MENA Hydrogen Alliance
An initiative of Dii Desert Energy

Roland Berger

THE POTENTIAL FOR GREEN HYDROGEN IN THE GCC REGION

Dii & Roland Berger

May 2021

Content

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Executive Summary

The pivotal role of emission-free energy carriers is becoming visible in all corners of the globe. Swiftly dropping costs of green power are leading to increased competitiveness and growing market shares for green power. As green power becomes cheaper, so does green hydrogen produced from green power. As a result, energy carriers based on green hydrogen become more and more attractive on the path to the decarbonized economy. In spite of great doubts only until a few years ago, today hydrogen is believed to have the potential to become the 'new oil' or the 'new natural gas'. The GCC countries have the advantage of having plenty of space, sunshine and, in some areas, wind energy amidst being prosperous, expanding economies open for innovations. Thus, it is not surprising that the GCC region has quickly become one of the highest-ranked regions in terms of lowest-cost and largest-scale renewable energy projects. Not only the steep learning curves and the relatively low costs of capital, but also the culture of protecting the natural environment as a heritage for next generations is making GCC a natural leader in the energy transition. Hence GCC, like any other energy marketplace, is subject to an accelerating transition towards becoming carbon emission free itself and a significant exporter of emission-free energy Estimates indicate that the global market for green hydrogen may eventually reach 500 m MT by 2050, whereas hydrogen production annual revenues in GCC could grow up to USD 70-200 bn.

The energy transition in GCC will have a major impact on the industries in the region. Particularly, it will impact labor needs, not only in terms of quantity, but also skill requirements of emerging jobs. The emerging 'green energy' economy will offer a spectrum of localization opportunities across the value chain. This will include renewables (mainly solar and wind), electrolysis systems producing hydrogen, potentially upgrading to synthetic fuels, transport, storage and innovative demand-side processes. As the localization opportunities of the hydrogen economy in GCC is still a rather unexplored subject, this joint report of Roland Berger with the international industry network, Dii Desert Energy, is zooming in on the localization and the resulting job creation potential of hydrogen economy in the region. In the short term, job creation seems to be most obvious in the area of renewable generation and electrolysis technologies. In the long term, labor needs will undoubtedly arise along the entire green energy value chain. Estimates point at up to 1 million direct and indirect jobs by 2050.

Public and private stakeholders in GCC may benefit from the following recommendations for hydrogen-related job creation:

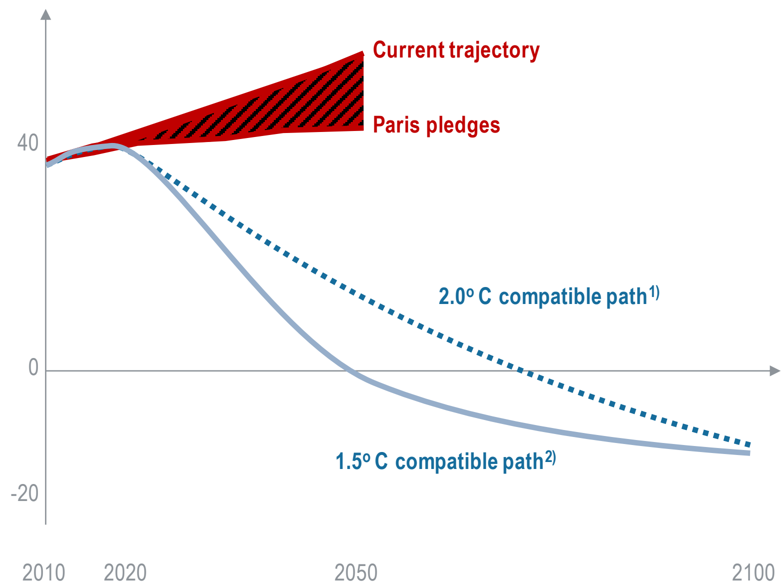
1. Create a vision, give a clear direction and create conditions for success
2. Combine learning and fast growth with economies of scale through 'Hydrogen Valleys', ecosystems focused on successful hydrogen business and trade, attracting investors
3. Connect to the international movements for hydrogen business expansion, particularly becoming part of technology partnerships
4. Make sure the local communities will have the 'license to operate' and be the master of the market by education, training and knowledge

A. GLOBAL H_2 ECONOMY TO DEVELOP SIGNIFICANTLY IN THE COMING DECADES

I. H_2, A KEY LEVER TO DRIVE THE WORLD'S DECARBONIZATION

In the last decades the **increase in CO_2 emissions has profoundly changed the** trajectory of the **world's climate**. It's only recently that governments and populations have acknowledged this phenomenon and have become more and more conscious of the **negative impact that climate change** can have on **societies** and **economies**. In the **Paris Agreement**, 196 countries agreed to **limit global warming to 2ºC and pursue efforts to limit the temperature increase to 1.5ºC.** However, the commitments made after Paris Agreement are not enough to define a path for emissions reduction that complies with the 2ºC goal *(see Illustration 1).*

Illustration 1: Evolution of greenhouse gas emissions depending on level of commitment [gigatons per year]



Scenario explanation

> **Current trajectory**: No measures taken, rising emissions leading to disastrous impact on environment

> **Paris pledges**: Increase in temperature up to +3.2º C, also leading to devastating impact

> **1.5º C & 2.0º C compatible paths**: Best scenarios with less devastating impacts according to scientists – High commitment from countries required to reach ~25 CO_2 Gt by 2030

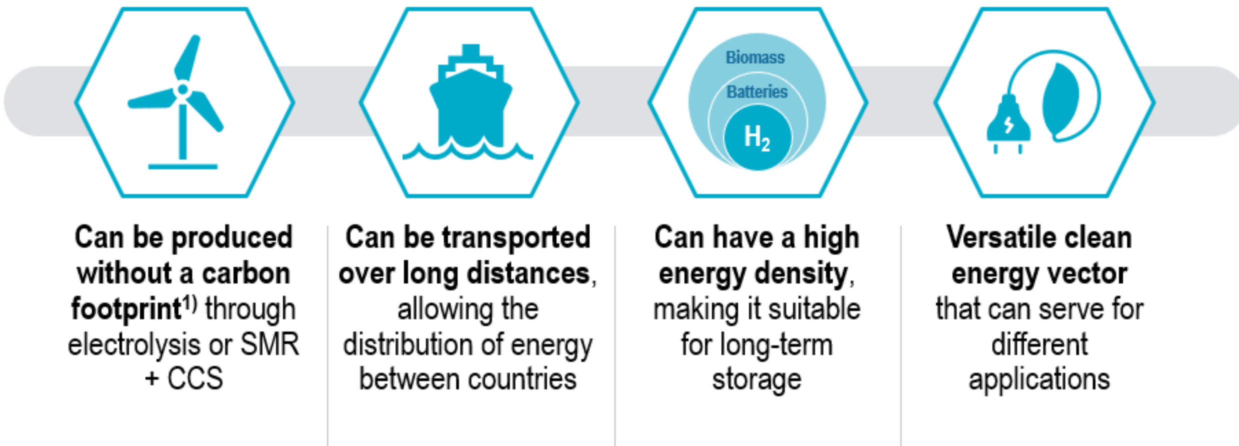
1) Temperature rise limited to 2.0ºC; 2) Temperature rise limited to 1.5ºC

Source: UN, Roland Berger

According to S&P global, the COVID-19 pandemic has increased the **awareness of governments towards climate policy** and has placed at the fore-front the **importance of the energy transition**. For instance, the European Union expects to mobilize at least €1 trillion in sustainable investments over the next decade through the European Green Deal, . In addition, it is estimated that COVID-19 has reduced the long-term oil demand by 2.5 million (m) barrels per day (~3% of the global demand), favoring the energy transition away from oil.

Hydrogen has been recognized as the “missing piece” for the energy transition. Hydrogen's **multiple positive intrinsic characteristics** make it a **clean and versatile energy carrier** *(see Illustration 2)*, while its high gravimetric (energy/weight) energy density characteristics and the availability of raw materials needed to scale up the production ensure it is a **competitive energy carrier.**

Illustration 2: Benefits of clean hydrogen (blue and green)

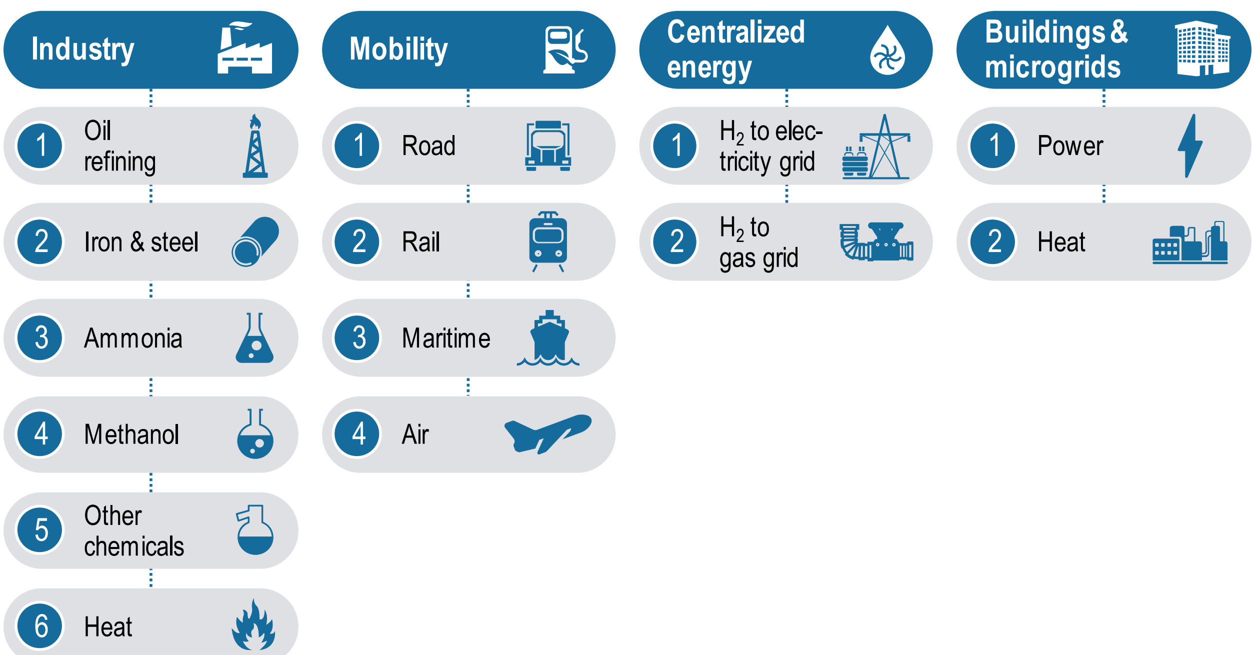


1) Depending on H_2 production type (with current capture technologies, up to 98% of CO_2 emissions in the blue hydrogen production process can be captured. Questions remain for methane leakage in exploration and transport, as well as subsequent usage of the captured CO_2)

Source: Hydrogen Europe

Within economies and societies, hydrogen has **several applications** that **guarantee low CO_2** emission and **enable the energy transition** *(see Illustration 3)*.

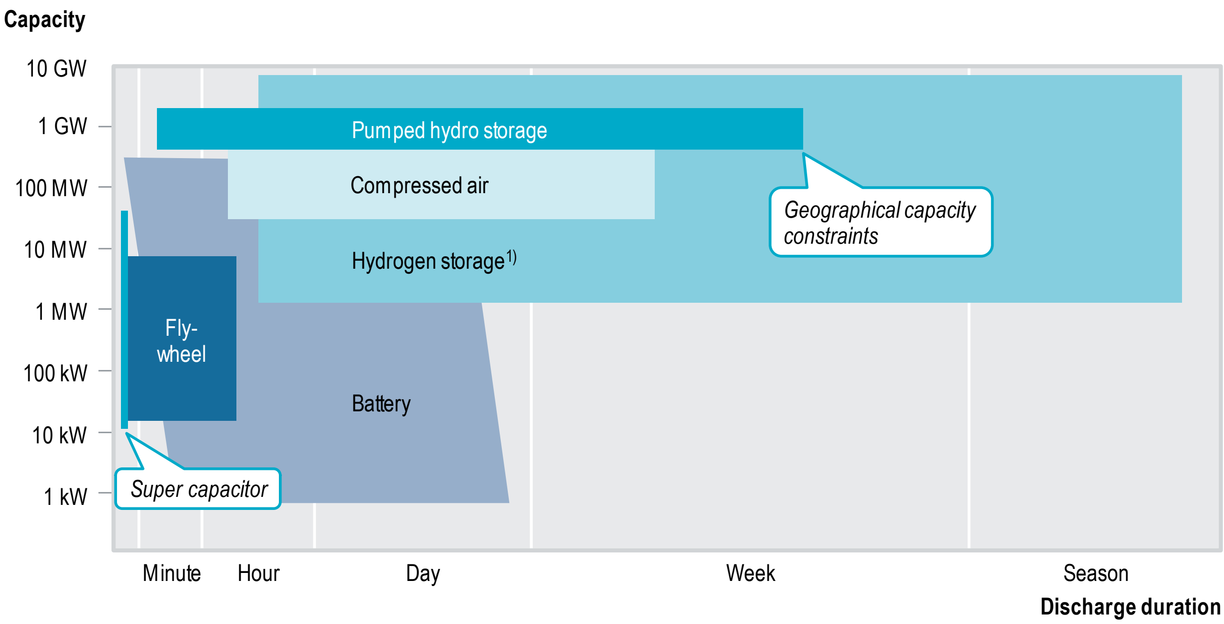
Illustration 3: Mapping of hydrogen end-uses



Source: International Energy Agency (IEA), press review, expert interviews, Roland Berger

Additionally, **hydrogen can be utilized to store energy for significant time-frames** *(see Illustration 4)* utilizing different storage means (e.g., large tanks, salt caverns). According to Geostock (Entrepose Group), some countries from the Gulf Cooperation Council (GCC) have geological conditions that could allow the development of large-scale underground storage facilities in rock formations which could serve as a buffer for varying seasonal demand.

