce" green "hydrogen on an industrial scale. Another request from the Moroccan Institute for Research in Solar Energy and New Energies (IRESEN) aims to set up a platform for applied research on "Power to X", knowledge transfer and strengthening of existing capacities: The Green Hydrogen and Applications Platform (Green H2A)."*

In conclusion, there is a strong political will led by the Ministry of Energy, Mines and Environment, to produce green hydrogen for the domestic market and to export to the European market. In the context of the EU Green Deal, the export component is a top priority for the country, as it will help create a critical industrial mass in Morocco for Power-to-X. In the short-medium term, experts foresee approximately 70 to 90% for exports and 10 to 30% for the domestic market. The development of a local value chain of hydrogen shall support Morocco's ambition to become a hub in the Maghreb region, which will consequently lead to green job creation as well as socio-economic and industrial development. (More information about the Government of Morocco's green hydrogen strategy in the Annex).

**56** Conclusion of the National Committee on "Power to X", which took place on 30th March 2020. Available at: https://mem.gov.ma/Pages/actualite.aspx?act=150.

**57** L'Office Nationale des Hydrocarbures et des Mines (ONHYM) is in charge of all gas infrastructures aspects within the National Commission on Green Hydrogen.

**58** Official website of TangerMed. Available at: https://www.tangermed-passagers.com/index.php/fr/trafic-au-port-tanger-med-premier-semestre-2017.

**59** TangerMed, 1 September 2020. Available at: https://www.tangermed.ma/en/tanger-med-35eme-port-a-conteneurs-au-monde-en-2019/.

## 5.2 Jordan

Together with Morocco and both being Kingdoms, Jordan has been the pioneer in developing renewable energy in the MENA region over the last ten years. An early accelerator has been the fact that no gas was delivered by Egypt via the Arab gas pipeline anymore, leading to extremely high electricity prices and a need to urgently diversify the generation mix. Jordan managed to decrease the tariff for solar PV in an impressive manner. From a 200 MW bidding round in 2013 when prices were USD 16.9 cents/kWh, prices went down to between USD 6-7 cents/kWh in 2015 and eventually around USD 2.5 cents/kWh in 2019![60]

Even though the projects suffered several delays and management by the Ministry of Energy and Mineral Resources (MEMR) could have been improved in certain cases, by the end of 2019, Jordan managed to deploy1,470MW of renewable energy projects of which PV: 592 MWIPPs and 509 MW net metering and wheeling, and 370 MWof wind capacity.[61] Furthermore, in 2019, 26% of the total installed generation capacity and 15% of the total generated electricity come from renewable energy sources. In addition to the utility-scale projects, Jordan implemented a net metering/wheeling regulation, which can be seen as a model for the whole MENA region. This market segment has been developed as an important second leg over the years, and even residential solar PV had a significant pick up, given high retail electricity prices. Overall, Jordan has the highest installed capacity of solar PV per capita in the MENA region,[62] whereby increased renewable energy penetration introduces significant technical and economic challenges to the current energy system, that is already over-committed on conventional and fossil fuel based resources and capacities.

Specifically on wind, Jordan has an installed capacity of 370 MW with a total of six projects: four utility-scale in the Southern part of the country more than 80 MW each at - Maan, Rajef, Fujeij and Tafilah – and two small-size research/pilot projects with a combined capacity of 1.5 MW in Ibrahimiyah and Hofa in the North of the country. Developers report the possibility to produce electricity at USD 3 cents/ kWh from wind.

While the energy system in Jordan already in 2019 had a surplus, during the Covid-19 crisis in 2020, all wheeling projects had to be temporarily stopped to avoid a massive oversupply of electricity.[63] This situation put the possibility to export electricity at an even higher priority and indeed agreements were signed to connect the Jordanian power grid to Saudi Arabia in August,[64] and on 27th September 2020 to supply power to Iraq 1,000 GWh/year starting in 2022.[65]

The desire for energy storage, the increased energy independence and competitiveness may provide an opening for hydrogen to be considered in the future energy mix. At present, the energy strategy has not considered hydrogen technologies due to the lack of awareness, or near term technological viability.

60 MEMR and international developers.

61 National Electricity Power Company annual report 2019.
Available at: https://www.nepco.com.jo/store/docs/web/2019_ar.pdf.

62 Arab Future Energy Index (AFEX) (2019), RCREEE and UNDP.
Available at: https://www.rcreee.org/sites/default/files/final_afex_re_2019_final_version-1.pdf.

63 Source: Mustakbal Cleantech.

64 “Saudi Arabia and Jordan to develop electricity interconnection grid.” The National.
Available at: https://www.thenationalnews.com/business/energy/saudi-arabia-and-jordan-to-develop-electricity-interconnection-grid-1.1064650.

65 Jordan, Iraq sign agreement to connect grids. MenaFN.
Available at: https://menafn.com/1100865846/Jordan-Iraq-sign-agreement-to-connect-grids.

Apart from exporting electricity, exporting green molecules seems like another interesting option to look at, with additional synergies of providing a solution to the seasonal storage challenge. What has Jordan been doing in the field of green molecules and how do we assess the potential?

The potential is vast, given the strategic location, including suitable infrastructures, such as an existing gas pipeline to Egypt, a natural gas link to Israel, an LNG terminal in Aqaba and of course excellent solar and wind resources, also located towards the south of the country where desalinated seawater would not be too far. The country is developing a RO project close to Aqaba to support growing demand for water and aims to convey sea water to Wadi Araba for possible use in agriculture projects.

In addition, Jordan has a sizable chemical business, largely focused on potassium and bromine industries. They could act as local off-taker for green molecules, and create value added downstream industries based on green molecules. With the high prices for energy, trucks and buses might also be powered by green hydrogen in the future, and a large refinery south of Amman could use green hydrogen. The ambitious NEOM project, just 200km south of Aqaba, could be a partner, rather than a competitor for production of green hydrogen or Ammonia, to create synergies locally and for export. Undoubtedly, Jordan would have all ingredients to produce low-cost green hydrogen, with the possibility to export internationally via Aqaba port. However, the water scarcity of the country remains a challenge and unfortunately, little has happened until today and we believe that international partnerships, e.g. with Germany, making use of the EUR 2 billion facility for green hydrogen projects, would be crucial to boosting the development. Many jobs have been created in the solar and wind sector, and Jordan could build on this to develop a green hydrogen economy.

Jordan's scientific and chemical industry and engineering community is also well versed and able to support the development and operation of pilot projects, and be an early contributor to the hydrogen wave, just as it has in the RE space.

## 5.3 Oman

Oman's government revenues are almost exclusively,72% [66] in 2020, relying on fossil fuels exports. The 2016 oil price crisis dug the budget deficit to around 20% of GDP (USD 13.8 billion)[67] and forced the government to issue huge amounts of debt. This led to the creation of an economic program for oil diversification (Oman Vision 2040) where RE plays a significant part.

However, the country faces major challenges: the expected lifetime of proven resources is significantly less than for other GCC countries;and at the same time an extremely challenging situation fiscally for the low oil and gas price, following the crash of the oil market in 2020. For the current budget, Oman has the highest break-even price in the region and even among the highest globally. Only very recently, the country embarked on a transition phase towards RE, including other strategic national initiatives to prepare the country for the future with the Oman Vision 2040.The national oil & gas and largest upstream company in the country, Petroleum Development Oman (PDO),in 2020 is being renamed Energy Development Oman (EDO). As the first move of such a kind in the region, this highlights the global trend of oil & gas companies to reinvent themselves as energy companies,

66 PWC Middle East (2020). Oman Budget 2020 Key Highlights.
Available at: https://www.pwc.com/m1/en/services/tax/me-tax-legal-news/2020/oman-budget-2020-key-highlights.html

67 World Bank (2017). Oman's Economic Outlook.
Available at: https://www.worldbank.org/en/country/gcc/publication/oman-economic-outlook-october-2017.

accelerating the change of business model towards more RE and sustainable technologies. EDO has publicly declared an interest in green hydrogen and is working to assess the potential for the country. To harvest its world class RE potential, the country launched tenders and partnerships to develop world-class energy infrastructure.[68] In this context, the current sub investment grade rating is clearly making things more challenging. Also, it is worth to note that OQ as other main player in the sector recently announced the formation of a renewable business unit.

