The potential for green hydrogen in GCC countries

Presentation for Dii event

MENA Hydrogen Alliance
An initiative of Dii Desert Energy

Roland Berger

Dubai, February 2021

Today's presenters

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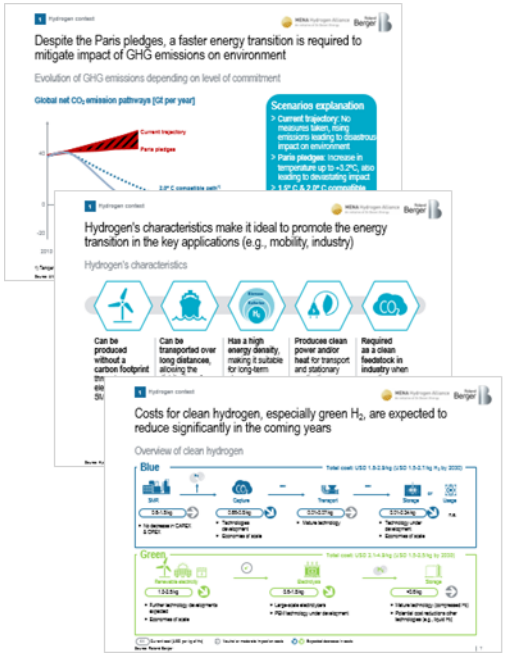
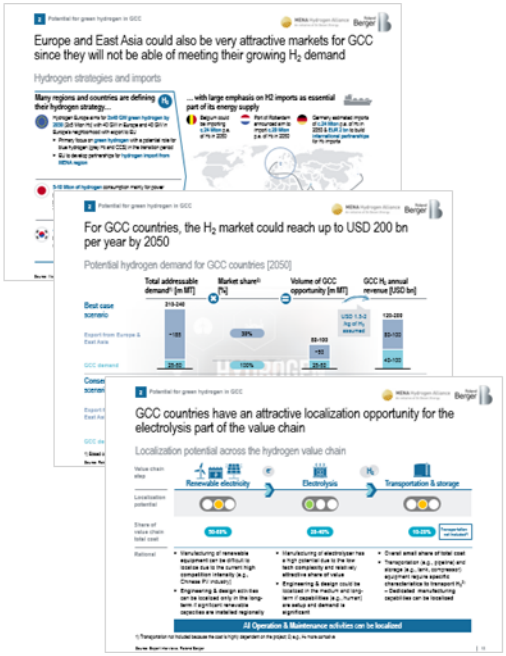
In our upcoming study, we showcase the tremendous potential in the region for green hydrogen

Overview of the study chapters

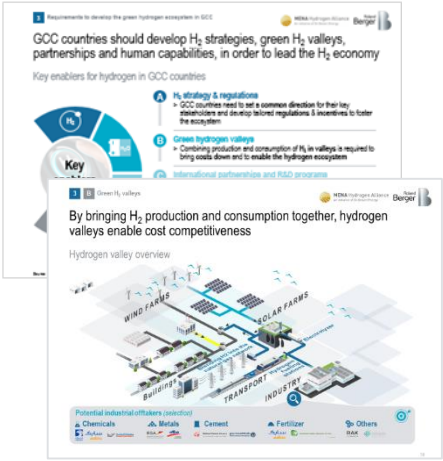
1 Green hydrogen, the basics



2 Potential for green hydrogen in GCC



3 Requirements to develop the green hydrogen ecosystem in GCC



1. Green hydrogen, the basics

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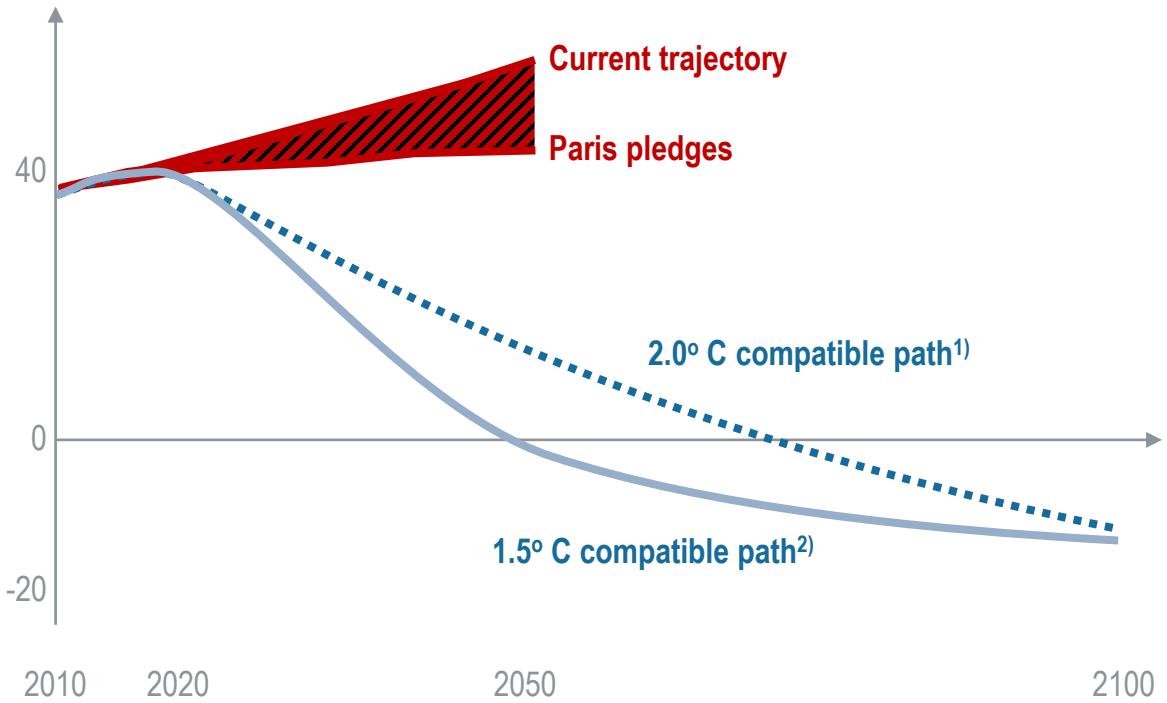
Despite the Paris pledges, a faster energy transition is required to mitigate impact of GHG emissions on environment

Evolution of GHG emissions depending on level of commitment

Global net CO_2 emission pathways [Gt per year]



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

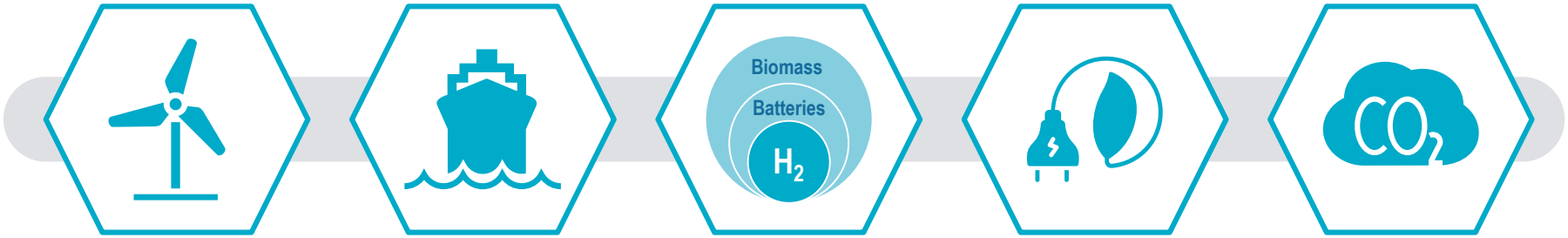
Source: UN, Roland Berger

Scenarios explanation

- **Current trajectory**: No measures taken, rising emissions leading to disastrous impact on environment
- **Paris pledges**: Increase in temperature up to +3.2°C, also leading to devastating impact
- **1.5° C & 2.0° 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