Illustration 4: Energy storage capacity by technology



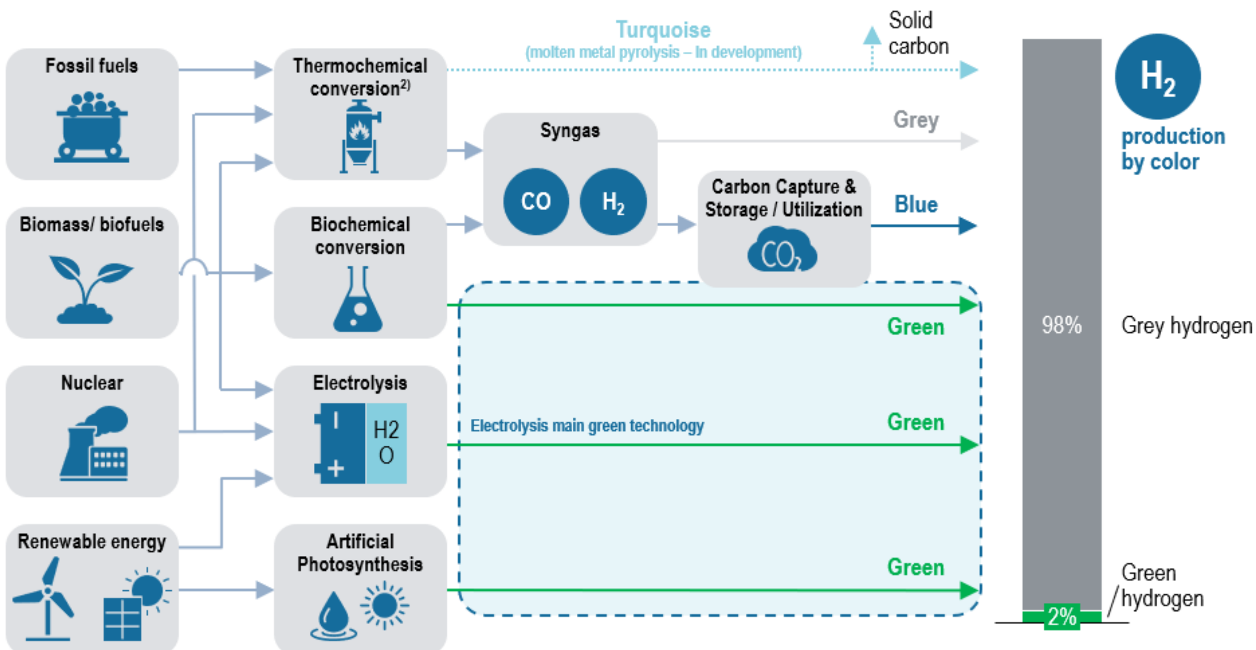
1) IEA data updated due to recent developments in building numerous 1 MW hydrogen storage tanks

Source: IEA, JRC Scientific and Policy Report

Recent national and **regional** (e.g. Europe) **hydrogen strategies** focus primarily on developing **green hydrogen**, which highlights the economic and climate-friendly potential of the molecule.

Although other types of hydrogen (e.g., blue or turquoise, *see Illustration 5*) may play an intermediate role, green hydrogen will grow supported by the expected drop in its price and its limited CO_2 emissions.

Illustration 5: Hydrogen production[1)] pathways and types [2019]



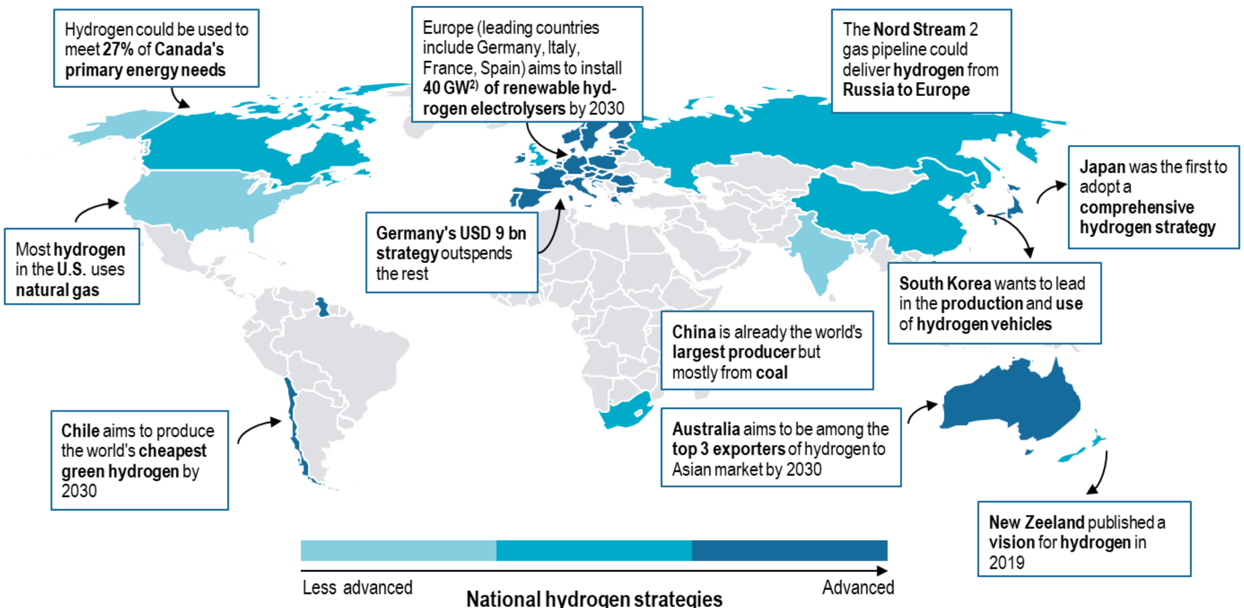
1) Considering **only Dedicated hydrogen** production; 2) Most applied are Steam Methane Reforming (SMR), Partial oxidation (POX), Autothermal Reforming (ATR) or Coal Gasification – Upcoming are Methane pyrolysis and Plasma reforming

Source: IEA, Press review, Roland Berger

The **cost of green hydrogen** is **expected to become competitive with blue hydrogen by 2025** and with **grey hydrogen by 2030** in GCC countries according to various sources (e.g., (Hydrogen Council, 2020), (IHS Markit, 2020)). The cost of renewables is expected to remain the key driver (~60% of the cost per kg of green hydrogen) and the significant drop expected in the cost per kW of eletrolyzers, due to R&D, economies of scale and standardization, will also represent an important lever to reach USD 1.5-2.0 per kg by 2030 or before.

By the end of 2020, the **42+ countries** (including the EU) had **developed strategies and plans focusing on hydrogen development** *(see Illustration 6)*. The largest share of the countries have focused their national strategies on green hydrogen (e.g., Chile, Germany, Netherlands, Portugal), reinforcing renewable-based hydrogen as the key long-term option.

Illustration 6: Hydrogen potential development around the world [2020]



1) Eurasia Group, International Energy Agency; Bloomberg
2) The 2x40 GW initiative of the European industry association Hydrogen Europe aiming to invest in 2x40 GW hydrogen infrastructure, half of which should be deployed inside the EU and half in the Ukraine and Northern Africa

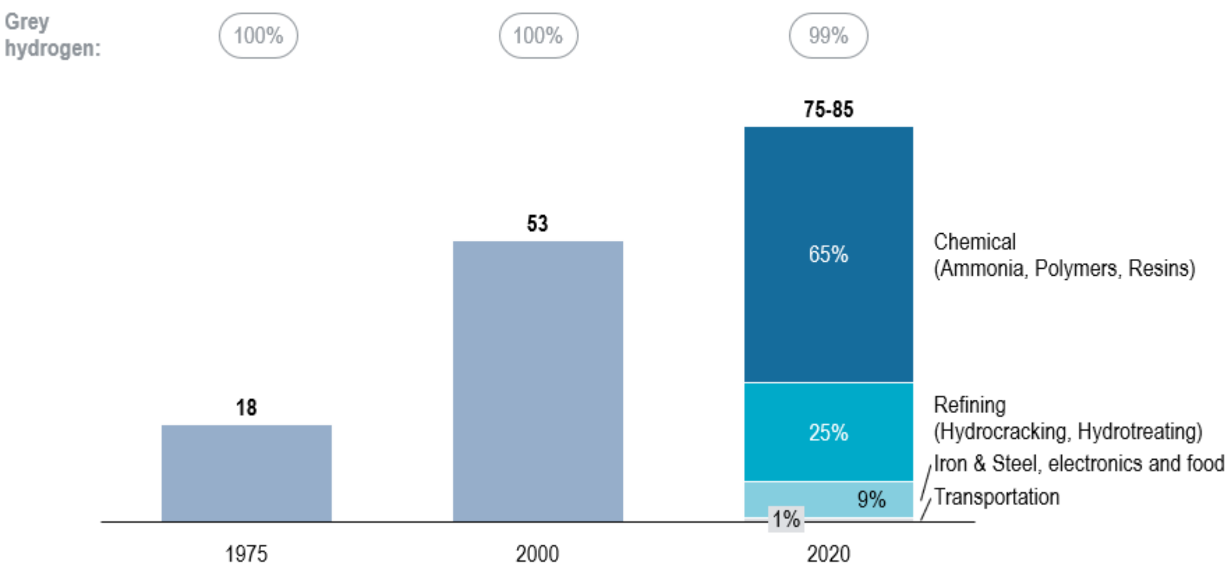
Source: Eurasia Group, International Energy Agency, Bloomberg

II. H_2 GLOBAL DEMAND EXPECTED TO REACH ~580 M MT BY 2050

In the recent years, hydrogen has gained traction world-wide with **chemical and refining industries** in particular driving an **increase in demand**. According to the (IEA, 2019), the international hydrogen demand grew approximately four fold since 1975 and **reached ~75-85 m MT in 2018** *(see Illustration 7)* with grey hydrogen, the most cost competitive hydrogen over the afore-mentioned period (1.5-2.5 USD/kg), utilized in key industries:

- **Chemical industry**, using ammonia as a feedstock to produce fertilizers (~65% of 2018 total demand).
- **Refining industry**, using hydrogen to lower the sulfur content of diesel fuels (~25% of the 2018 total demand).
- **Other sectors,** such as mobility or electricity production, have not so far significantly utilized hydrogen, primarily due to low cost competitiveness, lack of infrastructure (e.g., hydrogen refueling stations) and underdeveloped technologies.