A 50 MW utility-scale wind farm in Harweel in the Dhofar province has been commissioned by UAE developer Masdar in 2019. On solar PV, a 100 MW project was developed by the Japanese trading house Marubeni on behalf of PDO in the Salalah governorate in the South of the country. Furthermore, the financial close for the 500 MW Ibri II solar power plant has been announced in March by ACWA Power as consortium leader. A comprehensive program to launch several GW of solar & wind projects over the coming years has been published by national utility Oman Power and Water Procurement Company (OPWP).

On the Hydrogen side, the first Oman hydrogen symposium held at German Technical University in October 2009 demonstrated a market volume perspective around USD 20 billion by 2050. In January 2020, GU Tech, in partnership with Hydrogen rise opened the Oman Hydrogen Centre aiming to become an international competence hub for research, technology, education, industry application and economy.[69]

Furthermore, the Belgian consortium DEME Concession and the Port of Antwerp partnered with Oman to develop a multi 100 MW green hydrogen plant in Duqm to provide green molecules locally to a chemical complex and international markets. The first phase currently under progress consists of a feasibility study for an envisaged electrolyzer capacity estimated between 250 and 500 MW.[70] More recently, in September 2020, EJAAD, the Sultanate's premier platform for energy innovation has launched a bid for a feasibility study to unlock the potential of hydrogen for Oman's economy.[71]

68 Oman launched the first IPP in the Middle East in 1994.
Available at: https://energy-utilities.com/ownership-of-middle-east-s-first-ipp-transferred-news083256.html.

69 Kothaneth, L..,"First Green Hydrogen Centre opens in Oman." Oman Daily Observer. 27th January 2020.
Available at: https://www.omanobserver.om/first-green-hydrogen-centre-opens-in-oman/.

70 "Deme and partners present Hyport®duqm, a large-scale green hydrogen project in Oman".
Available at: https://www.deme-group.com/news/deme-and-partners-present-hyportrduqm-large-scale-green-hydrogen-project-oman-1.

71 Prabhu, C., "Oman to study potential for hydrogen-based economy." Oman Daily Observer. 26thSeptember 2020.
Available at: https://www.omanobserver.om/oman-to-study-potential-for-hydrogen-based-economy.

## 6.1 Bringing Desertec 3.0 to Life: Regional Partnerships to Accelerate the Development of "Green Molecule Value Chains Based on Green Electrons"

The emergence of green hydrogen from RE can be seen as an incredible opportunity for MENA countries to accelerate their energy transition towards emission-free technologies and become a true "Powerhouse" (Desertec 3.0). Green molecules can be stored and transported to local and world markets easier than green electrons and the variety of applications well beyond the power sector provides an unprecedented possibility to create many new jobs in future sectors.

The current setting could not be more favourable: the ambitious agenda and massive support by Europe for the sector will help to kick start the development of hydrogen economies in the MENA region and at the same time, Europe will source huge amounts of green molecules, for which MENA could be the preferred partner.

With 2020 being a year of big paradigm shift and crisis of the global oil and gas industry, accelerating the trend away from fossil fuels, one should wisely reflect on the profound implications. There is a considerable potential to create new winners, but also losers.

## 6.2 Some Policy Recommendations

1) **In the first place let the 'green developments' be driven by the local and regional stakeholders for the benefit of the local and regional society.**

2) **Carefully consider environmental factors** and make sure that renewable energy sources are used throughout the hydrogen production process. Place the **green hydrogen** production **in the heart of the social and economic transition towards sustainability**.

3) Make sure that **internationally accepted certification/guarantees of origin** for green hydrogen are a priority. Policy makers need to ensure that this is achieved as aprerequisite for the creation of a market for green molecules.

4) **Encourage stakeholder to support, realistic, but still ambitious, national plans** for green hydrogen with **clear milestones and execution timelines and aligned with forced decarbonization and ramping up renewables.**

5) **'Speed with smartness'** will bring the cost curve down fast and reach competitiveness **sooner**. A completely new, flexible, and more innovative approach is required.

6) **Discourage the production of GHG emission in Hydrogen making process.**

7) Make sure that **international technical and safety standards** are created and implemented.

8) **Carefully design and consistently apply support mechanisms which may be needed temporarily** to bridging the gap from green to grey hydrogen until 'green' will be able to stand on its own feet in the market.

9) **Aim big scale!** Green Hydrogen Plants, with or without derivative green molecules like ammonia or other synthetic fuels, must be built in large scale (**100s MW to several GW**) in order to be reasonably competitive.

10) **Ensure Green Hydrogen demand is studied well**, qualitatively, and quantitatively.

11) **Forge long term partnerships with large demand centers for green hydrogen**, like in far east and EU.

12) Ensure that long term **local and international off-take agreements** are feasible and are in place.

13) Leverage existing **know how and success stories in MENA for structuring projects** (SPV and PPP models).

14) **Leverage existing know how and success stories in financing projects** via international development institutions in developing MENA countries and large commercial banks in GCC countries.

15) **De-risk the technology and projects for early adopters by providing suitable guarantees** (MIGA and others) to avail competitive long-term financing rates.

16) **Introduce favorable taxation structures for green hydrogen projects** to spur growth and competitiveness.

17) Build a **complete environmental plan** on emission reduction and sustainability at large.

## Annex I: *Hydrogen Applications*

***Industrial applications*** of hydrogen, namely: oil refining, ammonia production for fertilizers (obtained on a large scale by the Haber-Bosch process), methanol production and steel production.

In ***transport***, hydrogen could have a variety of applications: the battery electric vehicle (BEV) relying on electric batteries for power and the fuel cell electric vehicles (FCEVs) using hydrogen. Even if not completely mature today, the FCEV market could reach USD 14 billion by 2026.[72] Daimler or Volvo trucks already unveiled their plans to bring hydrogen trucks on the market. Several countries in Europe already use hydrogen to fuel public buses, Solaris Urbino 12 hydrogen first used in Stockholm are now consisting of a fleet of 25 in the streets of Wuppertal and 15 in Cologne. On the rails side, the French Alstom hydrogen trains entered regular service in Germany and Austria in September 2020.

In ***buildings***, hydrogen could be blended into existing natural gas distribution networks, with the highest potential in multifamily and commercial buildings, particularly in dense cities while longer-term prospects could include the direct use of hydrogen in hydrogen boilers or fuel cells.[73]

In ***power generation***, hydrogen can complement batteries as mid to long-term (i.e. seasonal) storage and long term as a fuel to blend in CCGTs or even power a 100% new generation of H2 turbines.

## Annex II: *The Government of Morocco is taking important steps to kick-start a local hydrogen economy*

### 1) Policy:

- The establishment of the National Hydrogen Commission on Green Hydrogen with public-private sector representatives to develop a Green Hydrogen Roadmap 2050 for Morocco, which will be followed by in-depth studies addressing different aspects along the hydrogen value chain. The Commission consists of working groups leading specific subjects and conduct these in-depth studies: for example Masen and ONEE may lead the RE upstream; ONHYM the gas infrastructures task force; OCP the (ammonia) chemical middle-down stream, and IRESEN has been identified as lead R&D, Innovation, capacity building and engineering of local content. The working groups shall elaborate recommendations in their respective field of competence and each of them will have a dedicated subject to deep dive and develop.

- The development of an integrated program for the production of green ammonia and synthetic fuels by redeploying renewable energy.

- Willingness to export and Morocco as a future hydrogen hub.