Clean hydrogen's characteristics make it ideal to promote the energy transition in the key applications

Hydrogen's characteristics



Can be produced without a carbon footprint through electrolysis or SMR + CCS

Can be transported over long distances, allowing the distribution of energy between countries

Has a high energy density, making it suitable for long-term storage

Produces clean power and/or heat for transport and stationary applications

Required as a clean feedstock in industry when recycling captured CO_2

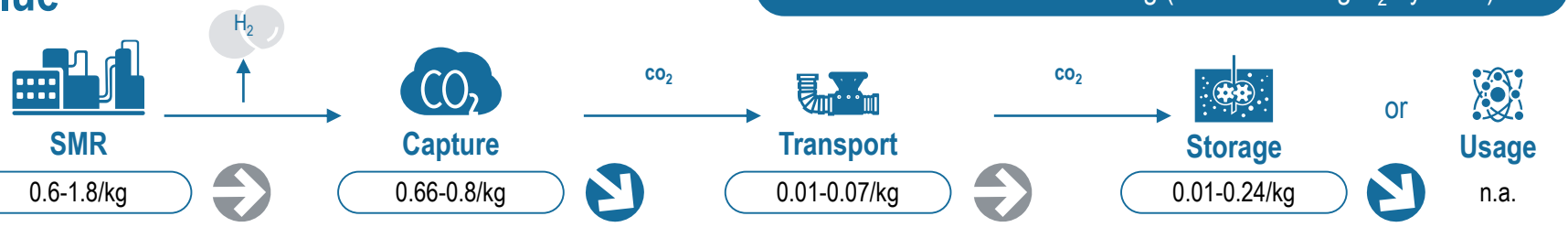
Source: Hydrogen Council

Costs for clean hydrogen, especially green H_2, are expected to go down significantly

Overview of clean hydrogen

Blue

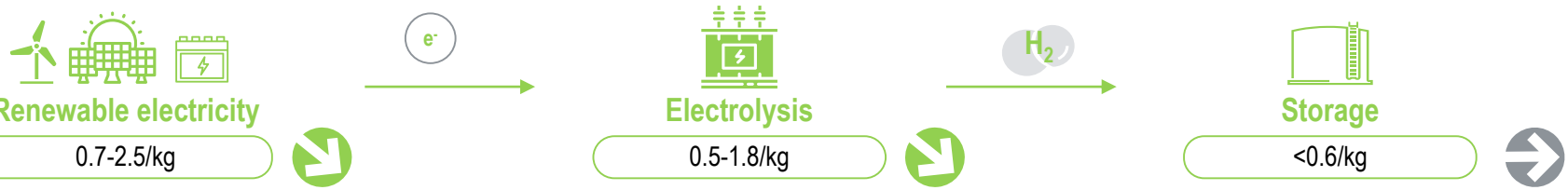
Total cost: USD 1.8-2.9/kg (USD 1.5-2.7/kg H_2 by 2030)



SMR	Capture	Transport	Storage	Usage
0.6-1.8/kg	0.66-0.8/kg	0.01-0.07/kg	0.01-0.24/kg	n.a.
> No decrease in CAPEX & OPEX	> Technologies development > Economies of scale	> Mature technology	> Technology under development > Economies of scale	

Green

Total cost: USD 1.8-4.9/kg (USD 1.3-2.5/kg by 2030)



Renewable electricity	Electrolysis	Storage
0.7-2.5/kg	0.5-1.8/kg	<0.6/kg
> Further technology developments expected > Economies of scale	> Large-scale electrolyzers > PEM technology under development	> Mature technology (compressed H_2) > Potential cost reductions other technologies (e.g., liquid H_2)

XX 2025 cost [USD per kg of H_2] — Neutral or moderate impact on costs — Expected decrease in costs

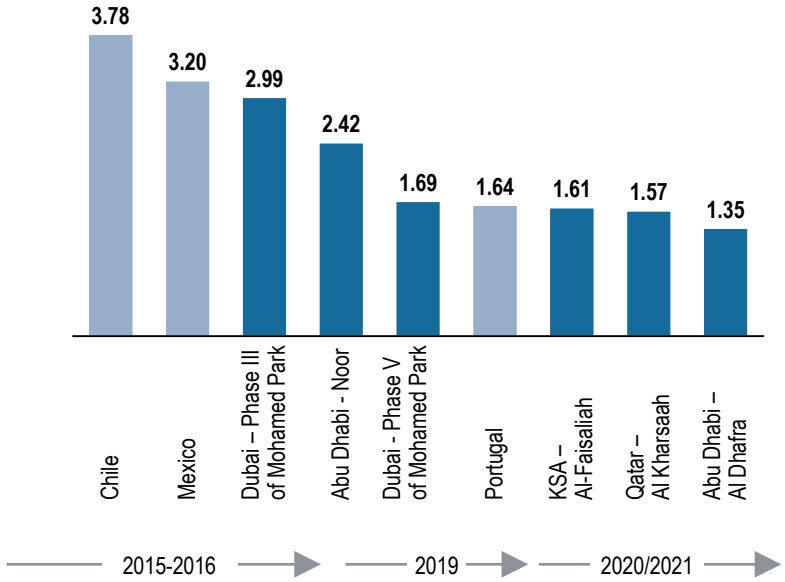
Source: Roland Berger

The economics of green hydrogen will only improve with continued costs reductions in both renewables and electrolyzers