Illustration 7: Historical hydrogen demand by application [m MT, 1975 – 2020]



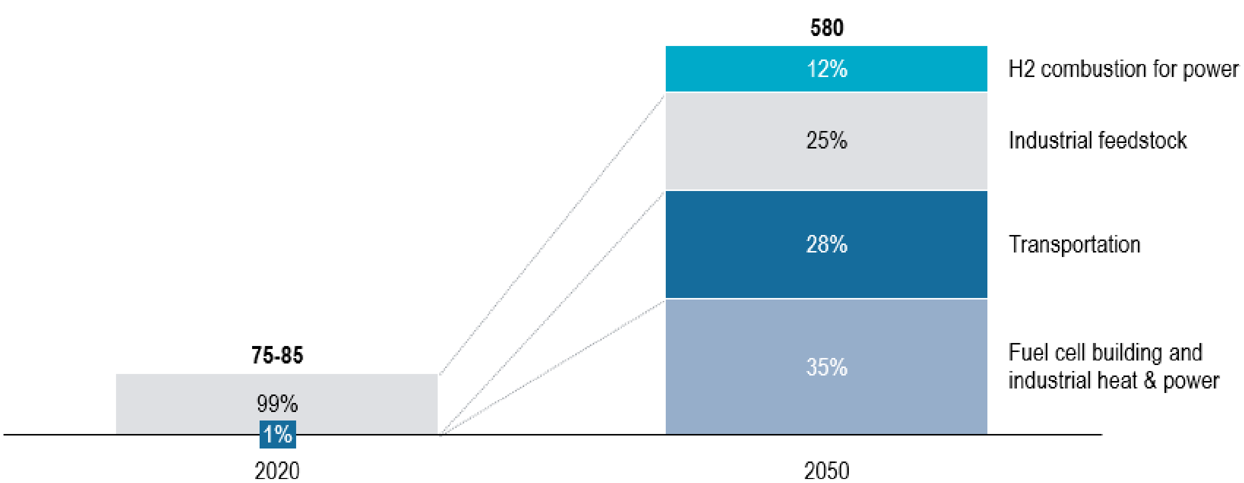
Source: IEA, Roland Berger

In the upcoming decades, **hydrogen stakeholders** (e.g., producers, international hydrogen-related initiatives) are **expecting a significant growth in the hydrogen sector** driven by **three main factors**:

- **Reduction in the Levelized Cost of Hydrogen (LCOH)**: The cost of producing hydrogen is expected to **drop between 30%** (IEA, 2019) **to 50%** (Hydrogen Council, 2020) **by 2030** in GCC countries**.** This is expected to be driven by the continued **decrease in cost of renewable electricity** (e.g., through economies of scale and improved manufacturing technologies) and by **lower capital expenditure investments required** in the hydrogen value chain due to scaling up of manufacturing activities (e.g., lower cost of electrolyzers and other equipment along the value chain). Furthermore, there are several **projects** (e.g., AquaVentus and NorthH2 in Europe) **and collaboration platforms worldwide** (Catapult or HyDeal in Europe) targeting a **drastic cost reduction** in hydrogen (100% green hydrogen for €1.5/kg by 2030).
- **Awareness from companies and market pressure**: Increasing global awareness for the impact of CO_2 emissions on climate change is expected to add further pressure on companies. Several **energy companies have announced a net-zero strategy by 2050** (e.g., Iberdrola, Eni, Enel, BP). In addition, several trends in the investment field, such as sustainable finance, are likely to influence a shift of investments towards companies with lower impact on the environment.
- **Increase in regulations and incentives favoring clean hydrogen adoption**: Given the concerns and awareness around the climate change challenge, policymakers and governments are expected to increasingly introduce **policies and regulations fostering reduction of CO_2** and utilization of green technologies such as hydrogen. For instance, the **European CO_2 market** is expected to have a significant impact on the economy, fostering green products and activities. In **Japan**, the 2017 target of 80% emissions reduction by 2050 is currently under revision and could be expanded to **zero emissions by 2050** (Reuters, 2020)**.**

Given this context, demand is expected to increase significantly, reaching up to **~580 m MT by 2050** *(see Illustration 8)* – hydrogen demand, throughout this paper, includes the demand for hydrogen and derivative products – driven by a rise in new applications such as **building** and **industrial heat & power**, as well as **transportation**. Hydrogen used as an industrial feedstock is expected to increase to ~150 m MT a year.

Illustration 8: Global hydrogen demand forecast [m MT, 2019-2050]



Source: Hydrogen Council

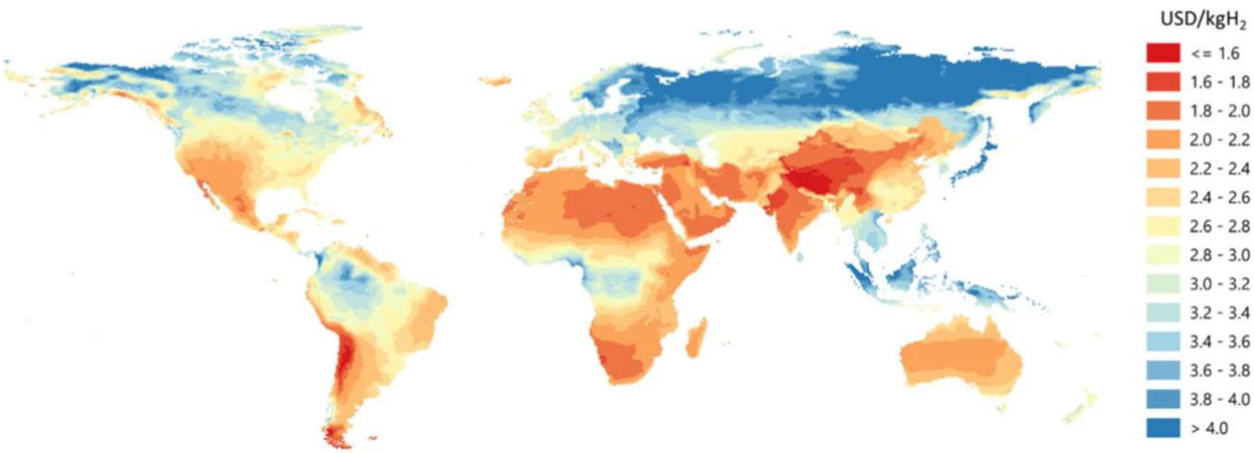
B. HIGH LOCALIZATION POTENTIAL FOR GCC COUNTRIES

I. POTENTIAL H_2 REVENUES FOR GCC COUNTRIES TO REACH USD 70-200 BN BY 2050

GCC countries have a number of competitive advantages that can enable them to play a **significant role on a global and regional scale**:

- **Abundance of solar & wind energy**: The GCC region has amongst the **highest solar radiation in the world**. In addition, some areas benefit from strong and regular wind, making the GCC a **high potential region for renewables**. According to the IEA, the abundance of renewables makes GCC region potentially one of the **most cost competitive for hydrogen production** (IEA, 2020) with long-term cost potentially reaching USD 1.5-2 per kg *(see Illustration 9)*.

Illustration 9: Potential long-term cost of green hydrogen based on solar photovoltaic & onshore wind systems [USD/kg]



Source: IEA

- **Significant funding availability**: GCC countries have **taken advantage of the Oil & Gas economy** to create significant financial reserves, which are often channeled through the important investors such as sovereign funds (e.g., Saudi Public Investment Fund, Abu Dhabi Investment Authority) and international funding sources.
- **Advanced export infrastructure and central location to energy demand markets:** GCC countries have proven track record in building and operating export infrastructure (e.g. United Arab Emirates' Jebel Ali and Saudi Arabia's Jeddah ports among the top 40 ports in the world (World Shipping Council, 2019)) and are well positioned between the potentially large European and East Asian markets (see illustration 10).
- **Local capabilities:** The region's highly qualified workforce in the Oil & Gas sector represents a major opportunity for the development of the hydrogen economy in the region.

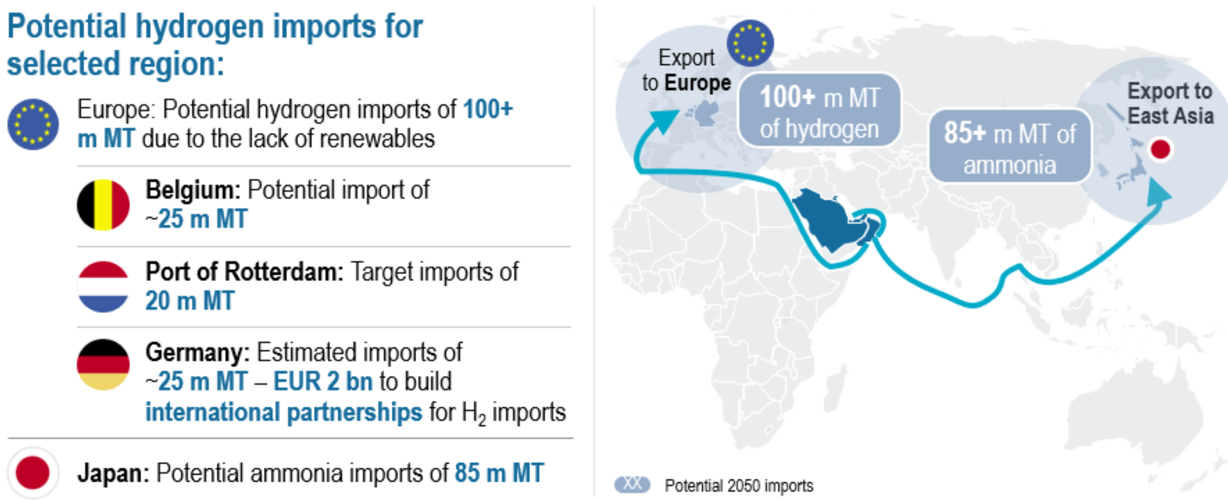
In addition to these **key competitive advantages**, **the future large demand markets** (e.g., EU, Japan) will have **difficulties to ramp up the needed capacities** for H2 production locally considering the timeframe to build the production assets. Furthermore, they might face obstacles **preventing the deployment** of **local large-scale production capacities** to supply their market which would create an **attractive export opportunity for GCC countries**. Indeed, these future large markets could face the following obstacles:

- **Less competitive renewable resources**: Countries could be limited by the low availability of solar and wind due to their geographic location and the limited space availability (for example, a solar park such as Noor Abu Dhabi Solar Park requires 800 ha).
- **Reluctance due to concerns around biodiversity and impact in agricultural land:** Construction of renewable capacity can happen at the expense of the biodiversity and natural environments (e.g. forest). The development of solar PV could impact valuable agricultural land. Offshore wind can further create competition with fishing activities and biodiversity concerns (birds and marine animals). For countries with concerns about these topics, building the required renewable capacity for the hydrogen production could be challenging

- **Public acceptance of power generation and transport assets:** Communities in the large demand markets (e.g., EU, Japan) can oppose the development of power generation and transport assets (e.g., grid, pipelines) next to their local areas

The **resulting opportunity for GCC countries could be significant.** For instance, EU hydrogen imports could reach 100 m MT in 2050 with Germany and Belgium each importing ~25 m MT, while East Asia, especially Japan, could import ~85 m MT of ammonia *(see Illustration* 10*)*. The cost competitive hydrogen from GCC countries could be in a prime position to capture this opportunity and be a key enabler in global decarbonization.

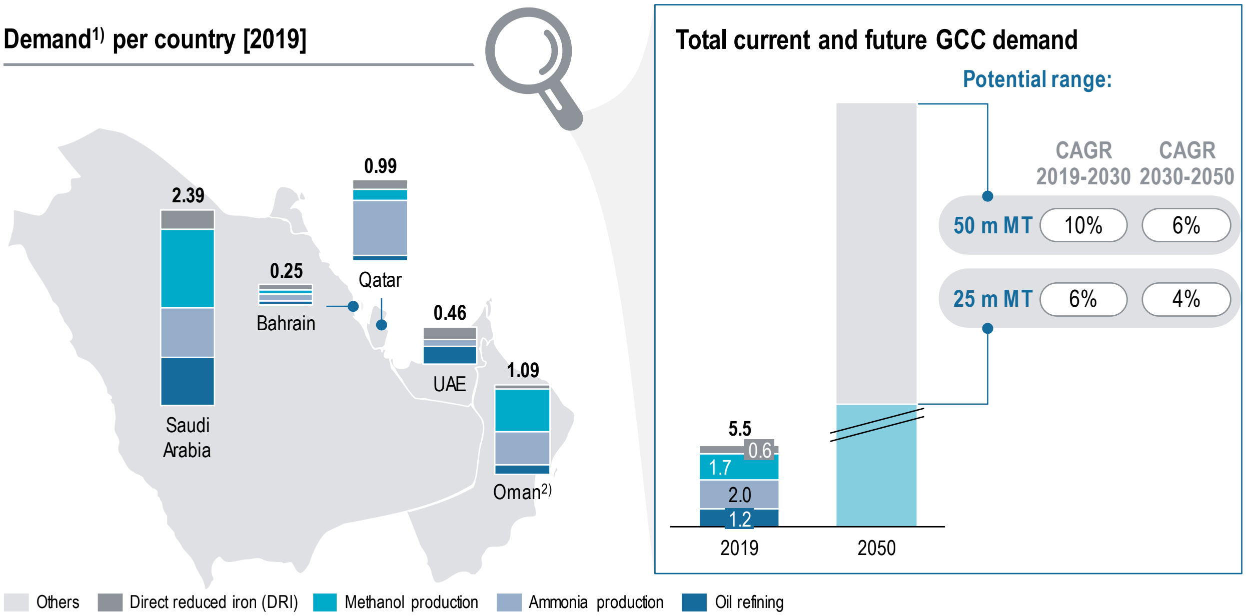
Illustration 10: Potential 2050 hydrogen imports of selected regions and countries [2050]



Source: Vision Port of Rotterdam, Germany's National Hydrogen Strategy, EU Hydrogen Strategy, METI, Hydrogen Korea Team, Roland Berger

In addition to potential export markets, GCC countries can cater for their own regional demand. The **GCC demand in 2019 amounted to ~5.5 m MT**, mainly driven by industrial applications. The regional demand **could reach 25-50 m MT by 2050** driven by existing industries in the region (e.g., methanol and ammonia production) and local activities (e.g., transportation, energy) *(see Illustration 11)*. It is assumed that green hydrogen will be the most competitive hydrogen source by 2050 supported by policies and regulations and thus 100% of local demand is assumed to be supplied through green hydrogen.