72 Wadhwani, P., Prasenjit, S., Fuel Cell Electric Vehicle Market Size, FCEV Industry Report 2026. September 2020.

73 International Energy Agency (2019). The Future of Hydrogen Seizing today's opportunities. Technology report. June 2019

**2) Regulatory Framework:**

- Within the activity of the National Commission, the improvement of the legal framework and regulation is a prerequisite to attract investments in the hydrogen sector and efforts are being made towards this objective through the National Commission on Green Hydrogen.

**3) Research & Development:**

- The development of a research and development platform dedicated to green hydrogen with IRESEN at the Green Energy Park (GEP) in co-operation with OCP Group to lay the foundation for local labor to develop the local industry with highly qualified products and services. The focus is to develop know-how, capacity building and infrastructures to train people, PhD students and technicians. The vision is for Morocco to be the backyard for a bigger hydrogen cluster: starting from a privileged partnership between Morocco and Germany, this could be further developed at the regional level to become the MENA-Europe Hydrogen Valley. On a regional ground, this dedicated platform aims at becoming a digital-physical cluster to conduct R&D, b2b, networking and demonstration processes.

- Preparation of a large and scientific-technological conference with international partners dedicated to green hydrogen, The World Power to X Summit, scheduled for December 2020 as hybrid conference.

**4) Pilot Projects (in development phase):**

- Small scale pilot project – some MW of electrolysis - for the production of green ammonia with OCP Group is at an advanced stage. The partners in this project are OCP Group, IRESEN, the 'Université Mohammed VI Polytechnique' (UM6P) and Fraunhofer IMWS& IGB centers. OCP core strategy 2019-2020 looks at promoting sustainable industrial solutions in the circular economy, by producing green ammonia, hydrogen and methanol. To implement this vision, the group in 2018 has signed an MoU with Fraunhofer IMWS to mainstream green hydrogen and green ammonia as raw materials for the fertilizer industry. The partners commend the Green Energy Park (GEP) and to Fraunhofer IMWS with the execution of the first pilot for the production of hydrogen and ammonia to Africa. It will have a capacity of 4 tons of ammonia per day and scale-up will allow around 600,000 tons per year.

- First large scale project for the production of green hydrogen with around 100 MW of electrolyzer capacity with Masen, called 'reference project' to produce also green ammonia, financed by the German government through KfW..

## Annex III: *NEOM*

As a key pillar of Vision 2030, NEOM was announced in 2017 by Mohammed Bin Salman, crown prince of the Kingdom. The project foresees the construction of a completely new city on 26,500 square kilometres are, along with a 468-kilometre waterfront on the red Sea, in the north-western Saudi province of Tabuk. Works on the ground have recently started.

The mega project worth USD 500 billion funded by the Saudi Arabia's Public Investment Fund aims to revolutionize Saudi society, reduce dependence on oil, and make the country a technology hub, where Artificial intelligence and internet of thing will introduce Saudi Arabia into the fourth industrial revolution. Below is some information obtained from NEOM:

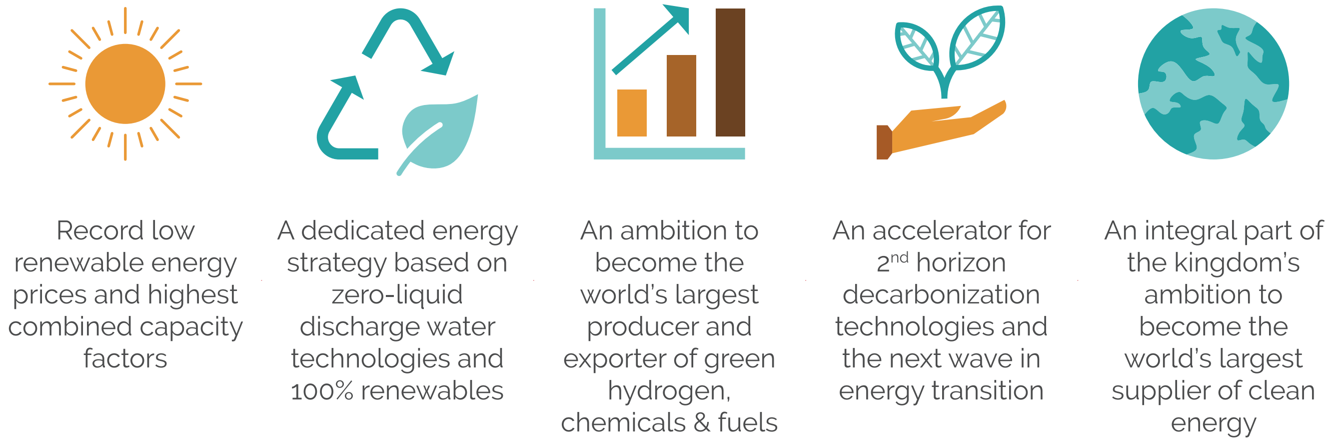



***Figure 4:*** *NEOM: Bringing a Circular Economy to Life* | ***Source:*** *NEOM's presentation at the 3rd online meeting of the MENA Hydrogen Alliance.*


***Figure 5:*** *NEOM at a glance*

NEOM could produce green hydrogen at world record low prices of around 1.5 USD/kg due to an optimal supply of low price RE, with a high combined solar PV and wind capacity factor of over 70%, with generation profiles even highly complementary between day and night according to measurements in the area.

On 7thJuly 2020, NEOM, together with the partner ACWA Power and Air Products announced the world's largest green hydrogen project Thyssenkrupp have been announced as the technology provider for the green hydrogen to the project and Haldor Topsoe for the conversion to ammonia. With a targeted production of 650 tons of green hydrogen per day when the project will be operational in 2050, around 1.2 million tons of ammonia shall be produced annually and exported to world markets.[74] The amount of green hydrogen would be sufficient to power approximately 700,000 fuel cell cars.

74 "Air Products, ACWA Power and NEOM sign agreement for USD 5 billion production facility in NEOM powered by renewable energy for production and export of green hydrogen to global markets", ACWA Power, 7thJuly 2020. Available at: https://www.acwapower.com/news/air-products-acwa-power-and-neom-sign-agreement-for-5-billion--production-facility-in-neom-powered-by-renewable-energy-for-production-and-export-of-green-hydrogen-to-global-markets/

## 8.1 Introduction

- In the Global Energy Transition context and decarbonization, all hands must be on deck.
- There is no magic quick fix or silver bullet solution. It is a collaborative effort across all stakeholders and industries.
- A double win can be achieved: accelerated energy transition driven by sustainable economic recovery.
- An important element of this double win is Green Hydrogen, i.e. hydrogen produced from electrolysers powered by renewable energy resources.
- Hydrogen is a versatile energy carrier with a wide range of uses and unique attributes, especially for energy sectors that are hard to electrify with renewable resources but can be made greener through sector coupling.
- So, if Green Hydrogen is technically a key enabler of decarbonization, then the next step or barrier to break is economics.
- This translates to: How much does Green Hydrogen costs to produce and how to calculate that as well as analyze pathways of cost reduction?
- A financial model toolkit for analyzing levelized cost of Hydrogen becomes necessary. This new and free service (offered on SaaS basis) is now available from Dii for its network members and associated partners.

## 8.2 How Does it Work?

- The financial model toolkit is a discounted cash-flow model coupled with visual representation in charts and graphs, and analytical features of one- and two-dimensional sensitivity analysis.
- Basically, the toolkit is a calculation engine that feeds on user supplied input parameters and provides calculated outputs of LCOH in $/Kg H2 plus plenty of charts for easier analytical what-If-scenarios representation.
- To run the model and provide a report, the user (desktop researcher) provides Dii with the required "input parameters".
- This is a one-page Inputs Form that covers the attributes of Green Hydrogen Electrolyser Plant. Dii runs the model and provides a report. Service Done!