Renewable generation and electrolysis costs

Worldwide solar auctions records

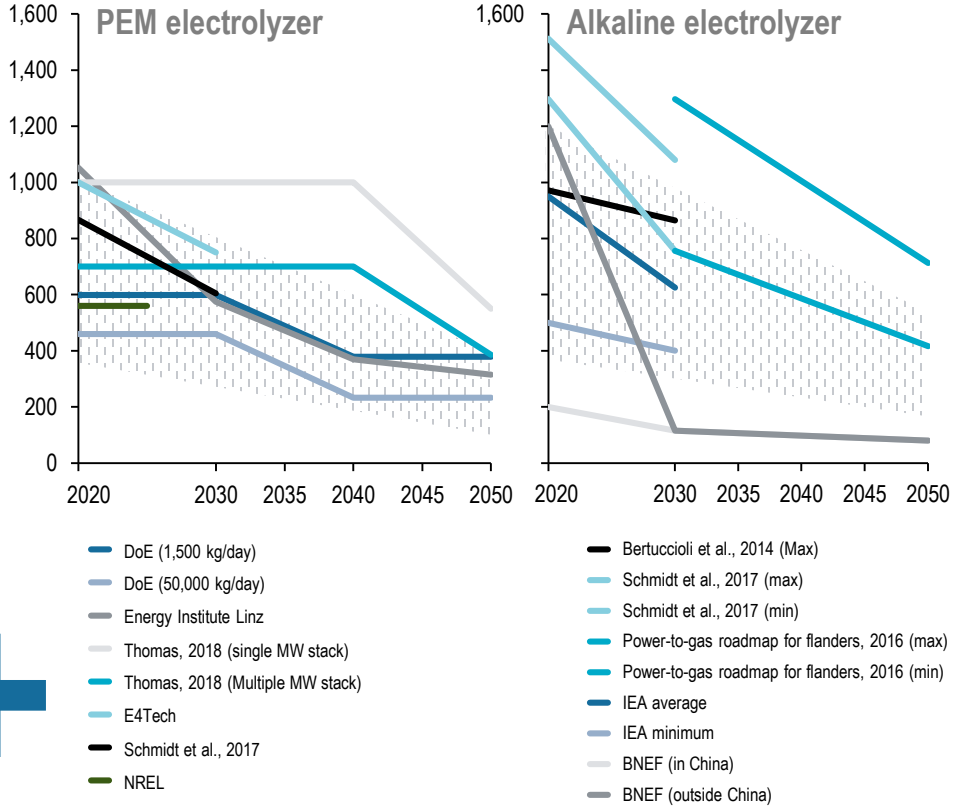
[US cent/kWh2]



LCoE of solar in GCC is expected to get to 10-15 USD/MWh by 2030 (some tenders have already achieved this price)

Electrolyzer cost forecast by technologies

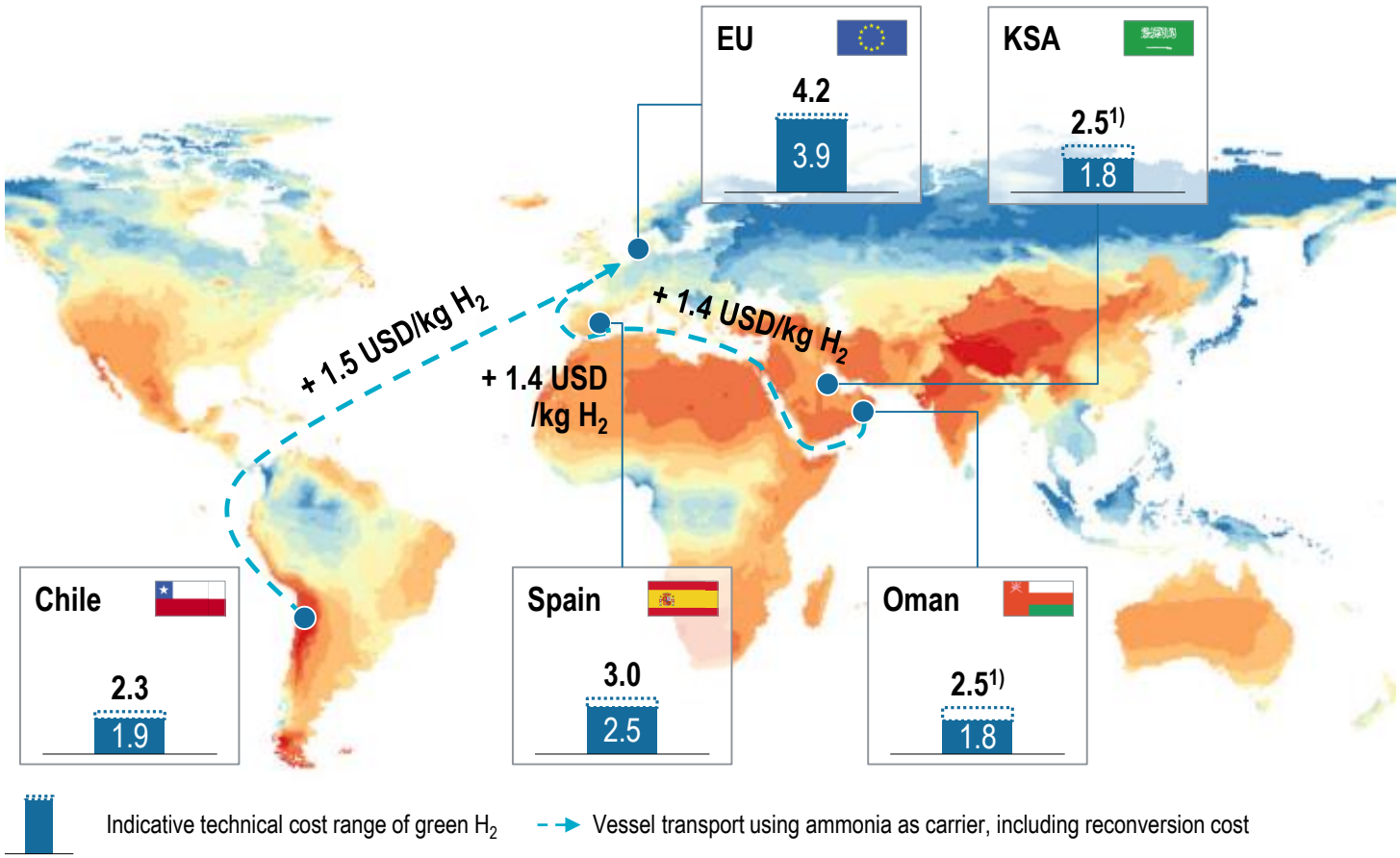
[USD/kW]



Source: NREL, DoE, IEA, EIL, Thomas, E4Tech, Schmidt et al., Bertuccioli et al., P2G roadmap for flanders 2016, Bloomberg, Agora-Energiewende, Roland Berger

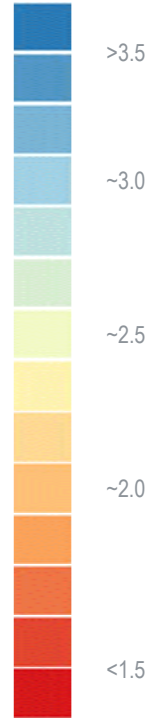
GCC countries can potentially be one of the most competitive locations to produce and export green hydrogen

Green H_2 production and export cost forecast [2025, USD/kg of H_2]