Illustration 11: GCC current and future hydrogen demand by application [m MT]



1) Demand for other chemicals not included; 2) Announced projects included

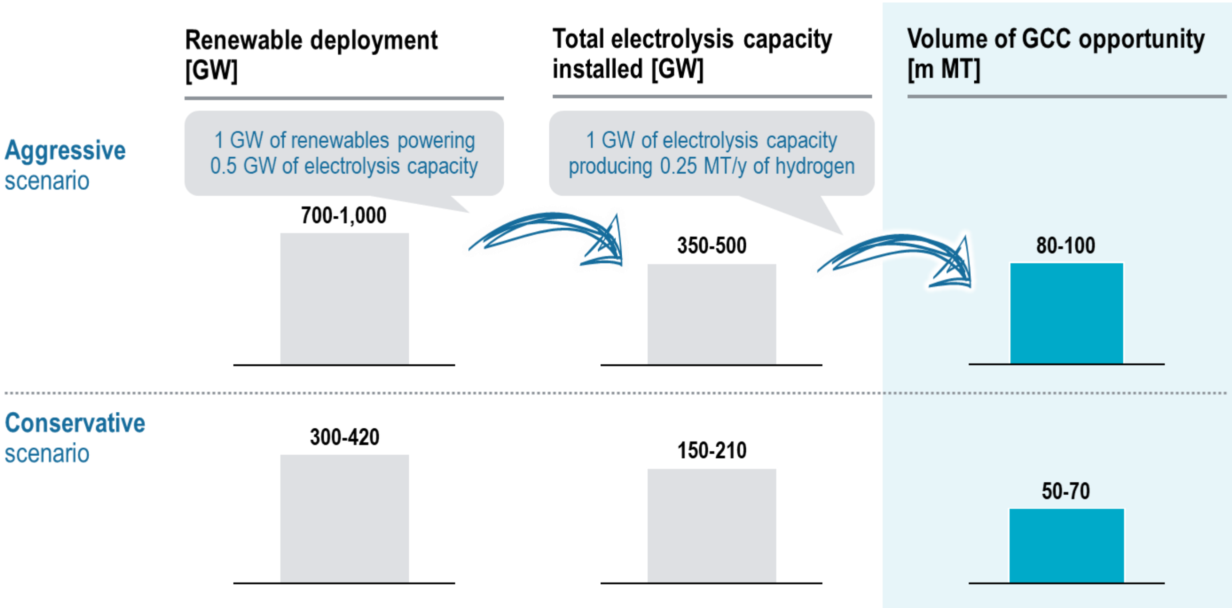
Source: IEA, Roland Berger

GCC countries are in a prime position to achieve this ambition by leveraging distinct competitive advantages which will enable to develop the local hydrogen industry and also access a significant share of the global market. Given their competitive advantages, the future hydrogen market share of these countries will depend on how much hydrogen they can phyisically supply.

Conservative and aggressive scenarios are defined based on the level of renewable deployment that could be achieved in GCC countries:

- **Conservative scenario**: Supposing that GCC countries continue the renewable deployment in line with the 2030 targets (~100-140 GW per decade), they would be able to dedicate those 300-420 GW for the hydrogen production accordingly (*see Illustration 12*). This renewable deployment would power ~150-210 GW of electrolysis capacity to produce 50-70 m MT of hydrogen per year by 2050.
- **Aggressive scenario**: GCC countries could deploy a higher amount of capacity to address a larger share of the market (*see Illustration 12*). Chile, for example, plans to deploy 300 GW for hydrogen production by 2050 (Government of Chile, 2020). As GCC is ~3 times larger than Chile in terms of surface, we estimate that GCC could deploy a renewable capacity of 700-1,000 GW. This renewable capacity would power ~350-500 GW of electrolysis capacity, that could produce 80-100 m MT of hydrogen per year by 2050.

Illustration 12: Potential hydrogen opportunity for GCC countries [2050]

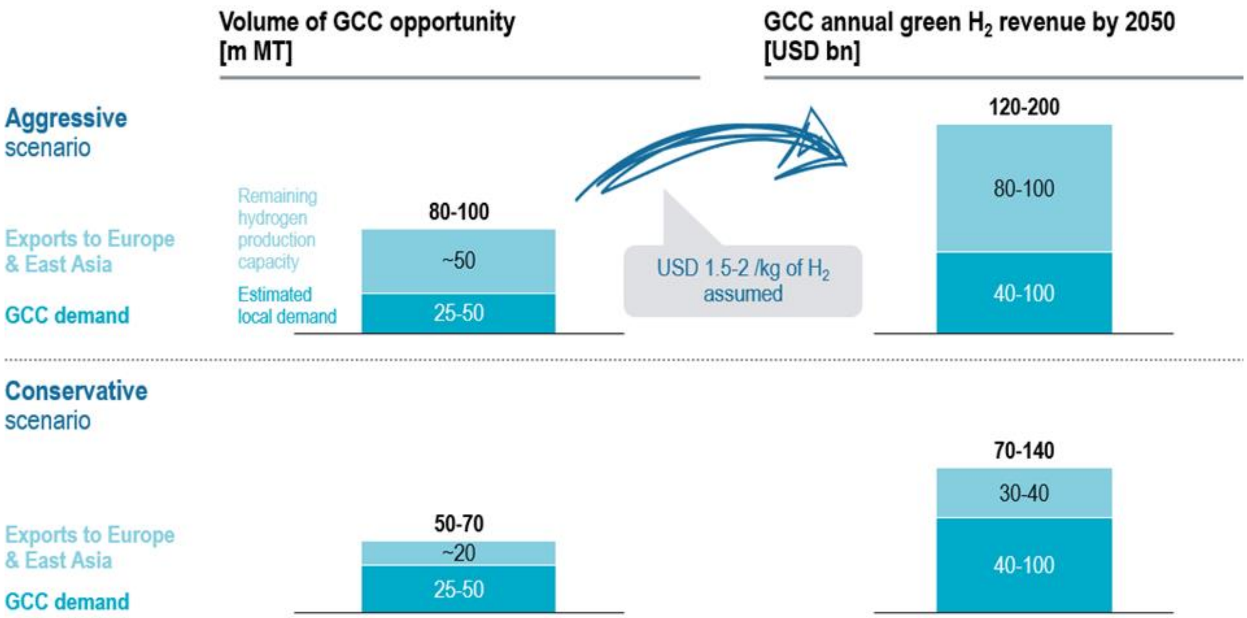


Source: Roland Berger

Installing the afore-mentioned renewable and electrolysis capacities would allow the GCC countries to capture a large share of the international markets leading to potential **generation of USD 70-200 bn annual revenue from hydrogen by 2050:**

- **Conservative scenario**: In addition to supplying the local hydrogen demand, GCC countries would supply ~20 m MT for the Europe and East Asia markets by 2050 (equivalent to 10% market share in Europe and East Asia markets) resulting in potential generation of **USD 70-140 bn annual revenue** from hydrogen by 2050 (*see Illustration 13*).
- **Aggressive scenario:** In addition to supplying the local hydrogen demand, GCC countries would supply ~50 m MT for the Europe and East Asia markets by 2050 (equivalent to 30% market share in Europe and East Asia markets) resulting in potential generation of **USD 120-200 bn annual revenue** from hydrogen by 2050 (*see Illustration 13*).

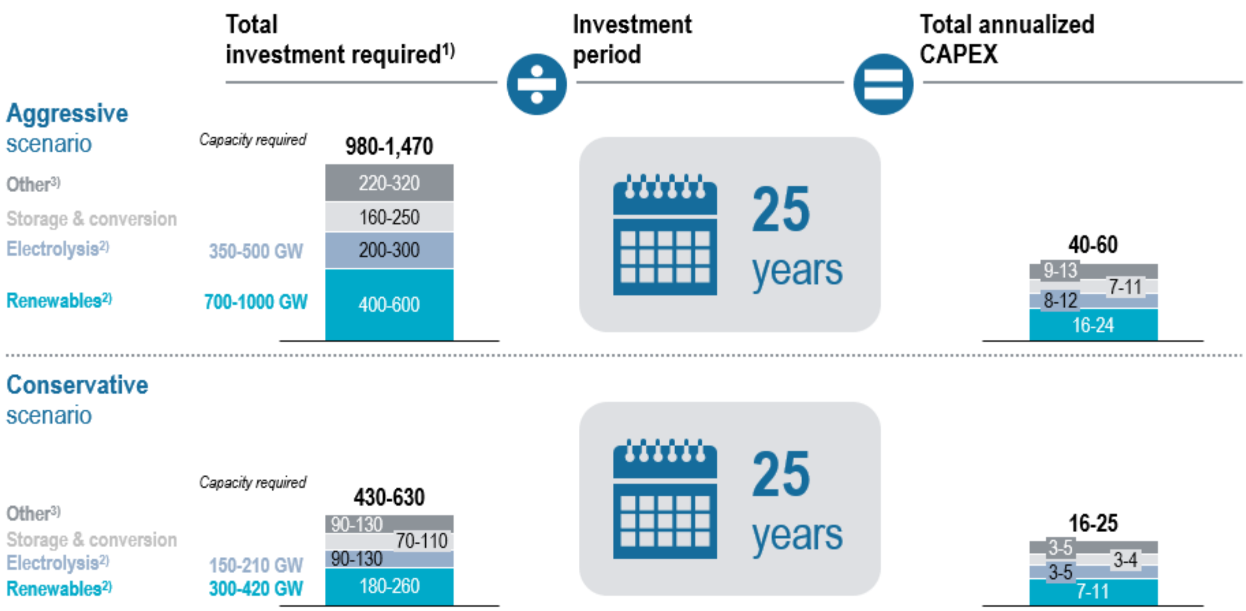
Illustration 13: Potential hydrogen revenues of GCC countries [2050]



Source: Roland Berger

Installing the renewable & electrolysis capacities mentioned would require an annual **investment of USD 16-60 bn over a period of 25 years** *(see Illustration 14)*, mainly driven by the cost of installing the renewable capacity (30-40% of the total).

Illustration 14: Estimation of investments required from GCC countries by 2050 [USD bn]



1) Investments required to capture the 50-100 m MT GCC opportunity by 2050 – Factor of USD 15 k CAPEX/kg applied (ratio from large projects combined with a 30% efficiency gain);
2) CAPEX/GW assumed: USD 0.4-0.6 bn for renewables, USD 0.4-0.6 bn for electrolyzer; 3) Includes costs for grid connection, electricity storage, water, nitrogen and pipelines

Source: Roland Berger

The key **competitive factors to address the Europe and East Asia export markets** will be the **hydrogen price** and the **carbon emissions related to hydrogen production**, due to the anticipated regulations in these geographies (e.g., European CO_2 regulation). To be competitive on both factors, GCC countries must produce green hydrogen and make significant investments in the near future to reach cost competitiveness before potential competitors (e.g., Morocco, Spain, Australia), thereby harvesting the early-mover benefits.

The journey to a large-scale green hydrogen production facility running at full capacity has not been achieved yet world-wide, and obstacles and delays may arise; moving early – with the support of relevant policies and regulations – will allow GCC countries to be at the forefront of the hydrogen race.

II. GCC COUNTRIES' GREY H_2 CAPACITY AND RECENT INVESTMENTS IN GREEN H_2

GCC countries currently have a hydrogen production capacity of 5-6 m MT/year mainly utilizing Steam Methane Reforming (SMR) (grey hydrogen) which primarily addresses refineries and ammonia demand requirements.

More recently, GCC countries **have made progress** on the **green hydrogen front** with several promising projects and initiatives being announced in 2020 and early 2021.

In **Saudi Arabia**, a **large-scale 2 GW green hydrogen production facility for Ammonia** is being planned in NEOM, located on the west coast of the country *(see Illustration 15)*. This project is being developed through a partnership composed of **ACWA Power, Air Products and NEOM**, with **thyssenkrupp** as the hydrogen technology partner and is one of the largest green hydrogen projects in the world. Given the availability of competitive and low-cost renewable energy, NEOM will **produce green hydrogen at scale and convert it to green ammonia for export**. Air Products is going to be the distributor of the green product. NEOM's prime location enables world record **low renewable energy prices**, and among the highest combined capacity factors by solar and wind energy beyond 70%, aiming to produce hydrogen between USD 1.5-1.95 per kg depending on the set-up.