## 8.3 Toolkit Content

- The financial model toolkit is an XLS file with 8 sheets.
- The integrity of the toolkit structure and calculation engine is secured and protected against unintended formulae edits.
- A content sheet provides quick navigation hyperlinks to all sheets.
- By providing a list of input parameters, a model run will generate an 11-page pdf report.

### 8.3.1 Toolkit Inputs Form

- The Inputs Form (xls file) data set is in six categories:

  **1)** General (Life cycle up to 40 years, economies of scale, technology & costs ref. years)
  **2)** Finance Structure (gearing, equity & debt rates)
  **3)** CAPEX (breakdown required)
  **4)** OPEX (fixed & variable, energy & water, land lease, escalation rates, stack replacement intervals)
  **5)** System (capacity, efficiency, degradation, oversizing, capacity factor)
  **6)** Decommissioning & Residual Value

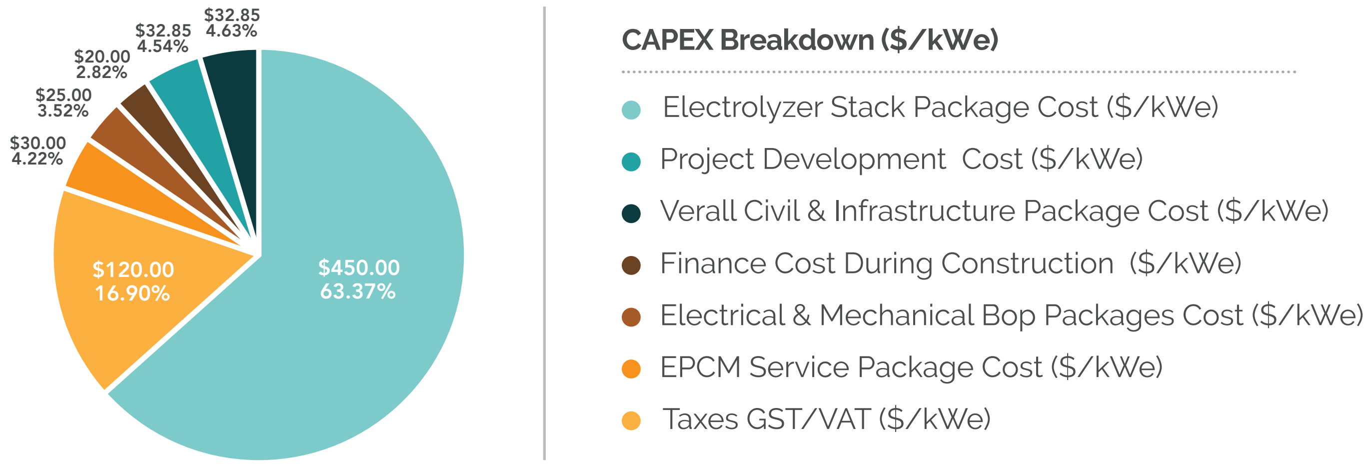
- For each input parameter, a few notes and remarks are provided. The user can also add his/her special notes as well. It is worth noting that quality and validity of input data is key.

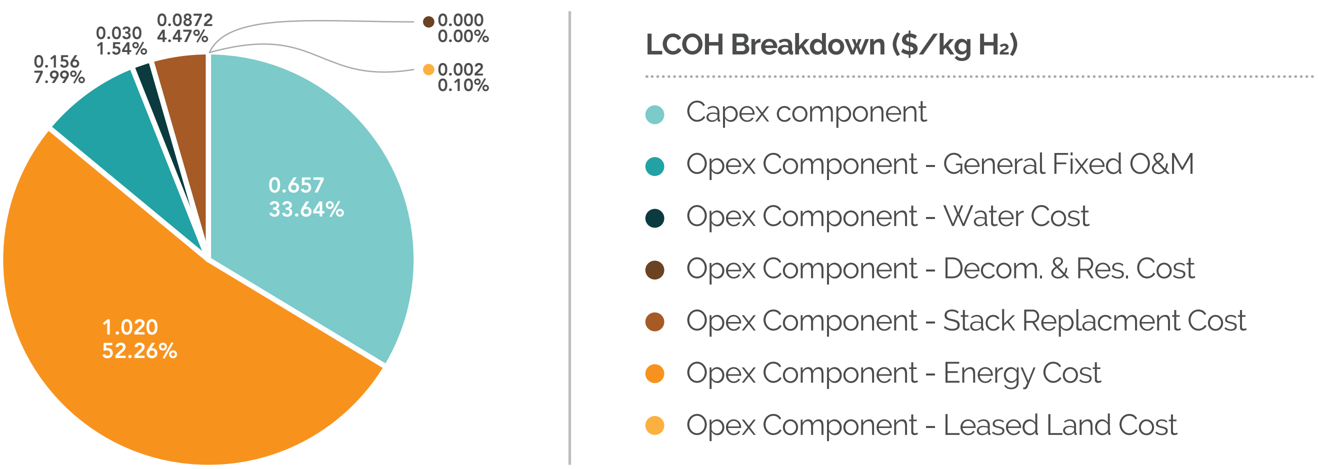
### 8.3.2 Toolkit Direct Outputs

- The toolkit direct outputs are in three categories:

  **1)** Direct calculation outputs, LCOH baseline case
  **2)** CAPEX breakdown with chart
  **3)** LCOH breakdown chart

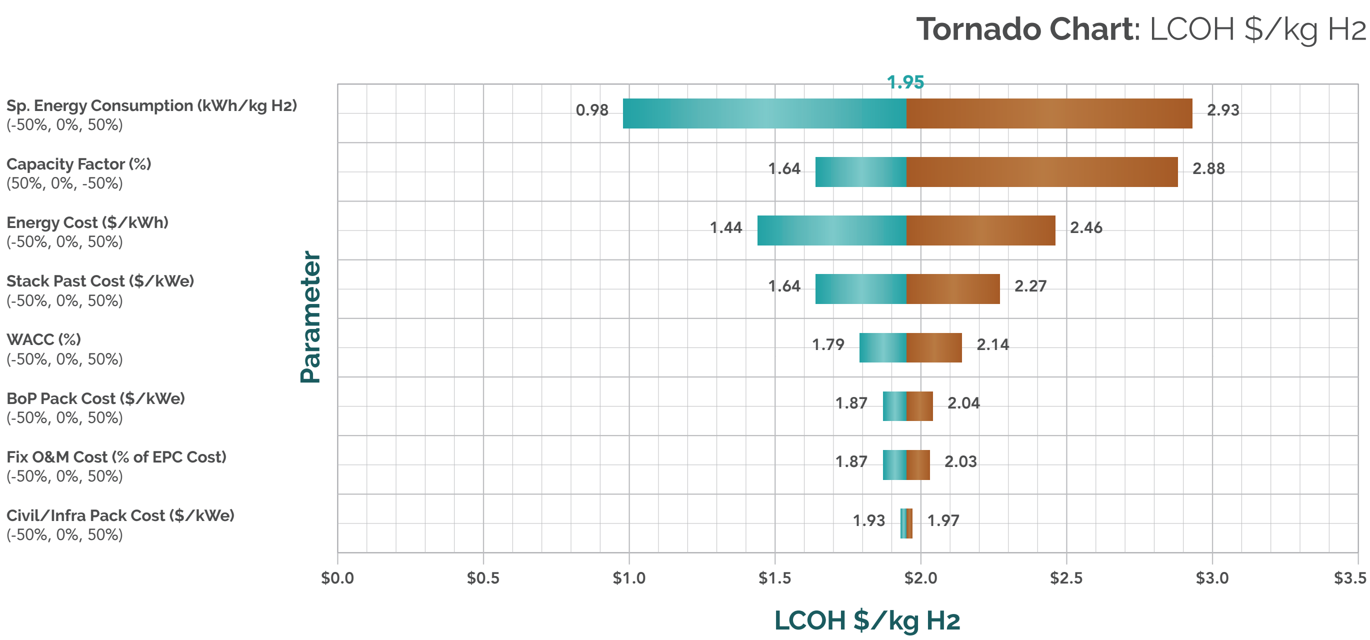
| Outputs - 20 Years | | |
|---|---|---|
| LCOH Component | Component $/kg $H_2$ | Component Percentage |
| Capex Component | 0.656597 | 33.64% |
| Opex Component - Energy Cost | 1.020000 | 52.26% |
| Opex Component - General Fixed O&M | 0.155961 | 7.99% |
| Opex Component - Water Cost | 0.030000 | 1.54% |
| Opex Component - Stack Replacement Cost | 0.087245 | 4.47% |
| Opex Component - Leased Land Cost | 0.001941 | 0.10% |
| Opex Component - Decom. & Rest. Cost | 0.000000 | 0.00% |
| | | Total Percentage Check |
| | | 100% |
| **LCOH ($/kg $H_2$)** | $1.951743 | |
| **LCOH (AED/kg $H_2$)** | 7.172656 | |