Indicative costs

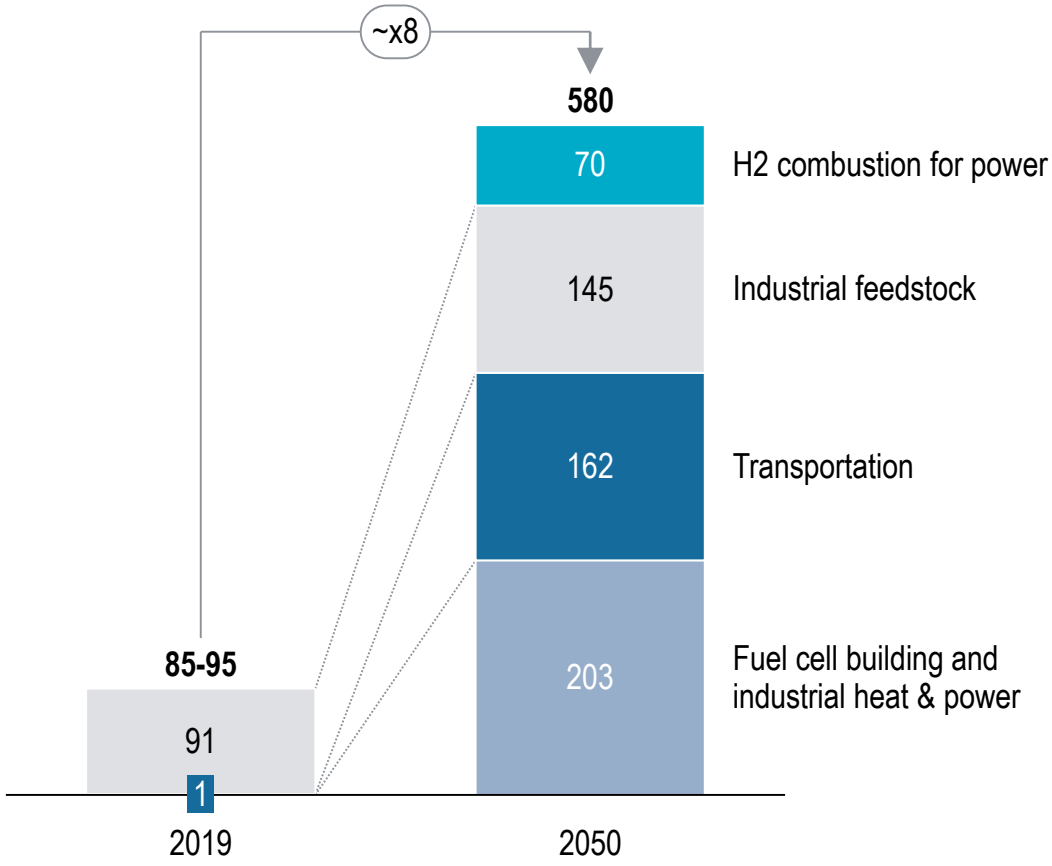
Long-term LCoH potential for solar & onshore wind hybrid setups [USD/kg H_2]



1) Under ideal conditions, the production cost could get to 1.5USD/kg by 2025
Source: IEA, IRENA, Dii LCOH model, Roland Berger

The reduction in costs is expected to lead to an increase in the H_2 demand of ~x8 by 2050

Hydrogen demand forecast by type[1] [m MT]



1) Considering only dedicated hydrogen

Key drivers:

> Drop in costs along the value chain

> Government policies & regulations supporting the hydrogen economy

Key growing hydrogen types:

> "Green" from electrolysis

> "Blue" from Steam Methane Reforming with Carbon Capture & storage

Demand enabled by **global trade system** connecting low-cost supply & demand (similar to LNG)

Source: IRENA, IEA, Hydrogen Council, Roland Berger

2. Potential for green hydrogen in GCC

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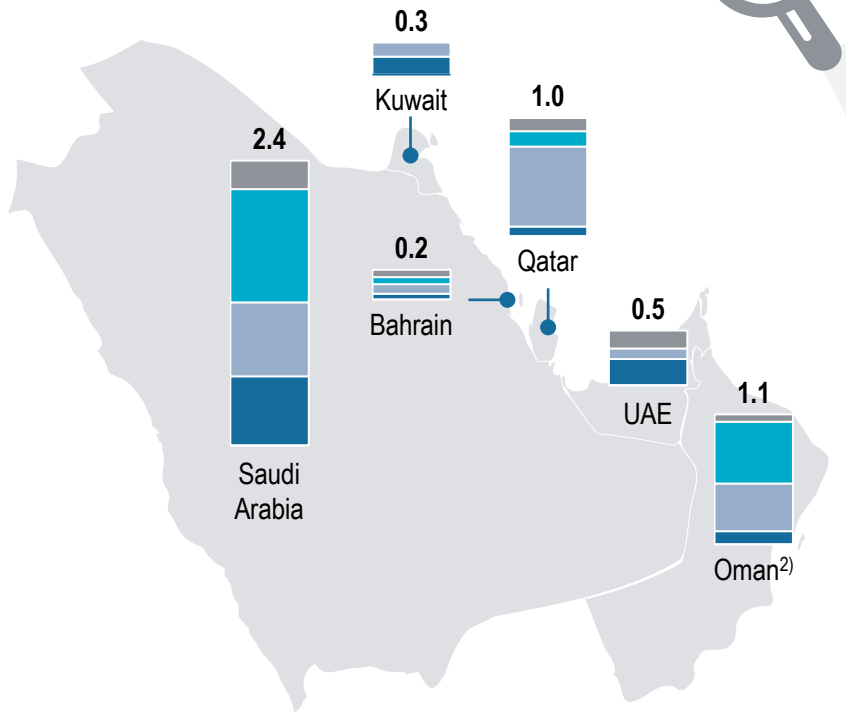
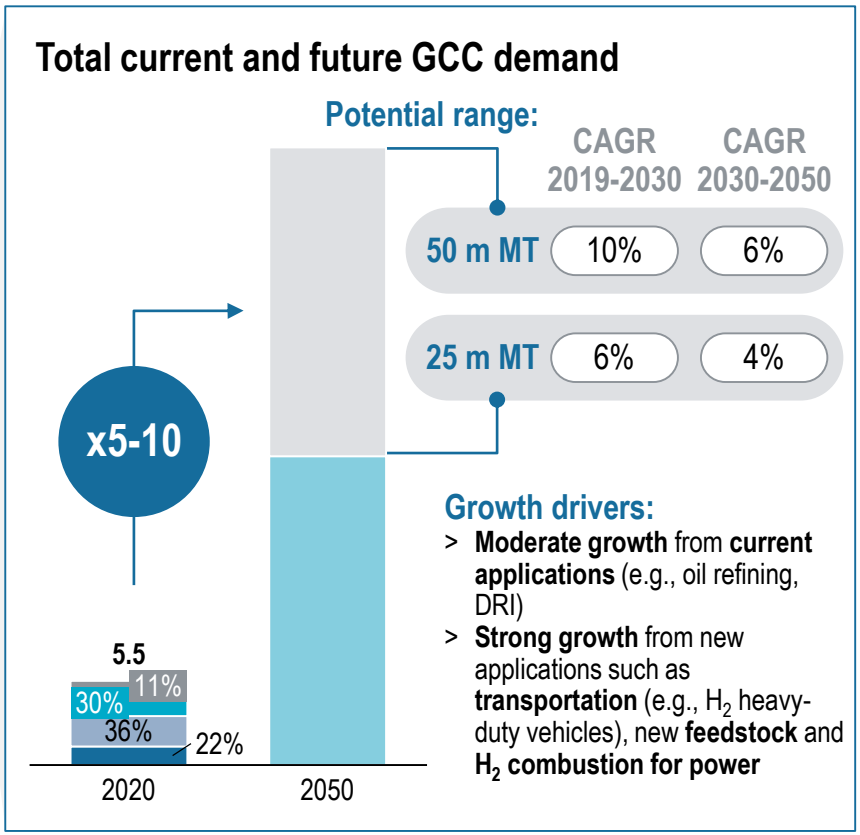
GCC H_2 demand is expected to grow significantly in the following years