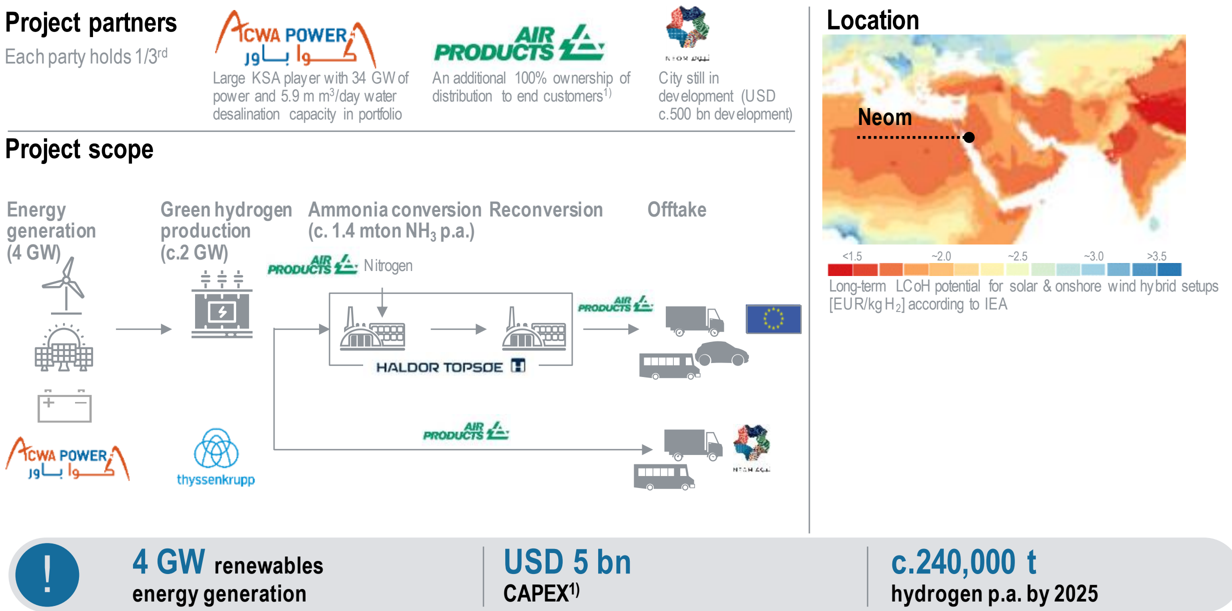
Neom has developed a **comprehensive localization approach and strategy** which could have the potential to make it a first hydrogen valley in the MENA region. As a core element of the above-mentioned green hydrogen project, the electrolyzers are envisioned to be assembled by thyssenkrupp locally with a focus on the cells. Considering the size of the project with approx. 2GW of electrolyzer capacity, the local manufacturing could serve as an incubator for Neom and other green hydrogen projects nationally and potentially internationally for electrolyzers and the broader value chain.

Furthermore, in December 2020, the **Hyport® Duqm Green Hydrogen Project** was announced in **Oman**. The project plans for a 250-500 MW electrolyzer powered by solar and wind (Deme Group, 2020). In addition, Sohar Port aspires to become the Middle East's first green hydrogen generation hub powered by gigawatts of solar.

In the United Arab Emirates (UAE), an industrial-scale green hydrogen pilot project of **DEWA and Siemens** is in commissioning phase (DEWA, 2020). In addition, the **Ministry of Energy and Infrastructure** launched the' **UAE Hydrogen Technical Committee** in 2020, which brings together the key stakeholders who will be able to shape the future of hydrogen in the UAE. Furthermore, the Abu Dhabi National Oil Company (ADNOC), ADQ and Mubadala have launched the **Abu Dhabi Hydrogen Alliance** aiming at developing UAE's international leadership in hydrogen and a substantial green hydrogen local economy (Mubadala, 2021). **Mubadala** also signed a Memorandum of Understanding with **Siemens Energy** and other energy players to **accelerate green hydrogen capabilities** in UAE. This project is unique since the goal is to produce e-fuel (great potential in the region) with airlines as off-takers, as well as to promote hydrogen based ecosystems. These developments signal significant green hydrogen developments in the future, which will enable **GCC countries to advance rapidly**.

Moreover, under the umbrella of Dii Desert Energy, the **MENA Hydrogen Alliance is bringing together private and public sector actors and academia to kick-start a (green) hydrogen economy** based on low-cost value chains for green molecules in the region and beyond.

Illustration 15: Overview of NEOM project in Saudi Arabia



1) Air Products invests an additional USD c.2 bn in the distribution to end customers resulting in a total investment of Air Products of USD 3.7 bn

Source: Air Products, IEA, Roland Berger

III. HIGH POTENTIAL FOR LOCALIZING ELECTROLYZERS

The **production of green hydrogen** usually follows a **four-step process** involving different stakeholders and technologies. The four steps include *(see Illustration 16)*:

- **Renewable generation**: Production of green electricity from renewable sources (e.g., solar, wind).
- **Electrolysis**: Conversion of the electricity into hydrogen via electrolyzers.
- **Transportation, storage & distribution**: Storage of hydrogen in tanks or combined with another molecule. Transportation and distribution to the consumption location.
- **Final use**: Consumption of hydrogen as a feedstock by off-takers in their industrial process or in other applications (e.g., fuel cell vehicle, centralized electricity system).

Illustration 16: Hydrogen value chain overview

Source: Roland Berger

GCC countries have an **attractive localization opportunity** along the **hydrogen value chain** (see *Illustration 17*). Among the value chain elements, **electrolysis has the largest potential in the short-term**. The **key opportunity lies in the manufacturing activities**, due to:

- **Technological maturity**: The electrolysis technology (Alkaline and PEM) is mature and doesn't have any major technological barrier.
- **Limited industry development**: Capacities for large-scale electrolyzers are just being ramped up and, given the overall market growth, this creates an opportunity for GCC countries.
- **Attractive share of value**: This step of the value chain represents a 20-40% share of the total cost.

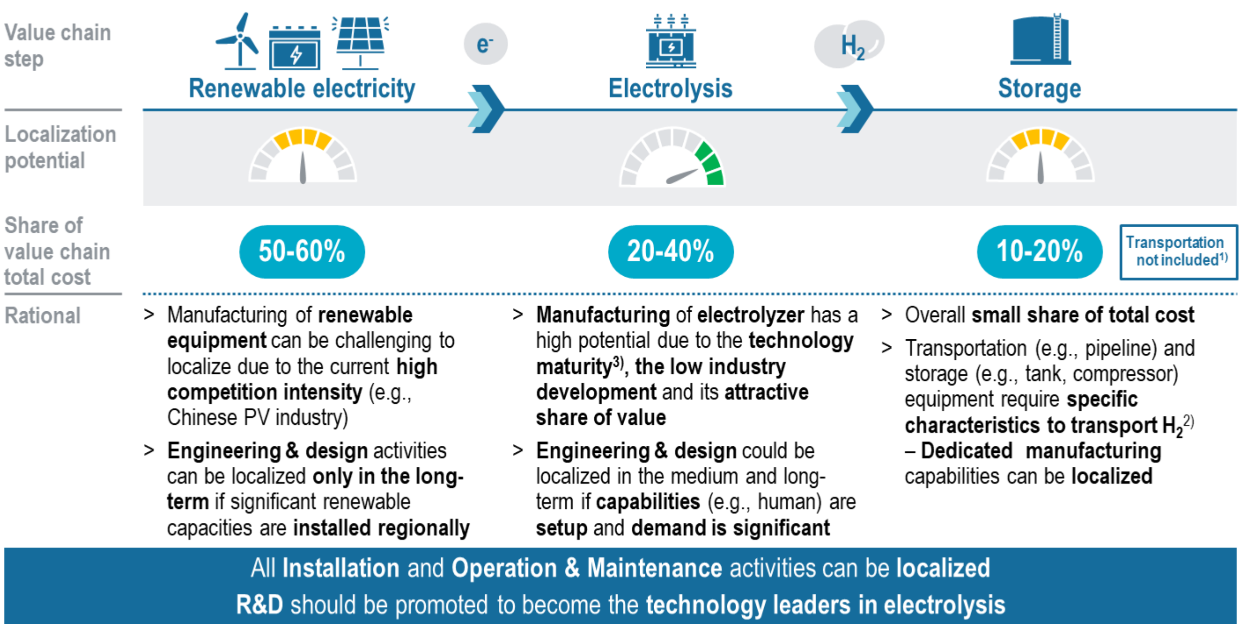
Additionally, **engineering & design activities could be localized** in the **medium and long-term** if the demand is significant and the required capabilities are developed. **R&D activities should be promoted to gain technological leadership** along the hydrogen value chain**.** These activities would require significant efforts to build human capabilities (e.g., dedicated programs, international partnerships) and the localization of these activities would take a lengthier timeline than other activities in the sector.

Opportunities further exist in other parts of the value chain:

- **Renewable electricity**: Engineering & design activities can be localized in the long-term if significant renewable capacities are installed regionally. Other activities (e.g., manufacturing, R&D) require targetted strategies due to high competition (e.g., Chinese PV industry).
- **Transportation & storage**: Despite the small share of the value chain total cost (10-20%), opportunities can arise from the specific requirements for hydrogen transportation (e.g., reinforced pipelines and tanks to resist hydrogen corrosiveness) and dedicated manufacturing capabilities could be localized. Opportunities created will depend on the types of transport vectors used (e.g., ammonia, LOHC).

Across the whole value chain, **all installation and operation & maintenance activities will need to be localized,** contingent on the right human capabilities being in place and could also represent an opportunity for GCC countries.

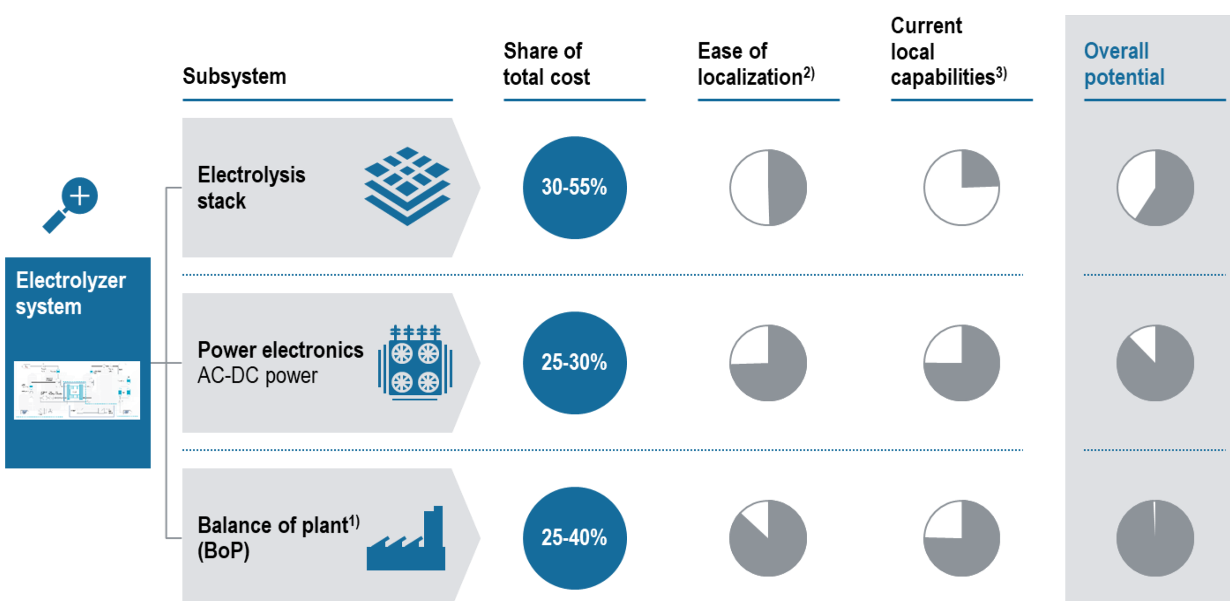
Illustration 17: Localization potential across the hydrogen value chain (final use not considered)



Source: Expert interviews, Roland Berger

Within electrolyzer systems, balance of plant and **power electronics components** are the subsystems with the **highest potential for localization** (see *Illustration 18*). Indeed, both subsytems combine a significant share of the total electrolyzer cost (25-40% and 25-30% respectively), some of the capabilities required are already in place in the GCC countries (e.g., metal fabrication and electronics manufacturing production capabilities) and the limited complexity of the subsystems enables a reasonable ease for fast localization. Despite a higher share of total cost (30-55%), the electrolysis stack part has a lower overall potential in the short & medium-term, mainly due to the complexity of the technology and the international partnerships and significant investments required to develop the technology.