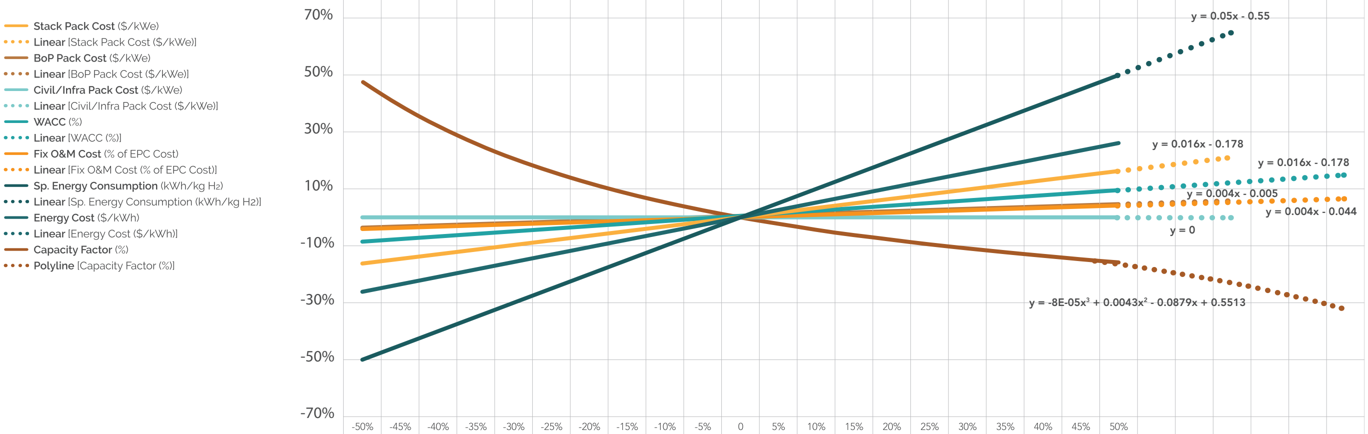




### 8.3.3 Toolkit Analytical Outputs

- Analytical what-if scenarios one-dimensional LCOH calculation outputs.
- Eight input parameters variances +/- 50%.
- Tornado chart.



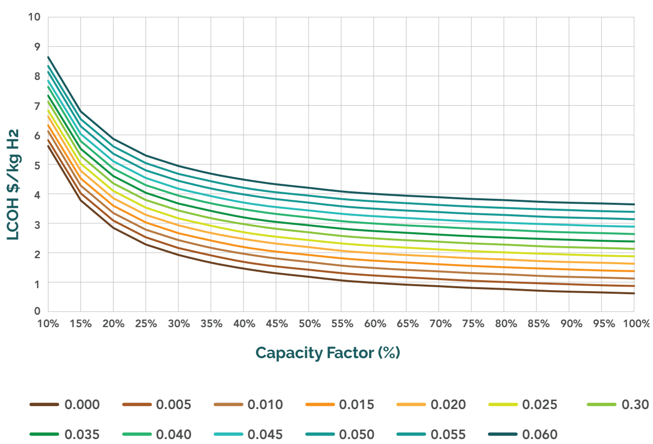
## LCOH 1D Sensitivity



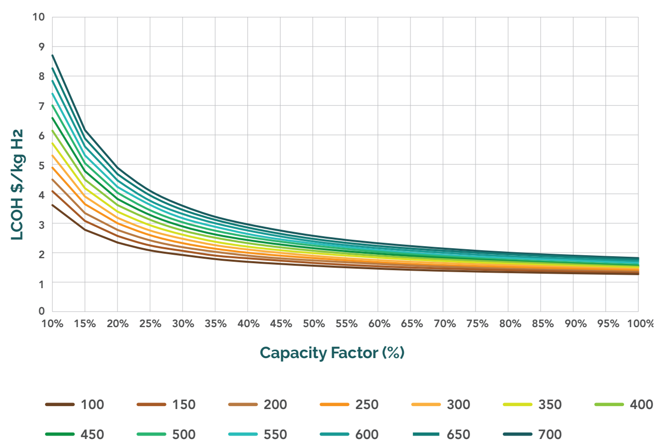

| | -50% | -45% | -40% | -35% | -30% | -25% | -20% | -15% | -10% | -5% | 0 | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% | 45% | 50% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stack Pack Cost ($/kWe) | -16.22% | -14.60% | -12.98% | -11.35% | -9.73% | -8.11% | -6.49% | -4.87% | -3.24% | -1.62% | 0.00% | 1.62% | 3.24% | 4.87% | 6.49% | 8.11% | 9.73% | 11.35% | 12.98% | 14.60% | 16.22% |
| BoP Pack Cost ($/kWe) | -4.33% | -3.89% | -3.46% | -3.03% | -2.60% | -2.16% | -1.73% | -1.30% | -0.87% | -0.43% | 0.00% | 0.43% | 0.87% | 1.30% | 1.73% | 2.16% | 2.60% | 3.03% | 3.46% | 3.89% | 4.33% |
| Civil/Infra Pack Cost ($/kWe) | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| WACC (%) | -8.49% | -7.69% | -6.88% | -6.06% | -5.22% | -4.38% | -3.52% | -2.66% | -1.78% | -0.90% | 0.00% | 0.91% | 1.82% | 2.74% | 3.68% | 4.62% | 5.57% | 6.53% | 7.50% | 8.47% | 9.46% |
| Fix O&M Cost (% of EPC Cost) | -4.00% | -3.60% | -3.20% | -2.80% | -2.40% | -2.00% | -1.60% | -1.20% | -0.80% | -0.40% | 0.00% | 0.40% | 0.80% | 1.20% | 1.60% | 2.00% | 2.40% | 2.80% | 3.20% | 3.60% | 4.00% |
| Sp. Energy Consumption (kWh/kg $H_2$) | -50.00% | -45.00% | -40.00% | -35.00% | -30.00% | -25.00% | -20.00% | -15.00% | -10% | -5.00% | 0.00% | 5.00% | 10.00% | 15.00% | 20.00% | 25.00% | 30.00% | 35.00% | 40.00% | 45.00% | 50.00% |
| Energy Cost ($/kWh) | -26.13% | -23.52% | -20.90% | -18.29% | -15.68% | -13.07% | -10.45% | -7.84% | -5.23% | -2.61% | 0.00% | 2.61% | 5.23% | 7.84% | 10.45% | 13.07% | 15.68% | 18.29% | 20.90% | 23.52% | 26.13% |
| Capacity Factor (%) | 47.74% | 39.06% | 31.83% | 25.71% | 20.46% | 15.91% | 11.93% | 8.42% | 5.30% | 2.51% | 0.00% | -2.27% | -4.34% | -6.23% | -7.96% | -9.55% | -11.02% | -12.38% | -13.64% | -14.82% | -15.91% |

- Analytical what-if scenarios two-dimensional LCOH calculation outputs.