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

Demand[1] per country [2020]



Total current and future GCC demand



Growth drivers:

- **Moderate growth** from **current applications** (e.g., oil refining, DRI)
- **Strong growth** from new applications such as **transportation** (e.g., H_2 heavy-duty vehicles), new **feedstock** and **H_2 combustion for power**

Others | Direct reduced iron (DRI) | Methanol production | Ammonia production | Oil refining

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

Source: IEA, Roland Berger

Europe and East Asia could also be very attractive markets for GCC since they will not be able of meeting their growing H_2 demand

Hydrogen strategies and imports

Many regions and countries are defining their hydrogen strategy…

Hydrogen Europe aims for **2x40 GW green hydrogen by 2030** (2x5 Mton H_2) with 40 GW in Europe and 40 GW in Europe's neighborhood with export to EU

> Primary focus on **green hydrogen** with a potential role for blue hydrogen (grey H_2 and CCS) in the transition period

> EU to develop partnerships for **hydrogen import from MENA region**

5-10 Mton of hydrogen consumption mainly for power generation & mobility and **85 Mton of CO_2-free ammonia** for power generation by 2050, with target of 3 USD/ kg H_2 by 2030 and 2 USD/kg H_2 by 2050

17 Mton of hydrogen consumption by 2050 mainly driven by mobility applications (32%), building heating and power (21%) and power generation (15%)

… with large emphasis on H2 imports as essential part of its energy supply

Belgium could be importing **c.24 Mton** p.a. of H_2 in 2050

Port of Rotterdam announced aim to import **c.20 Mton** p.a. of H_2 in 2050

Germany estimated imports of **c.24 Mton** p.a. of H_2 in 2050 & **EUR 2 bn** to build **international partnerships** for H_2 imports

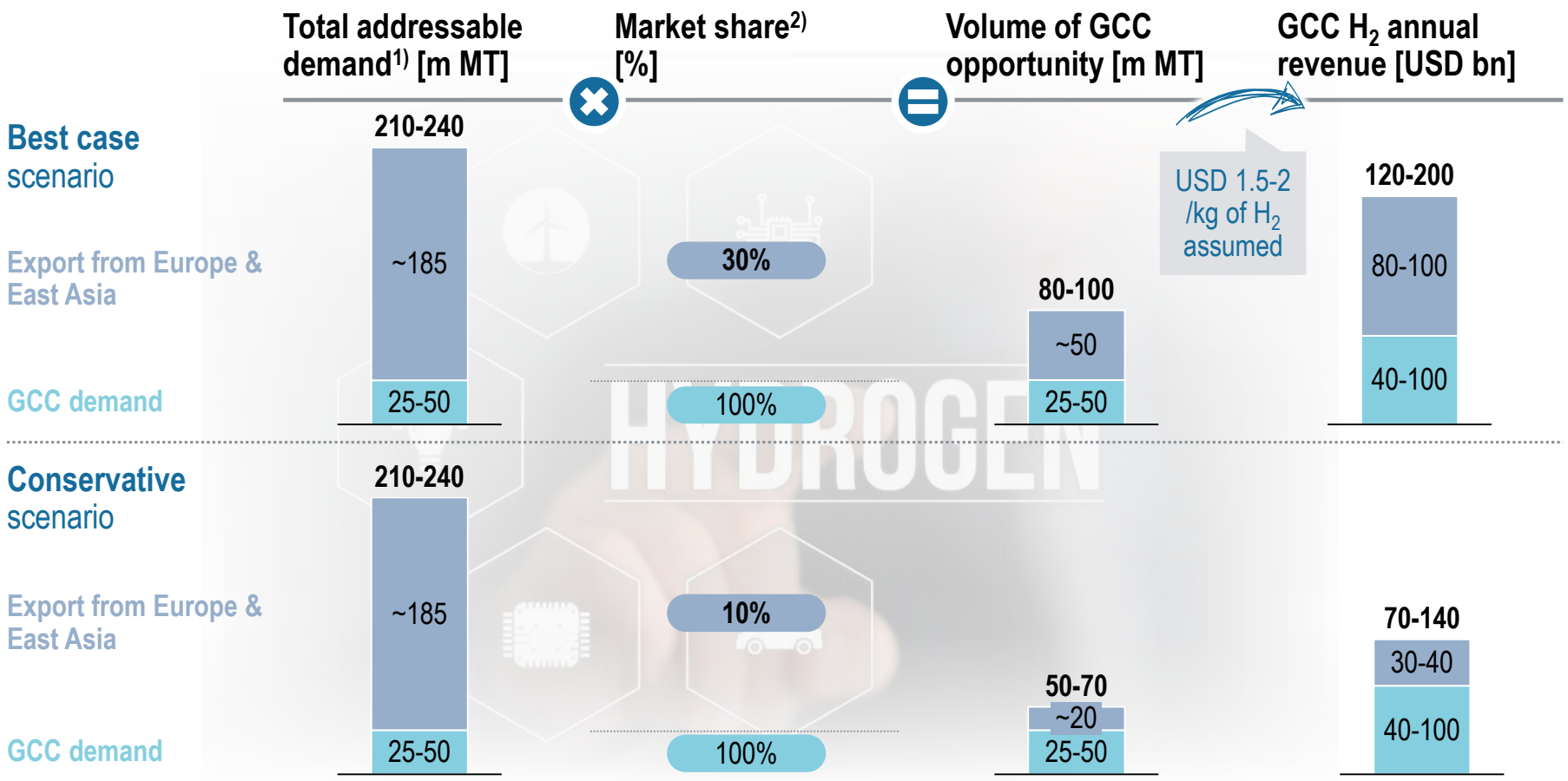
Total need for H_2 imports in Europe can be **up to 100 Mton** p.a. as Europe will not have sufficient renewable electricity to produce own H_2 demand

Japan is setting up import supply chains H_2 and ammonia needs, with **3.5 Mton of CO_2-free ammonia import by 2030** and 85 Mton by 2050

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

For GCC countries, the H_2 market could reach up to USD 200 bn per year by 2050

Potential hydrogen demand for GCC countries [2050]