Illustration 18: Localization potential of electrolyzer sub-systems



1) Including liquid & heat management, gas management and other parts such as cooling, sensors, valves, flow meters;
2) Including technology complexity and investment requirements; 3) Current presence of relevant capabilities in the GCC countries

High potential   Low potential

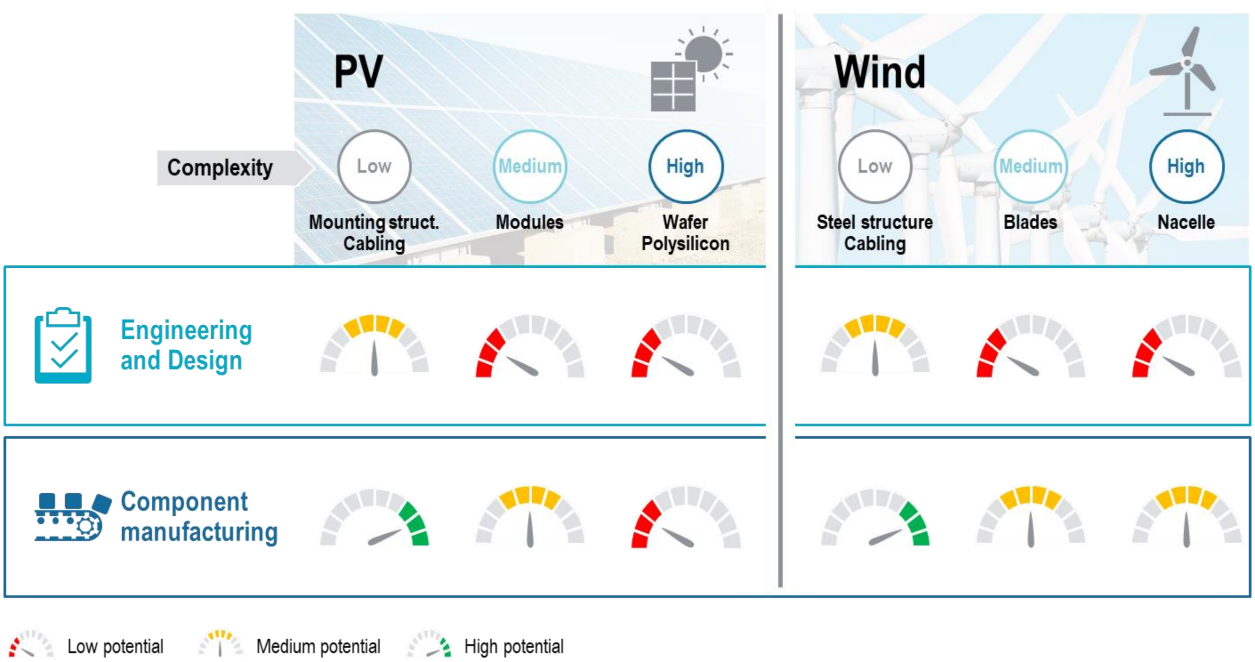
Source: RVO, EKZ, Kumar and Himabindu 2019, NREL, expert interviews, Roland Berger

In addition to electrolyzers, demand for green hydrogen in GCC countries will also support the **localization of the renewable energy value chain**. For PV and wind projects, non-complex components can potentially be engineered in GCC countries using the existing capabilities while more complex components are expected to be engineered outside the region at the location of the component manufacturer.

Manufacturing of non-complex PV components (e.g., mounting structures, cabling) is expected to be **localized in the short-term leveraging the current GCC capabilities.** Manufacturing of more **complex PV components** (e.g., wafer and polysilicon) **face high global competition leading to reduced competitive advantage** to localize for GCC countries.

Wind turbine components offer a comparably high potential to localize for GCC countries as the leading manufacturers globally have already succeeded in localizing the manufacturing of these components in various parts of the world (e.g., Asia, Latin America, Europe). **Non-complex wind turbine components** (e.g., steel structures, cabling) can be manufactured locally **using current GCC capabilities in the short-term**. Additionally, **more complex wind turbine components** (e.g., blades, nacelle) can potentially also be **localized** in GCC countries in **mid- and long-term by establishing partnerships** with international players and **ensuring technology transfer** (e.g. in 2017, Siemens Gamesa inaugurated Africa's first wind blade factory in Tanger, Morocco).

Illustration 19: Localization potential of Renewable Energy value chain



Source: Expert interviews, Roland Berger

IV. POTENTIAL OF ~1 M JOBS FROM THE GREEN H_2 VALUE CHAIN LOCALIZATION BY 2050

The development of the **hydrogen economy and localization of the value chain activities** represent **new employment opportunities** across a wide range of positions and skills. The GCC countries becoming a leading player in the hydrogen ecosystem could result in the creation of **400-900 k direct** and **indirect jobs** in the region by 2050.

This estimation is based on the afore-mentioned hydrogen economy scenarios of **USD 70-140 m** (Conservative case) and **USD 120-200 m** (Aggressive case) **revenue from green hydrogen production**. In addition, it is contingent on the level of local manufacturing activities in the GCC countries which foster local job creation.

In a **conservative case** it is assumed that GCC countries will achieve high levels of localization for manufacturing of low complexity components from the hydrogen value chain (e.g., steel structures, electrical components) and partially of medium complexity components (e.g. solar photovoltaic modules).

In the **aggressive case**, GCC countries will achieve high localization of low and medium complexity components while partially localizing the manufacturing of high complexity components (e.g. polysilicon).

Illustration 20: Localization scenarios

Scenario	1 Conservative case	2 Aggressive case
Hydrogen economy	**Medium** > GCC countries capture a market share of only 10% import market from Europe and East Asia	**High** > GCC countries manage to capture a 30% market share of Europe and East Asia markets
Local manufacturing	**Medium** > Low complexity components are highly localized > Medium complexity components are partially localized	**High** > Low and medium complexity components are highly localized > High complexity components are partially localized

> **Low complexity components:** Components which do not require sophisticated technologies to be localized in the region (e.g., steel structures, electrical components, piping)
> **Medium complexity components:** Components which are complex, but have a substantial potential to be localized in the region (e.g., PV Modules, nacelles)
> **High complexity components:** Components which are complex and require significant technology transfer to be localized in the region (e.g., polysilicon, compressors)

Source: Roland Berger

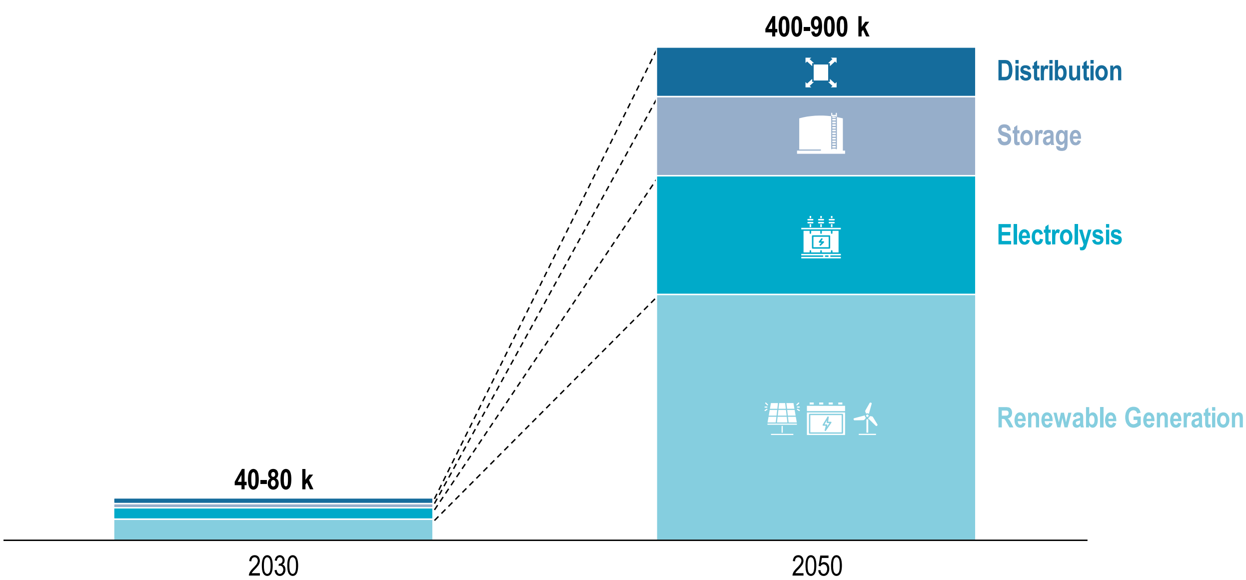
Consequently, it is expected *(see Illustration 20)* that the **largest job creation in the value chain** will be within the **renewable industry dedicated to green hydrogen**. **~200-450 k jobs are expected** to be created in the region by 2050 for the renewable generation related to hydrogen production, of which a majority will be for the manufacturing and construction of the renewable capacity.

Additionally, the **electrolysis industry is expected to contribute substantially** to the job creation in the region. By 2050, electrolysis and related industries have the potential to employ between **~100-220 k** people in GCC countries.

Lastly, **hydrogen storage** is expected to create **~65-150 k direct** and **indirect jobs** by 2050 while hydrogen distribution sector has the potential to create employment for **~45-90 k** people in the GCC countries.

A large share of the jobs created in hydrogen economy is expected to be in **manufacturing activities** across the hydrogen value chain, with a total of **~180-400 k** people employed in these activities by 2050. In addition, **~120-270 k** jobs are expected to be created in **design & installation-related activities**. Finally, **~100-230 k** jobs are expected within the **operation and maintenance activities** across the hydrogen value chain by 2050.

Illustration 20: Job creation by value chain activity [2030-2050]



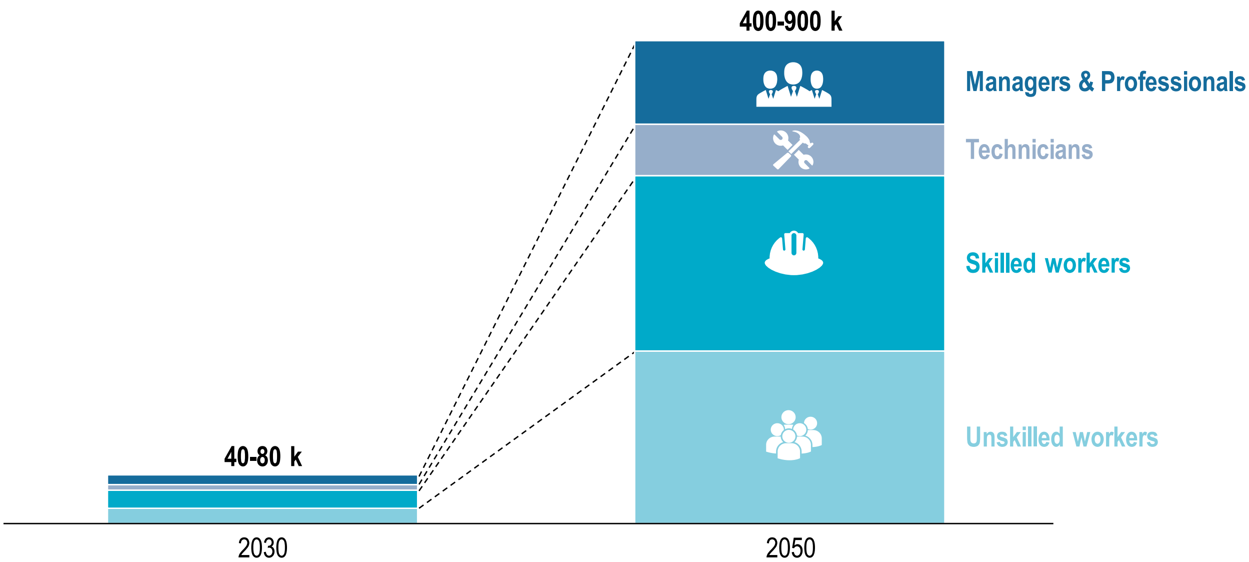
Source: Roland Berger

The development of the hydrogen industry in GCC countries will ensure the creation of a significant number of **high-skilled jobs** in the region *(see Illustration 21)*. It is estimated that **~75-150 k** people with a **university background** can be employed in the hydrogen and related industries as managers or professionals by 2050 mainly driven by design, project development and engineering activities. The majority of these will be **engineers** from diverse backgrounds consisting of primarily electrical, chemical and mechanical engineers.

Technicians will also be **required,** driven by manufacturing and O&M activities, with the potential to employ **~45-90 k technicians by 2050** across the hydrogen value chain.