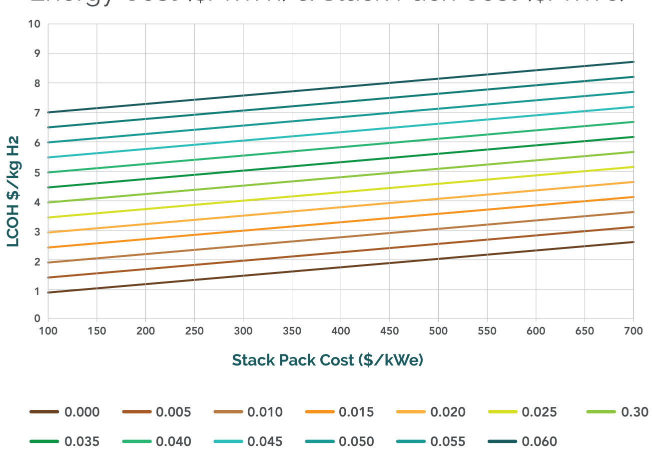
### LCOH Sensitivity 2D
Energy Cost ($/kWh) & Capacity Factor (%)



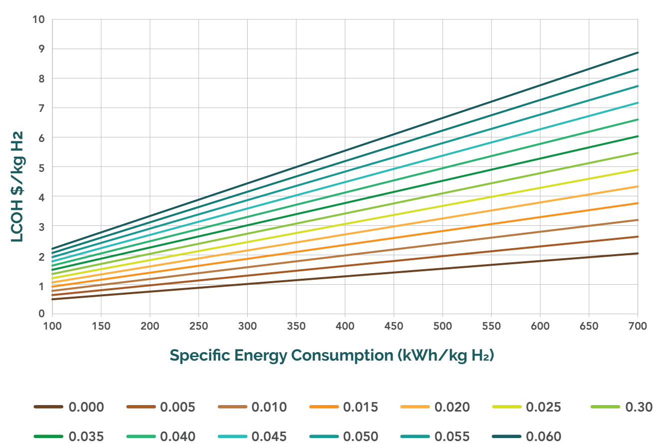

### LCOH Sensitivity 2D
Stack Pack Cost ($/kWe) & Capacity Factor (%)




### LCOH Sensitivity 2D
Energy Cost ($/kWh) & Stack Pack Cost ($/kWe)

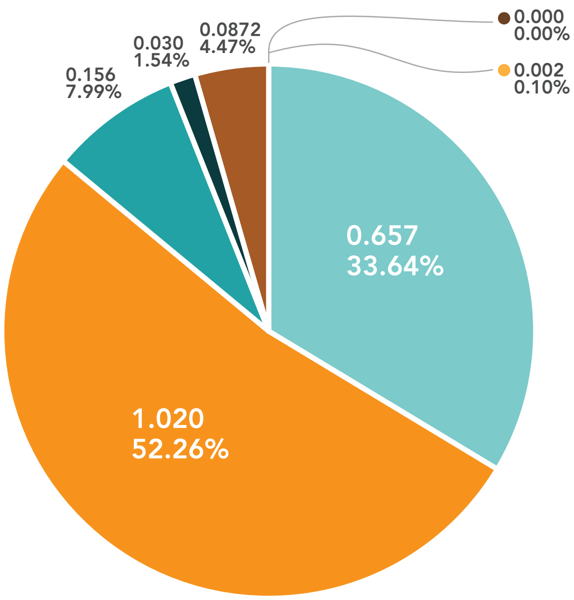



### LCOH Sensitivity 2D
Energy Cost ($/kWh) & Specific Energy Consumption (kWh/kg $H_2$)



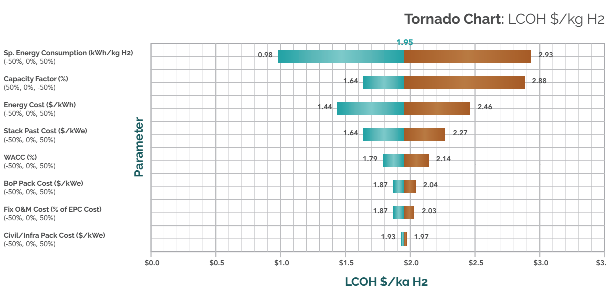
- Impact of Plant Lifecycle on LCOH: 20 years vs. 40 years

## 20 Years

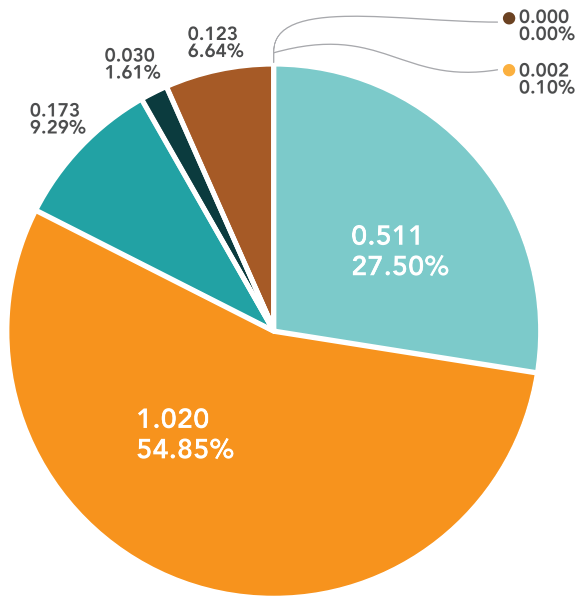



**LCOH Breakdown ($/kg $H_2$)**

- Capex component
- Opex Component - General Fixed O&M
- Opex Component - Water Cost
- Opex Component - Decom. & Res. Cost
- Opex Component - Stack Replacment Cost
- Opex Component - Energy Cost
- Opex Component - Leased Land Cost