1) Based on Hydrogen Council numbers for hydrogen demand in 2050; 2) Assumption

Source: Roland Berger

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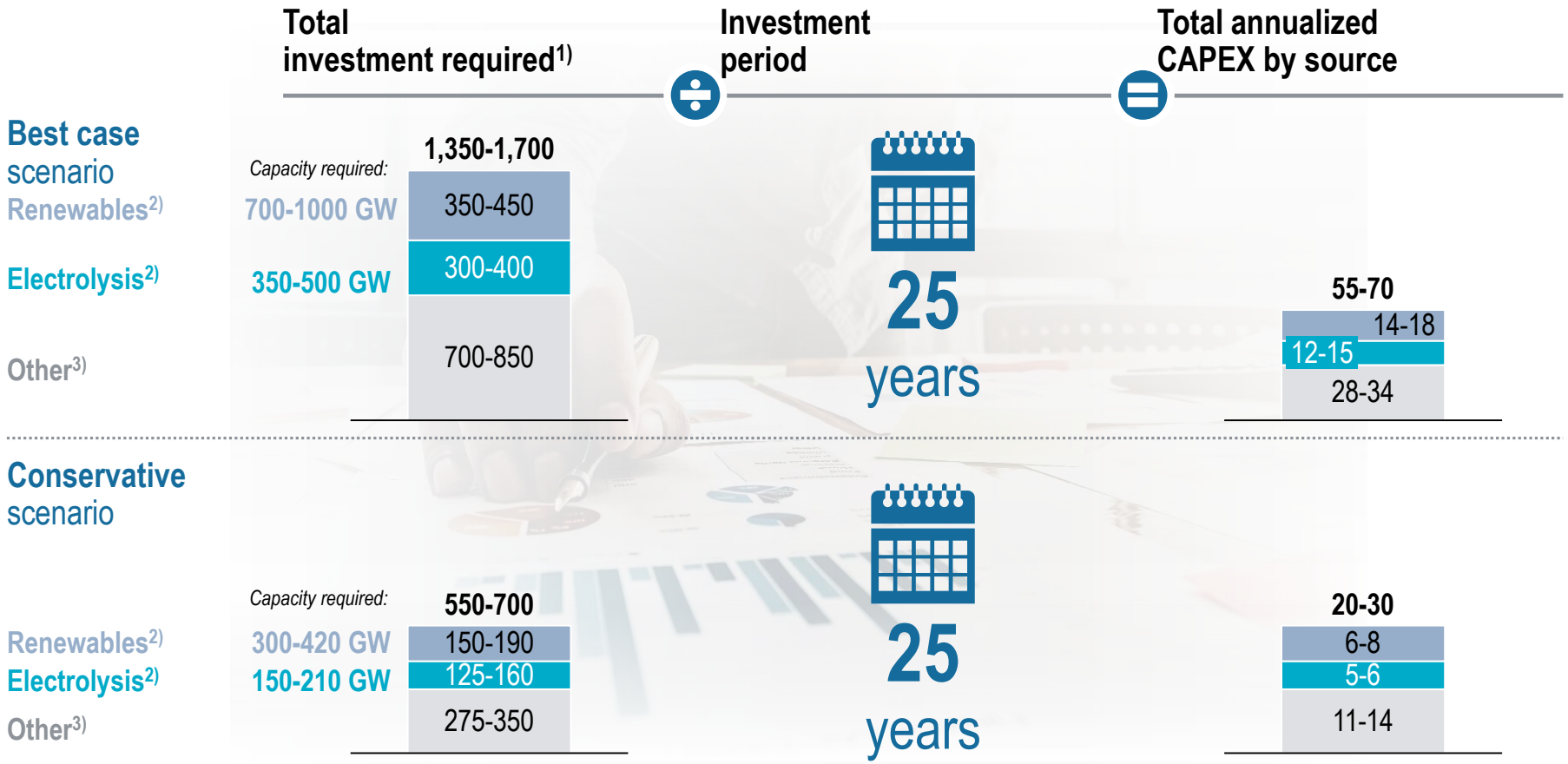
An investment of USD 20-70 bn p.a is required to capture the opportunity

Investment required to address potential GCC hydrogen markets [USD bn]



1) Investments required to capture the 40-105 m MT GCC opportunity by 2050 – Factor of USD 15 k CAPEX/kg applied (ratio from large projects combined with a 30% efficiency gain) – Based on Hydrogen Council numbers for hydrogen demand in 2050; 2) CAPEX/GW assumed: USD 0.4-0.6 bn for renewables, USD 0.7-0.9 bn for electrolyzer; 3) Includes water-related costs

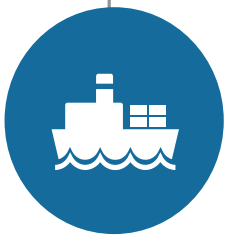
Source: Roland Berger

GCC countries can leverage their strong know-how and infrastructure from O&G to deploy the hydrogen ecosystem in the region

GGC countries capabilities related to the oil & gas sector

GCC countries have large **transportation infrastructure** including **pipeline, vessels and logistics networks**

Transportation infrastructure



Storage infrastructure

GCC countries have **large storage capacities** that can be adapted to store hydrogen

GCC countries have a **large pool of qualified labor** such as **electrical & chemical engineers**, **engineering technicians** and **skilled workers** in construction & gas distribution industries

Human resources

Know-how/capabilities

GCC countries have **strong capabilities for export** (e.g., trading, sales network) and know-how for **implementation of large & complex technical projects**

Source: Roland Berger

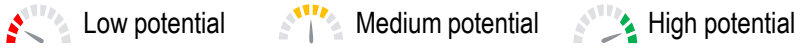
GCC countries have an attractive localization opportunity along the hydrogen value chain

Localization potential across the hydrogen value chain

Value chain step	Renewable electricity	e^-	Electrolysis	H_2	Transportation & storage
Localization potential					
Share of value chain total cost	50-60%		20-40%		10-20% Transportation not included[1]
Rational	> Manufacturing of **renewable equipment** can be challenging to localize due to the current **high competition intensity** (e.g., Chinese PV industry) > **Engineering & design** activities can be localized **only in the long-term** if significant renewable capacities are **installed regionally**		> **Manufacturing** of **electrolyzer** has a high potential due to the **technology maturity**[3], **the low industry development** and its **attractive share of value** > **Engineering & design** could be localized in the medium and long-term if **capabilities** (e.g., human) are **setup** and **demand is significant**		> Overall **small share of total cost** > Transportation (e.g., pipeline) and storage (e.g., tank, compressor) equipment require **specific characteristics to transport H_2**[2] **– Dedicated manufacturing** capabilities can be **localized**

All **Installation** and **Operation & Maintenance** activities can be **localized**
R&D should be promoted to become the **technology leaders in electrolysis**

1) Transportation not included because the cost is highly dependent on the project;
2) e.g., H2 more corrosive; 3) Absence of technological barrier
Source: Expert interviews, Roland Berger



Electrolyzer systems have potential for localization starting off with balance of plant and power electronics components

Localization potential of electrolyzer systems

Indicative

Electrolyzer system

Subsystems manufacturing	Share of total cost	Ease of localization[2]	Current local capabilities[3]	Overall potential
Electrolysis stack	30-55%			
Power electronics AC-DC power	25-30%			
Balance of plant[1] (BoP)	25-40%			

Comments

Manufacturing:

> **Stack**: High share of total cost but requires tech partnerships and significant investments – Localization potential in the long-term

> **Power electronics & BoP**: High fit due to ease of localization and capabilities already in the region

GCC H_2 demand (5-10% of total) will provide enough scale for electronics and BoP. **Exports will be needed** to achieve scale to be competitive in stack production