Workers will be the **job group with highest demand,** especially within the manufacturing and construction activities throughout the value chain. **~150-320 k skilled (e.g., electricians, metal and machinery workers) and ~150-360 k unskilled workers (e.g., labourers, assemblers)** are expected to be employed in the GCC hydrogen economy by 2050. As GCC countries become a hub for the global hydrogen economy, manufacturing jobs will be permanent while a part of construction workforce will eventually shift to other sectors as the hydrogen sector development & construction is scaled down.

Illustration 21: Job creation by skill level [2030-2050]



Source: Roland Berger

The emerging jobs in GCC hydrogen economy will create a **substantial demand for fresh graduates and experienced professionals in the region**. However, during the transition into the hydrogen economy, there is potential that part of the newly created positions can be filled leveraging existing local capabilities.

The region's **highly qualified workforce in the Oil & Gas sector** represents a major **opportunity** for the development of the hydrogen economy in the region.

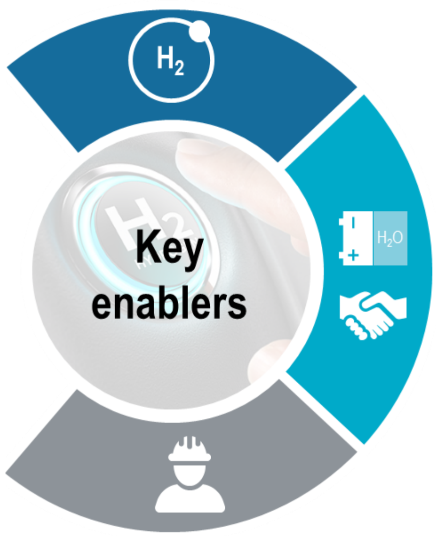
In particular, **potential exists in the manufacturing industry** currently supporting the Oil & Gas sector in the region. Part of the workforce in the manufacturing activities can transition into the manufacturing industry, which will support the hydrogen value chain.

The compatibility of the **positions and skills between the Oil & Gas and the hydrogen industry** will reduce the efforts needed to develop the workforce for the newly developing hydrogen sector, reduce the redundancies in the workforce driven by the decarbonizing of the economy and also support the Saudization efforts in the newly developing hydrogen economy.

C. H_2 STRATEGIES, INFRASTRUCTURE & HUMAN CAPABILITIES AS KEY ENABLERS

To accelerate the development of the hydrogen ecosystem, GCC countries must address **three key enablers** *(see Illustration 22)*.

Illustration 22: Key enablers for hydrogen in GCC countries



1 H_2 strategies, policies & regulations

> GCC countries need to set a **common direction** for their key stakeholders and develop tailored **regulations** & **incentives** to foster the ecosystem

2 Ecosystem development

> **Hydrogen valleys:** Combining production and consumption of **H_2 in valleys** is required to bring **costs down** and to **enable the hydrogen ecosystem**

> **International partnerships and R&D programs**:
  – In the short-term, GCC countries need to setup R&D partnerships with international technology providers to accelerate H2 ecosystem development
  – In the medium-term, R&D programs must be developed to enhance leadership

3 Human capabilities

> To develop the right human capabilities, GCC countries must enhance the **university & TVET programs and sector-specific trainings**

Source: Roland Berger

I. COMPREHENSIVE H_2 STRATEGIES AS A KEY ENABLER

Countries leading the push to decarbonize their economies, have focused their efforts on developing **specific and tailored hydrogen strategies**. In recent years, **42+ countries (including the EU) have developed strategies and plans focusing on hydrogen** *(see Illustration 6,* Illustration 23*)*.

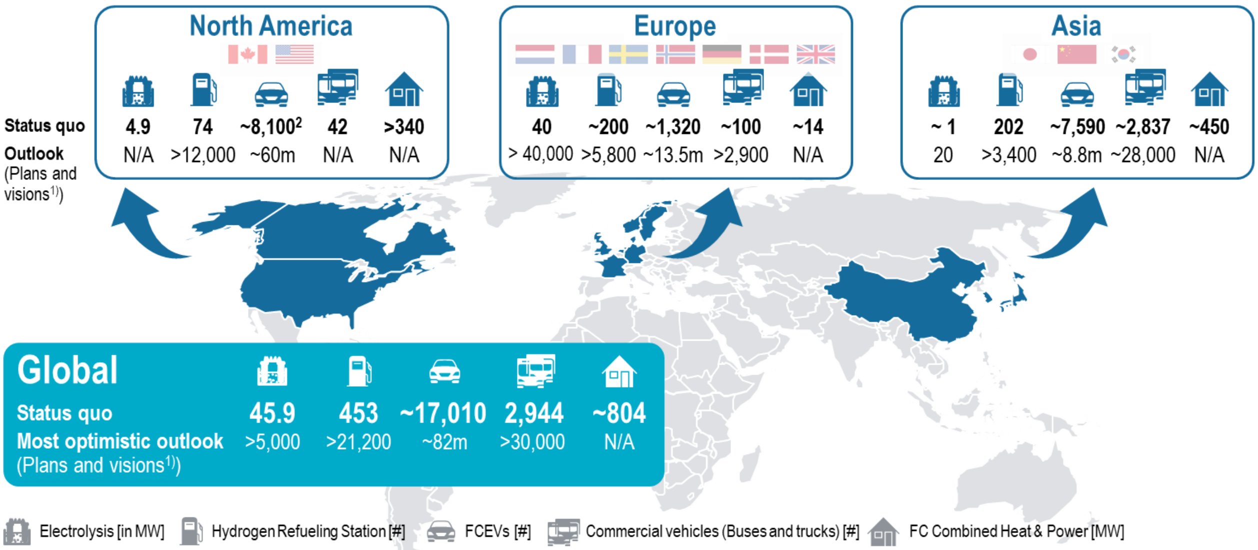
Often the **hydrogen strategies** are announced in parallel to the energy system integration strategies, providing a **framework for the green energy transition**, hence highlighting the importance of an integrated energy system in which all sectors can fully contribute to decarbonization. (e.g., European Union).

These hydrogen strategies define the approach for countries to develop their hydrogen economy. Most of the strategies include elements such as **quantified targets** and **roadmaps**. To ensure the quality and relevance of the strategy, key stakeholders (e.g. private sector, relevant ministries, citizens) are involved throughout the design process.

Quantified targets are a key element within the strategies of multiple **countries**. For instance, **2030 targets have been set in North America, Europe and Asia** on **hydrogen mobility and combined heat & power applications** *(see Illustration 23)*. Going forward, it will be also key for GCC countries to set quantified targets and define clear execution roadmaps.

The involved governments have communicated ambitions to have >80 m fuel cell cars on the road by 2030, and >21 k hydrogen refueling stations. In addition, >30 k commercial vehicles have been announced to decarbonize public transportation, with Asia representing the largest share of the global target (>28 k).

Illustration 23: Publicly stated plans of deployment of FCH technology by continent

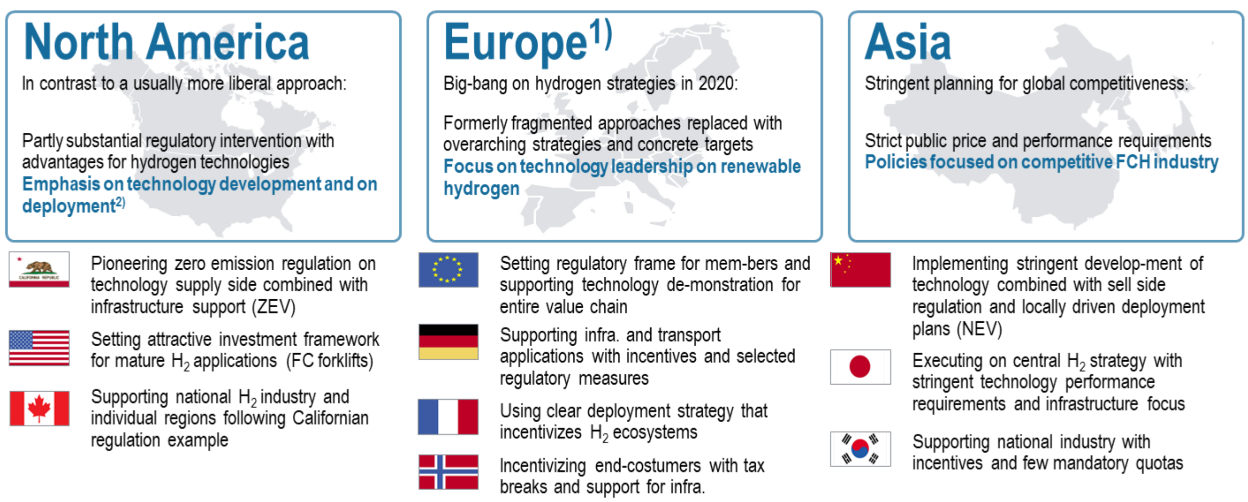


1) Sum of government´s publically stated ambition worldwide (Long-term 2030+) 2) 8,098 FCEVs in California

Source: Public reports and databases, Roland Berger

Countries with hydrogen ambitions have also developed their **regulatory landscape to foster the ecosystem** *(see Illustration 24)*. Approaches and tools differ depending on the region, varying from technology development (e.g. grant for pilot projects) to end-users (e.g. tax removal on hydrogen, performance requirement, carbon tax).

Illustration 24: Hydrogen policy landscape analysis



1) Only a selection of analyzed countries for Europe 2) For selected fuel cell market segments (e.g. forklifts in USA or FCEVs in California)

Source: Roland Berger

Key **best practices and next steps** can be derived from benchmarking, among others, U.S., China and Chile national hydrogen strategies, and must include *(see Illustration 25)*:

- **Quantified and realistic targets**: GCC countries must set realistic and meaningful targets in terms of hydrogen production, markets, and investments.
- **Comprehensive and integrated approach**: A comprehensive strategy specific to hydrogen including a clear roadmap for all stakeholders to set the ecosystem in motion with a clear direction.
- **Governance bodies**: Definition of a body to coordinate and oversee the development of the hydrogen ecosystem and manage the diverse stakeholders.

- **Engaging in international efforts**: GCC countries must support international efforts to work on guarantees of origin, which will be a major element in international trade

Illustration 25: Potential actions for GCC countries

	Benchmark developments	Potential actions for GCC
Targets	> **Quantified targets** on the short, medium and long-term defined in most strategies > **Significant investments planned** in the near future (e.g. Chile targets USD 5 bn investment by 2025)	> **H_2 production targets:** 15-30 m MT by 2030, to be on track to address the demand in 2050 > **Investment:** USD 5-25 bn yearly investment by 2030 to be on track for the required level of investment for 2050 > **Jobs**: 30-100 k by 2030, to support the potential development of the hydrogen economy
Approach	> **Hydrogen national policies defined**, sometimes linked to the overall energy strategy > **Multiple policy instruments** used (e.g. CO2 tariffs, subsidies, tax reductions) > **Exports of hydrogen planned** on the medium or long-term (e.g. Chile exports in "wave 3" of their plan) > **Action plans defined**, with strong focus on capability building and R&D[1]	> Develop a **comprehensive national policy** in line with local energy strategy > Develop **favourable regulatory environment** by removing **potential obstacles** (e.g. regulations not relevant to hydrogen) and by defining **incentive schemes** (e.g. subsidies, financing, etc.)
Governance	> **Clear governance and coordination bodies** outlined[2]	> Create **governance** and **coordination bodies** to oversee hydrogen developments, composed of key relevant entities in each country (e.g., Ministry of Energy, PIF and Aramco in KSA)

1) E.g. U.S. key hydrogen programs focusing on R&D for hydrogen technologies across value chain (e.g., production, storage); 2) E.g., Chile's governance bodies including Ministry of Energy, National Council for Green Hydrogen, National task force, etc. – China Hydrogen Alliance coordinating the hydrogen ecosystem in the country

Source: U.S. Department of Energy, Gobierno de Chile, Cleantech Group, China Hydrogen Alliance, Roland Berger

II. ECOSYSTEM DEVELOPMENT VIA H_2 VALLEYS, INTERNATIONAL PARTNERSHIPS AND R&D PROGRAMS

Hydrogen valleys combine **green hydrogen production, storage, distribution and final-use in one geographical area**, thereby forming an integrated ecosystem *(see Illustration 26)*. Hydrogen is produced via electrolysis powered by renewable capacity. The renewable capacity can be located onsite or in another location depending on the space available.

Hydrogen valleys typically focus on a wide variety of applications such as industrial use (e.g., chemicals, refining, iron & steel), mobility and energy storage, as well as having capabilities to export green hydrogen.