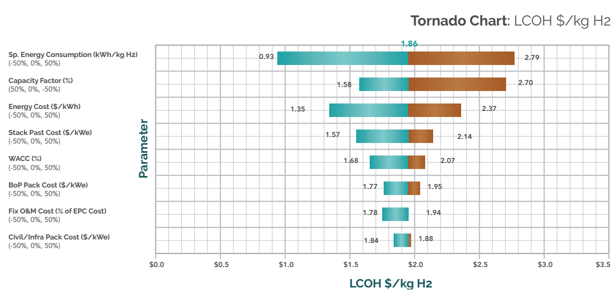



## 40 Years

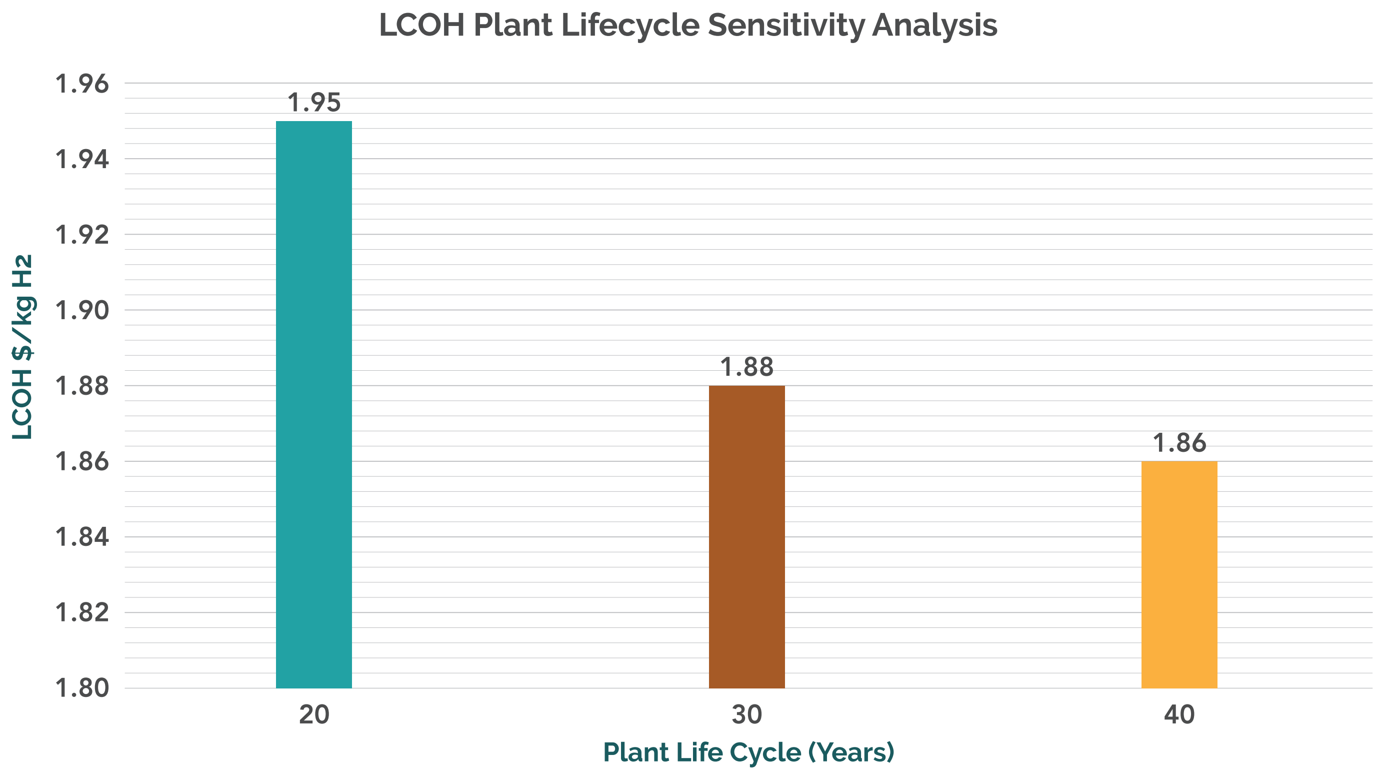



**LCOH Breakdown ($/kg $H_2$)**

- Capex component
- Opex Component - General Fixed O&M
- Opex Component - Water Cost
- Opex Component - Decom. & Res. Cost
- Opex Component - Stack Replacment Cost
- Opex Component - Energy Cost
- Opex Component - Leased Land Cost



- Impact of Plant Lifecycle on LCOH: 20 years vs. 30 years vs. 40 years




## 8.4 Takeaways

- The green molecules era has arrived.
- Their contribution to the energy transition will rise and accelerate.
- Balancing the technical solutions with sound economics will be critical to the success.
- Again, all hands must be on deck!

"Air Products, Acwa Power and NEOM sign agreement for USD 5 billion production facility in NEOM powered by renewable energy for production and export of green hydrogen to global markets", ACWA Power, 7thJuly 2020.
Available at: https://www.acwapower.com/news/air-products-acwa-power-and-neom-sign-agreement-for-5-billion--production-facility-in-neom-powered-by-renewable-energy-for-production-and-export-of-green-hydrogen-to-global-markets/.

Arab Future Energy Index (AFEX) (2019), RCREEE and UNDP.
Available at: https://www.rcreee.org/sites/default/files/final_afex_re_2019_final_version-1.pdf.

Appunn, K., "Sector coupling - Shaping an integrated renewable energy system." Clean Energy Wire. 25 April 2018.
Available at: https://www.cleanenergywire.org/factsheets/sector-coupling-shaping-integrated-renewable-power-system.

Black, A., Makundi, B., McLennan T., Africa's Automotive Industry: Potential and Challenges. African Development Bank.
Available at: https://www.afdb.org/fileadmin/uploads/afdb/Documents/Publications/WPS_No_282_Africa%E2%80%99s_Automotive_Industry_Potential_and_Challenges.pdf.

Bloomberg New Energy Finance (2020). Hydrogen Economy Outlook.
Available at: https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf.

CertifHy. (2019, March). CertifHy-SD Hydrogen Criteria.
Available at: https://www.certifhy.eu/images/media/files/CertifHy_2_deliverables/CertifHy_H2-criteria-definition_V1-1_2019-03-13_clean_endorsed.pdf.

Climate Scope (2019). Morocco, BloombergNEF.
Available at: https://global-climatescope.org/results/MA#power-market.

Conclusion of the National Committee on "Power to X", which took place on 30th March 2020.
Available at: https://www.mem.gov.ma/Pages/actualite.aspx?act=150.

Coukri, J. « Station de dessalement d'Agadir: voici où en est ce méga projet », 20 February 2020, Media24.
Available at: https://www.medias24.com/station-de-dessalement-d-agadir-voici-ou-en-est-ce-mega-projet-7768.html.

"Deme and partners present Hyport®duqm, a large-scale green hydrogen project in Oman".
Available at: https://www.deme-group.com/news/deme-and-partners-present-hyportrduqm-large-scale-green-hydrogen-project-oman-1.

Dii Desert Energy (2020). Corporate presentation.

Dii Desert Energy & Fraunhofer ISI (2012). Desert Power 2050 – Perspectives on a Sustainable Power System for EUMENA, Munich.

Dii Desert Energy (2019). P. van Son, T. Isenburg (2019). Emission-free energy from the deserts, The Hague.

Dii Desert Energy (2020). Levelized Cost of Hydrogen Toolkit Financial Model Analysis.

Dii Desert Energy Project Data Base 2020.

Direction of Observation, Cooperation and Communication, Ministry of Energy Mines and Environment of Morocco. Official website
Available at:

Dresp, S., Dionigi, F., Klingenhof, M., Strasser, P. Direct Electrolytic Splitting of Seawater: Opportunities and Challenges (2019).
Available at: https://pubs.acs.org/doi/abs/10.1021/acsenergylett.9b00220.

Duignan, A., Simonitsc, T. (2020). US Machinery Hydrogen 101. North America Equity Research. JP Morgan.

Engelhardt, M., "Morocco-to-X: BadrIkken and his team at IRESEN plan to transform the country into a hub for e-Fuels", Siemens Energy, 23rd April 2020.
Available at: .

European Commission (2020). Europe's moment: Repair and prepare for the next generation. Brussels, Press Release, 27thMay.
Available at: https://ec.europa.eu/commission/presscorner/detail/en/ip_20_940.

European Commission (2019). Renewable Energy – Recast to 2030 (RED II).
Available at: https://ec.europa.eu/jrc/en/jec/renewable-energy-recast-2030-red-ii.

European Commission, "A hydrogen strategy for a climate-neutral Europe", Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Brussels, 8thJuly 2020, COM(2020) 301 final.
Available at: https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf.

FAO Country Profile, Oman.
Available at: http://www.fao.org/countryprofiles/index/en/?iso3=OMN.

Fuel Cells and Hydrogen Joint Undertaking (FCH JU), (2020). Fuel Cells and Hydrogen for Green Energy in European Cities and Regions.
Available at: https://www.fch.europa.eu/sites/default/files/180926_FCHJU_Regions_Cities_Final_Report.pdf.

Fuel Cells and Hydrogen Joint Undertaking (FCH JU), (2019). Hydrogen Roadmap Europe, a sustainable pathway for the European energy transition.
Available at: https://www.fch.europa.eu/.

GIZ Morocco, National Energy Strategy.
Available at: http://giz-energy.ma/contexte-energetique/la-strategie-energetique-nationale/.

Hydrogen Council (2017). Hydrogen scaling up - A sustainable pathway for the global energy transition.
Available at: https://hydrogencouncil.com/wp-content/uploads/2017/11/Hydrogen-scaling-up-Hydrogen-Council.pdf.

Hydrogen Council (2020), Path to hydrogen competitiveness. A cost perspective.
Available at: https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf.

Hydrogen Europe. "Hydrogen in Industry".
Available at: https://hydrogeneurope.eu/hydrogen-industry.

International Energy Agency, (2019). Energy Policies Beyond IEA Countries, Morocco.