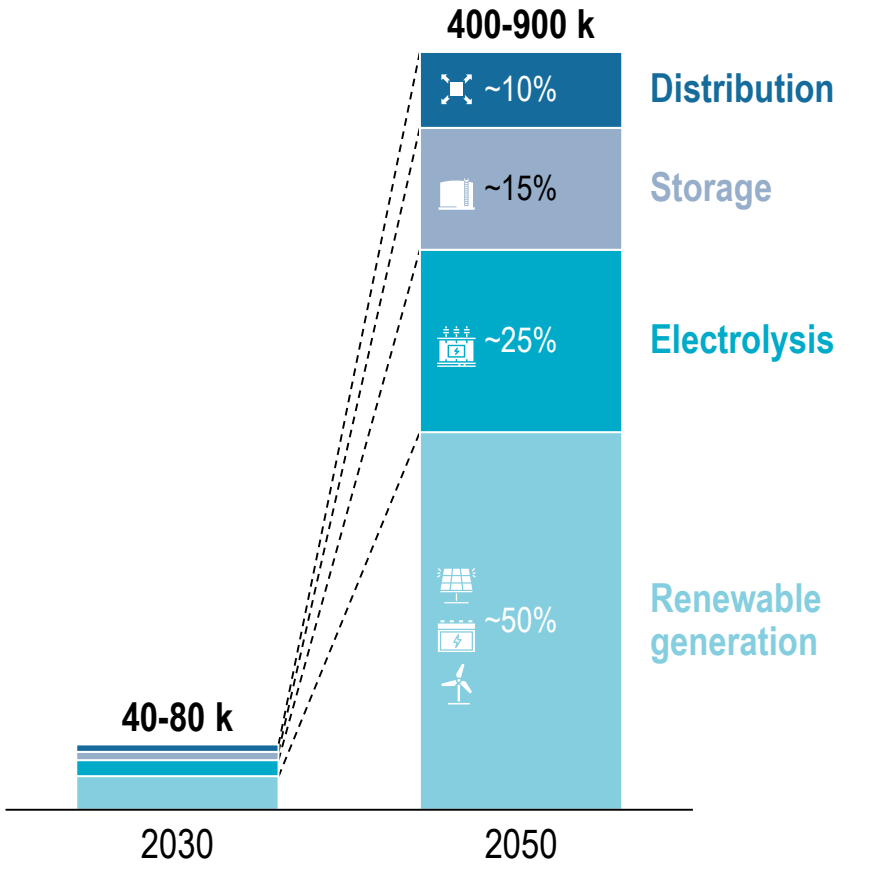
1) Including liquid & heat management, gas management and other parts such as cooling, sensors, valves, flow meters;
2) Including technology complexity and investment requirements; 3) Current presence of relevant capabilities in the GCC countries

 High potential  Low potential

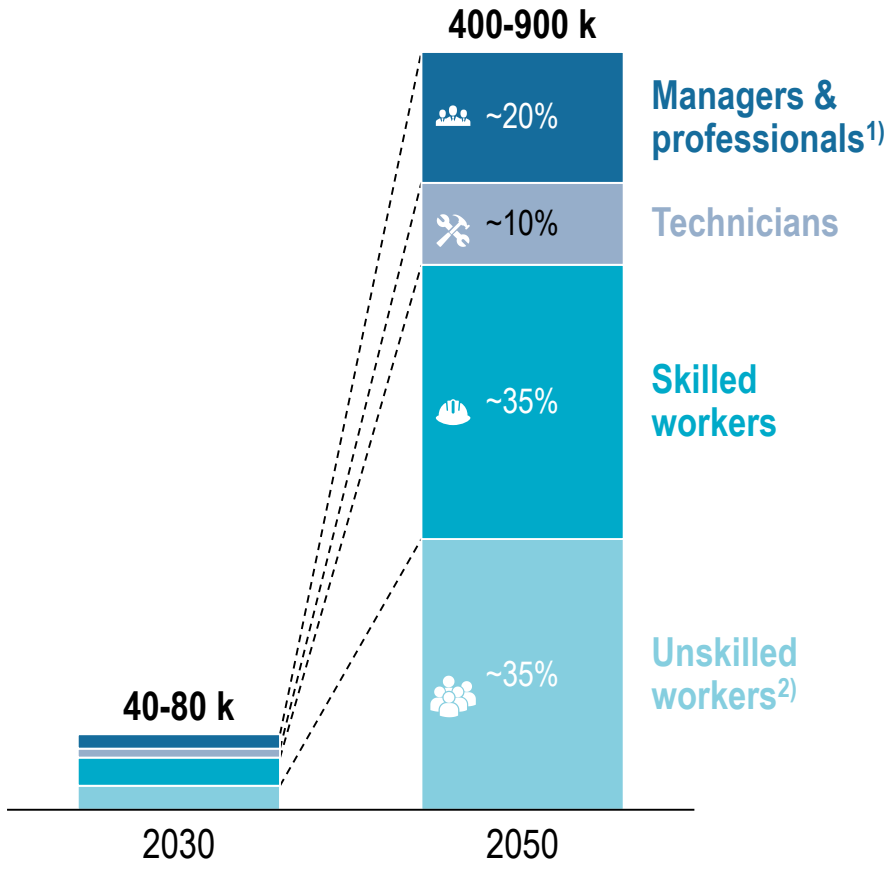
Source: RVO, EKZ, Kumar and Himabindu 2019, NREL, Expert interviews, Roland Berger

The localization of the key activities together with the development of the renewable capacity could create up to 900k jobs by 2050

Job creation along the value chain



Job creation by profession



Note: Job creation estimation based on potential revenues and employment multipliers specific to each part of the value chain

1) Includes mainly the engineers needed in hydrogen economy; 2) Includes the laborers and assemblers mainly needed for construction and manufacturing activities
Source: Economic Policy Institute, Global Trade Analysis Project, Roland Berger

3. Requirements to develop the green hydrogen ecosystem in GCC

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To address key challenges, GCC countries should develop H_2 strategies, green H_2 valleys, partnerships and human capabilities

Key challenges

- **Absence** of **high-level plans** and associated **regulations** to enable the ecosystem
- **Undeveloped green H_2 ecosystem** (e.g., offtakers, producers) and **transport network**
- **Heavy interest in blue H_2** due to local resources leading to a **risk of missing out** on **green H_2**
- **Conventional applications** (e.g., diesel mobility) currently **more cost competitive** than clean H_2
- **Lack of green H_2 capabilities** & **technologies** in the region
- **Limited water availability** for hydrogen **production in some areas**

Key enablers

A H_2 strategy & regulations

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

B Green hydrogen valleys

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

C International partnerships for R&D programs

> In the short-term, GCC countries should 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 technological leadership

D Human capabilities

> Well-established **education & training landscape** will develop the **skilled workforce** required to deploy the **hydrogen economy**

Source: Roland Berger

Similar to benchmarks, GCC countries should design H_2 strategies including targets and detailing a roadmap and key initiatives