Illustration 26: Hydrogen valley overview and potential off-takers

Source: Roland Berger

To build a competitive green hydrogen valley, several **requirements** need to be taken into account:

- **High electrolyzer load factor obtained through:**
  - **An optimized mix of complementary renewable sources**: Combination of several renewable sources (e.g. solar, wind) is required to ensure a combined production cycle maximizing electrolyzer utilization (key cost driver).
  - **Electricity storage capacity** (e.g., battery, hydro storage): Hydrogen valleys need electricity storage capacity to overcome the intermittent nature of renewables and to ensure a stable input for the electrolyzer during off-peak periods.
- **Hydrogen storage capacity:** Hydrogen storage facilities at the consumption site are required to ensure a constant flow of hydrogen to off-takers.
- **Pipelines for transport/distribution**: The large and stable hydrogen demand requires the use of pipelines to transport the hydrogen and increase the cost competitiveness *(see Illustration 27)*.

Illustration 27: Hydrogen delivery methods

	 Gaseous tube trailers	 Liquid tankers	 Pipelines	 Chemical hydrogen carriers
Overview	> Large tubes containing hydrogen under high pressure	> Large tanks able to store 5+ times as much hydrogen per load than gaseous tube trailers – Liquid hydrogen usually with high purity	> Hydrogen transportation via pipelines and compressors – It is possible to convert natural gas pipelines	> Chemical carriers blended with hydrogen – Method still under development
Use case	> Used when the quantity of hydrogen delivery is small (< 1 MT/day) and demand is not predictable	> Used when the demand is large and stable, but not enough for a pipeline	> Used when the demand is significant (k MT/day) and expected to remain stable in the long term (15+ years)	> Used when the hydrogen demand is significant, but not stable enough to warrant pipeline construction
Distance	> Short	> Short	> Short & Long	> Long

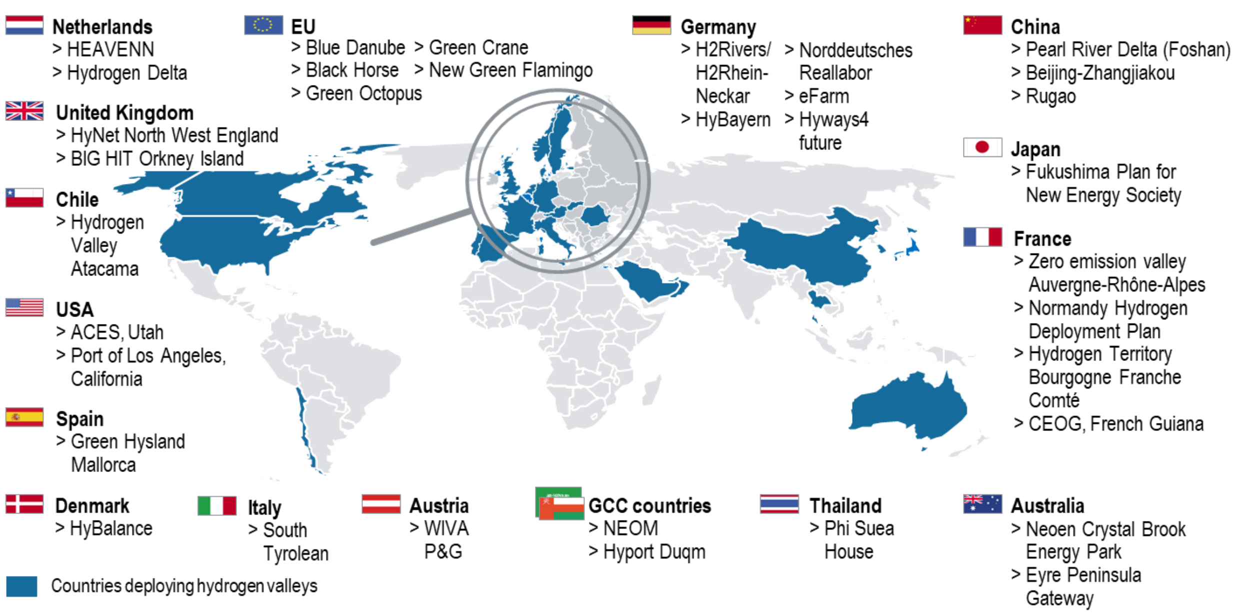
Source: U.S. Department of Energy

The hydrogen valley concept is a key enabler of hydrogen ecosystems due to the following **direct benefits**:

- **Lower hydrogen cost:** The valleys bring the costs down for off-takers by achieving economies of scale, significantly reducing the cost of transportation and enabling predictable supply and demand.
- **Heightened investment attraction:** Hydrogen valleys enable more competitive production costs, greater distribution of risk amongst different stakeholders (e.g., producers, off-takers) thereby fostering investors' confidence.
- **Increased adjacent industry localization:** The larger scale offered by hydrogen valleys make them more attractive (low hydrogen cost, ecosystem already in place) for localization of adjacent industries (e.g. cement industries) or equipment manufacturers (e.g. electrolyzer manufacturer).
- **Promotion of Green H_2 benefits:** H_2 valleys help to promote green hydrogen due to the scale and diversity of the stakeholders involved in the projects.

To **heighten their competitiveness and lead the race for global leadership in hydrogen**, it is important for **GCC countries** to develop **hydrogen valley projects** in the near future. Worldwide, 30+ hydrogen valleys have recently been developed *(see Illustration 28)* in 15+ countries. Europe hosts a large part of the projects (20+), in particular in countries such as Germany, France and the UK. Countries with high renewable availability such as Chile and Australia have also developed specific hydrogen valleys, with large projects under development.

Illustration 28: Global landscape of hydrogen valleys (selection)



Source: FCH JU, Roland Berger

In the short-term, GCC countries need to **setup R&D partnerships with international technology providers to accelerate the development of their hydrogen ecosystem**, in particular for advanced technologies (e.g. electrolyzer stack). Around the world, multiple partnerships are beeing formed combining technology providers (e.g., electrolyzer manufacturer) with energy stakeholders to develop green hydrogen projects. For instance, Snam (Italian energy infrastructure company) and ITM Power (British manufacturer of electrolyzer) have recently signed a partnership agreement to integrate the development of electrolyzer technology to green hydrogen projects. In the UAE, DEWA and Siemens have signed a partnership to launch a solar-based hydrogen electrolysis facility that is already being commissioned, with Siemens providing the technical knowledge and know-how.

In the medium and long-term, GCC countries could **develop R&D programs bringing together international technology providers, national champions and hydrogen coordinating bodies to develop technologies across the whole value chain** and strengthen hydrogen leadership. For example, in Europe the Fuel Cells and Hydrogen Joint Undertaking *(see Illustration 29)* organizes and coordinates projects to demonstrate and develop technologies (e.g. hydrogen bus pilot). It includes the European Commission, Hydrogen Europe (Industry association) and N.ERGHY (research group including universities and R&D centers).

Illustration 29: Fuel Cells and Hydrogen Joint Undertaking (FCH2 JU) overview

The Fuel Cells and Hydrogen Joint Undertaking was founded in **2008**

Since **2014**, the FCH JU is under the **EU Horizon 2020** Framework Program, awarded a **budget** of **EUR 1.33 bn** for 2014-2020

It is a **Public Private Partnership** (PPP) between the European Commission (EC), industry and research institutions

It supports **R&D** and **demonstration activities** for FCH technologies by European companies to accelerate **market introduction.** Projects will **improve performance, reduce cost** and **demonstrate** the **readiness** of the technology

European Commission
- Executive arm of the European Union
- Providing EUR 665 m in funding to the FCH2 JU's budget

Hydrogen Europe
- Representing over 100 companies and associations
- Leads the European FCH sector as industry association
- Advocates the industry's point of view

N.ERGHY
- Research grouping of more than 60 institutions (universities, research centers)
- Aligns the European research community and promotes its interests

Source: FCH JU, Hydrogen Europe, N.ERGHY, Roland Berger

III. REQUIREMENT FOR ENHANCED EDUCATIONAL PROGRAMS AND TRAININGS

The **development of the GCC hydrogen economy** will create a **large demand for qualified workforce**. Many job functions in the hydrogen sector will require new skills not existing in the current workforce, thus, it will be key to establish a human capability build-up (HCB) ecosystem to develop the skills needed in the sector.

The **HCB ecosystem should support the future sector workforce to gain the necessary skills** throughout their development journeys through relevant educational programs (University and Technical & Vocational Education), sector-specific upskilling trainings and on-the-job trainings to ensure the hands-on experience.

Educational programs need be established and revised to address the needs of this emerging sector. In the universities, bachelor and master programs related to science and engineering need to include hydrogen focus for the interested students to have the first insights on the subject and gain the required skills to serve in the sector. On the TVET level, existing programs need to be enhanced considering the workforce demand and skills required in the hydrogen sector especially in manufacturing, installation and maintenance subjects.

Part of the experienced workforce joining from other sectors (e.g. Oil & Gas) will re- skilling to serve in the hydrogen economy due to the sector specificities. Thus, it will be key to develop sector-specific upskilling trainings for experienced workforce joining the sector to adapt to the requirements of the hydrogen economy. These trainings will need to be supported by on-the-job trainings for the workforce to gain first-hand experience.

Coordination between the stakeholders will be key to develop the relevant programs and certifications and set the standards regarding the capability development to ensure that the future workforce gains the knowledge and skills needed in the sector.

D. CONCLUSION FOR GCC COUNTRIES

Driven by **countries' policies & regulations and drop in costs**, the **hydrogen** market is expected to **significantly grow** in the coming decades, with demand **potentially reaching ~580 m MT by 2050**.

The **GCC countries** can seize this opportunity by deploying **local large-scale production capacities and develop their hydrogen ecosystems**. By doing so, they could generate annual **revenues of USD ~70-200 bn and ~1 m jobs by 2050.** In the short-term, the **most attractive activity** to localize for GCC countries are the **electrolyzers,** which represents **20-40% of the total value chain cost.**

To unlock the full potential of the hydrogen economy, **GCC countries must address four key enablers.** First, GCC countries need to **set a clear direction** for all key stakeholders with **integrated hydrogen strategies**, including quantified targets and hydrogen-specific regulations and incentives. Second, GCC countries should **develop hydrogen valleys** to reduce production costs, attract additional investments and support the ecosystem development. Third, GCC countries must **develop international partnerships with key technology providers** to gather and develop the required knowledge to build leadership in hydrogen. Last**,** GCC countries must **enhance** the **university & training programs** and **sector-specific trainings** to prepare the qualified workforce needed to deploy the hydrogen economy across its wide value chain.

E. ABOUT

Roland Berger

Founded in 1967, Roland Berger is a leading global consultancy firm of European roots. It is German by origin and has grown to develop a strong global footprint. Its entrepreneurial spirit has shaped its growth and fueled its outstanding achievements since the early days of the firm. With over 50 years of continuous growth behind it and 2,400 employees working in 34 countries, Roland Berger is one of the leading players in global top-management consulting and has successful operations in all major markets. Through its particularly strong expertise and network in the energy sector globally, Roland Berger is at the forefront of discussions and developments related to energy transition and decarbonization, renewable energy, and green hydrogen. Roland Berger has done extensive work across all energy subjects globally for policymakers, sector companies and investors.

Dii

Dii Desert Energy is an independent, international public-private sector network operating from Dubai. Dii was launched in 2009 as an industry initiative in Germany (formerly known as 'Desertec Industrial Initiative') for accelerating the energy transition in the MENA region towards the supply of green electrons and molecules across the regional and global energy value chains. Our group is encouraging sustained prosperity and stability in the region through local value creation and jobs thanks to the energy transition. This has been established in the market as Desertec 3.0.

In early 2020, Dii launched the MENA Hydrogen Alliance to kick start green hydrogen economies and to provide a platform to discuss pathways forward and formulate joint studies. The alliance acts as an impartial advisor to promote projects, elaborating business cases and structures for mid-scale to giga-scale projects. It proposes the necessary policy and regulatory frameworks, identifies international off-takers and educates different stakeholders on technical and economic aspects of the entire value chain, including virtual and physical export of green energy.

Dii's platform of more than 50 companies and organizations from 25 countries is mobilizing top executives, public stakeholders, R&D institutions and academia supporting Our Mission: No Emissions!

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F. ACKNOWLEDGMENTS

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We appreciate the support provided for this document by the following list of interviewees:

Adamo Screnci, Dr Alessandro Zampieri, Amin Al Yaquob, Anas Almathami, Andrea Lovato, Dr Cetin Nazikkol, Damien Sage, Driss Berraho, Emanuele Bianco, Fadi Maloouf, Firas al Abduwani, Frank Wouters, Jost Herbert, Dr Malcolm Cook, Manthos Kallios, Manuel Kuehn, Mohamad El Nahi, Mohammed Lawati, Paul van Son, Ralph de Haan, Reshma Carmel Francy, Roland Kaeppner, Thamer Alghafees and Yousif Al Ali.

G. ILLUSTRATIONS

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