International Energy Agency (2019). The Future of Hydrogen. Seizing today's opportunities. Technology report. June 2019.
Available at: https://webstore.iea.org/the-future-of-hydrogen.

IRENA, (2018), Hydrogen from renewable power: Technology outlook for the energy transition.
Available at: https://www.irena.org/publications/2018/Sep/Hydrogen-from-renewable-power.

"Israel, Greece and Cyprus sign deal for EastMed gas pipeline". Euronews. 2ndJanuary 2020.
Available at: https://www.euronews.com/2020/01/02/israel-greece-and-cyprus-sign-deal-for-eastmed-gas-pipeline.

Kayed, M., "Jordan among leading countries in region for wind energy production — report". The Jordan Times. 20thFebruary 2020.
Available at: https://www.jordantimes.com/news/local/jordan-among-leading-countries-region-wind-energy-production-%E2%80%94-report.

Kothaneth, L.,"First Green Hydrogen Centre opens in Oman." Oman Daily Observer. 27thJanuary 2020.
Available at: https://www.omanobserver.om/first-green-hydrogen-centre-opens-in-oman/.

Megret O., Hubert l., Calbrytrably M., Carrere, H., Garcia-Bernet D., Bernet, N., Production d'hydrogène à partir de déchets. État de l'art et potentiel d'émergence. Rapport Final 2015. Record.

Melaina, M. W., and Antonia, O., Penev, M. (2013). "Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues". National Renewable energy Laboratory (NREL).
Available at: https://www.nrel.gov/docs/fy13osti/51995.pdf.

National Electricity Power Company (NEPCO) annual report 2019.
Available at: https://www.nepco.com.jo/store/docs/web/2019_ar.pdf#https://www.nepco.com.jo/store/docs/web/2019_ar.pdf.

OCP Group (2019). Sustainability Report 2019.
Available at: https://corpo.ocpgroup.ma/en/sustainability-report-2019.

Office National de Electricité et de l'Eau Potable (ONEE). Electricity activity Data

Installed capacity rising to meet Morocco's growing energy demand, Oxford Business Group.
Available at: https://oxfordbusinessgroup.com/overview/installed-capacity-rising-meet-moroccos-growing-energy-demand.

"Ownership of Middle East's first IPP transferred to Omani government", Informa, 7th May 2020.
Available at: https://energy-utilities.com/ownership-of-middle-east-s-first-ipp-transferred-news083256.html.

Parnell, J. "World's Largest Green Hydrogen Project Unveiled in Saudi Arabia". Green Tech Media. 7thJuly 2020.
Available at: https://www.greentechmedia.com/articles/read/us-firm-unveils-worlds-largest-green-hydrogen-project.

Pflugmann, F., De Blasio, N., "Geopolitical and Market Implications of Renewable Hydrogen New Dependencies in a Low-Carbon Energy World." Environment and Natural Resources Program Belfer Center for Science and International Affairs Harvard Kennedy School. Report 2020.
Available at: https://www.belfercenter.org/publication/geopolitical-and-market-implications-renewable-hydrogen-new-dependencies-low-carbon.

Prabhu, C., "Oman to study potential for hydrogen-based economy." Oman Daily Observer. 26th September 2020.
Available at: https://www.omanobserver.om/oman-to-study-potential-for-hydrogen-based-economy/.

"Projet «Power to X» : La mise enœuvres'accélère ». Finances News. 23rdJune 2020.
Available at: https://fnh.ma/article/developpement-durable/projet-power-to-x-la-mise-en-oeuvre-s-accelere.

PWC Middle East (2020). Oman Budget 2020 Key Highlights.
Available at: https://energy-utilities.com/ownership-of-middle-east-s-first-ipp-transferred-news083256.html.

"Saudi Arabia and Jordan to develop electricity interconnection grid." The National.
Available at: https://www.thenationalnews.com/business/energy/saudi-arabia-and-jordan-to-develop-electricity-interconnection-grid-1.1064650.

TangerMed official website.
Available at: https://www.tangermed-passagers.com/index.php/fr/trafic-au-port-tanger-med-premier-semestre-2017.

TangerMed, 1 September 2020.
Available at: https://www.tangermed.ma/en/tanger-med-35eme-port-a-conteneurs-au-monde-en-2019/.

Van de Graaf, T., Overland I., Scholten D., Westphal, K., The new oil? The geopolitics and international governance of hydrogen. Energy Research & Social Science 2020 Dec; 70: 101667. Published online 2020 Jun 30. doi: 10.1016/j.erss.2020.101667

Van Wijk, A., Chatzimarkakis, J., (2020). Green Hydrogen for a European Green Deal. A 2x40 GW Initiative. Available at: https://dii-desertenergy.org/wp-content/uploads/2020/04/2020-04-01_Dii_Hydrogen_Studie2020_v13_SP.pdf.

Van Wijk, A., Wouters, F., Rachidi, S., &Ikken, B. (2019, November). A North Africa - Europe Hydrogen Manifesto.
Available at: https://dii-desertenergy.org/wp-content/uploads/2019/12/Dii-hydrogen-study-November-2019.pdf.

Van Wijk, A., Wouter, F.,(2019). “Hydrogen: the bridge between Africa and Europe.”
Available at: http://profadvanwijk.com/wp-content/uploads/2019/09/Hydrogen-the-bridge-between-Africa-and-Europe-5-9-2019.pdf.

Van Wijk, A., van der Roest, E., & Boere, J. (2017). Solar Power to the People.Nieuwegein-Utrecht: Allied Waters.

Varadi, Wouters, & Hoffmann. (2018). The Sun is Rising in Africa and the Middle East - On the Road to a Solar Energy Future. Singapore: Pan Stanford Publishing Co ISBN-10: 9814774898.

Wang, A., van der Leun, K., Peters, D.,Buseman, M., European Hydrogen Backbone.

World Energy Council (2019), New hydrogen economy - hope or hype? Innovation Insights Brief. Available at: https://www.worldenergy.org/assets/downloads/WEInnovation-Insights-Brief-New-Hydrogen-Economy-Hype-or-Hope.pdf.

World Bank (2017). Oman's Economic Outlook.
Available at: https://www.worldbank.org/en/country/gcc/publication/oman-economic-outlook-october-2017.

Wadhwani, P., Prasenjit, S., Fuel Cell Electric Vehicle Market Size, FCEV Industry Report 2026. September 2020.

World Bank (2020). Jourdan's Economic Outlook. World Bank.
Available at: https://www.worldbank.org/en/country/jordan/publication/economic-update-april-2020.

World Bank (2019). Morocco's Economic Outlook. World Bank.
Available at: https://www.worldbank.org/en/country/morocco/publication/economic-outlook-april-2018.

World Bank (2018). Oman's Economic Outlook - October 2017 the World Bank.
Available at: https://www.worldbank.org/en/country/gcc/publication/oman-economic-outlook-october-2017.

The Regional Climate and Energy of Project in the Middle East and North Africa (MENA) of Friedrich-Ebert-Stiftung has commissioned, edited, reviewed, and published this study.

Year: 2020

## About FES Regional Climate & Energy Project MENA

The Regional Climate and Energy Project MENA advocates for an energy transition into renewable energy and energy efficiency. It continues to search for solutions for a just transition in the energy sector ensuring both, the protection of the planet and the people.

As the MENA region is one of the most affected areas by climate change, we contribute to policy advising, research, and advocacy in the areas of climate change policy, energy transition, and urban sustainability, with the support of research institutions, civil society organizations, and other partners in the region and in Europe.

**Sarah Hepp**

Head of the Regional Climate and Energy Project MENA

sarah.hepp@fes-jordan.org
Fes@fes-jordan.org
Friedrich-Ebert-Stiftung
Amman Office
P.O. Box 941876 Amman
11194- Jordan

**ISBN:** 978 - 9923 - 759 - 24 - 0