Overview of selected hydrogen strategy

Selection of countries with a hydrogen strategy

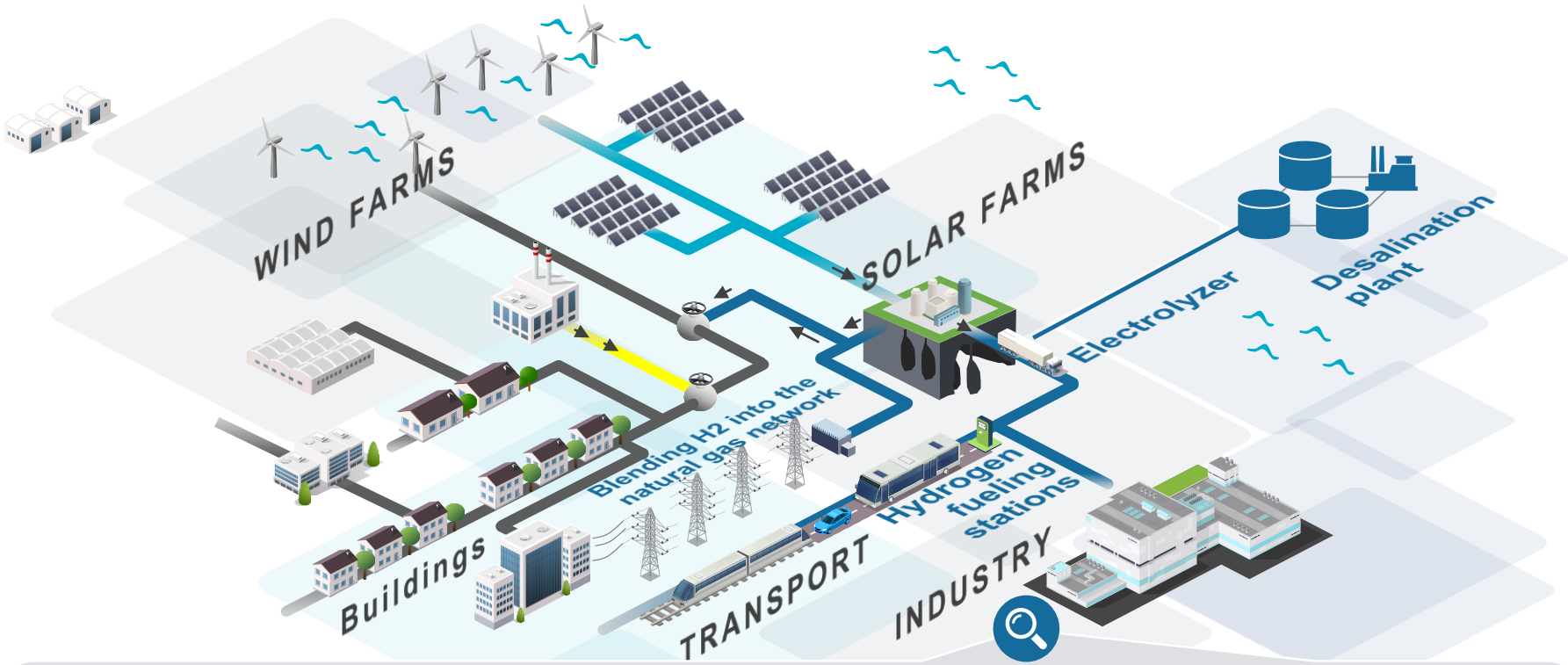
- **USA**
- **China**
- **Chile**
- Netherlands
- Norway
- Portugal
- Japan
- South Korea
- Australia
- New Zealand
- Germany
- …

	USA	China	Chile
Targets	> Some targets set at the federal level (e.g., FCEV)	> Quantified targets on mobility applications, infrastructure and production	> Clear and quantified targets for 2025 and 2030 (e.g., production, investments)
Strategy content	> Detailed roadmap for the coming decades > Prioritization of applications	> Detailed roadmap for Fuel Cell Vehicles	> Six pillars defined for actions (e.g., mission-oriented policies) > Three-step plan (e.g., application prioritization, export contribution)
Hydrogen initiatives	> Multiple initiatives, especially around R&D (e.g., Clean Coal & Carbon Management)	> Policies & regulations in place in 12+ provinces > Governance & coordination body in operation (China Hydrogen Energy Alliance)	> Detailed initiatives derived from the high-level strategy (e.g., financial incentives definition, task force creation, etc.)

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

By bringing H_2 production and consumption together, hydrogen valleys enable cost competitiveness

Hydrogen valley overview



Potential industrial offtakers *(selection)*

- **Chemicals**: ADNOC, sabic, DUQM REFINERY
- **Metals**: EGA, Emirates Global Aluminium, Aluminium for the world
- **Cement**: National Cement Co. p.s.c, Yanbu Cement Company
- **Fertilizer**: sabic, ADFERT, Abu Dhabi Fertilizer Industries Co. W.L.L
- **Others**: RAK CERAMICS, adnpm

Source: Roland Berger

Partnering with international leaders could foster local R&D in the region to lead the H_2 technological development

Fuel Cells and Hydrogen Joint Undertaking (FCH2 JU) overview

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

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

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

GCC countries should enhance the university & TVET programs and sector-specific trainings

Training & development – Overview

Enhancing educational programs

> **Bachelor** and **master programs** related to science and engineering need to offer **hydrogen focus**

> Existing **TVET programs** should be **enhanced** considering skills needed in the sector to develop **technicians** especially for **manufacturing, installation & maintenance activities**

Establishing sector-specific trainings

> **Sector-specific technical upskilling trainings** and **OEM certifications** are key **for the workforce** joining hydrogen economy to adapt to sector requirements

> **On-the-job trainings** will be needed for the workforce to gain **hands-on experience**

Ensuring stakeholder coordination

> Coordination between **stakeholders** – including policy makers, enablers, educational institutions and industry players – is key to **develop** the **relevant programs** and **certifications**

> Stakeholders need to work together to **set the standards** regarding the **capability development** to ensure alignment between the programs and the sectoral needs

Well-established education & training landscape will develop the skilled workforce for hydrogen economy

Source: Roland Berger

Multiple important announced initiatives are accelerating the momentum in the region for green hydrogen

Overview of recent hydrogen-related announcements in GCC

Not exhaustive

*Launch of **NEOM green hydrogen project***

***MoU** signed between **DEWA & Siemens** for green H_2 production*

*Launch of **DEME's hydrogen valley** in **Oman***

New alliance** in the green H_2 space between **Mubadala, ADNOC & ADQ

Source: Desk research, Roland Berger

Immense socio-economical benefits can be harnessed from the clean hydrogen economy for the region

Clean Hydrogen

Source: Roland Berger

About Roland Berger

MENA Hydrogen Alliance
An initiative of Dii Desert Energy

Roland Berger

Our competence stems from a broad and deep project experience in hydrogen and fuel cells: 25+ assignments in 2020 alone

Our project experience and network along the hydrogen value chain (selection)

1. Overall hydrogen market

- Market reviews, sizing and valuation
- Corporate strategy development, market entry support
- Technology analysis, benchmarking, commercialization strategies
- M&A support, incl. target search, commercial due diligence
- Business model development

- Development of a strategic clean H2 plan for an int'l energy company
- Market review and entry strategy for a diversified technology conglomerate
- Market analysis for int'l energy group

2. Production

- Feasibility studies, project partnering, business planning, funding support
- Commercialization strategies

- Feasibility study for a new pan-European green H_2 supply chain

3. Transport, distribution

- Project development support, network planning (HRS roll-out)
- Commercialization strategies
- M&A support

- Strategy development and funding story for an H_2 transportation start-up

Fuel cells and hydrogen applications / end uses

4. Mobility

5. Industry

6. Energy

- Technology assessment and benchmarking, commercialization strategies
- Decarbonization strategies
- Market reviews and entry strategies
- M&A support

- Strategic plan for a metallic BPP coating specialist
- Review of Chinese, German H_2 markets for a global OEM

7. Public policy

- Gov't strategies
- Sector studies
- Policy/regul. analysis, benchmarking
- Policy design (funding)

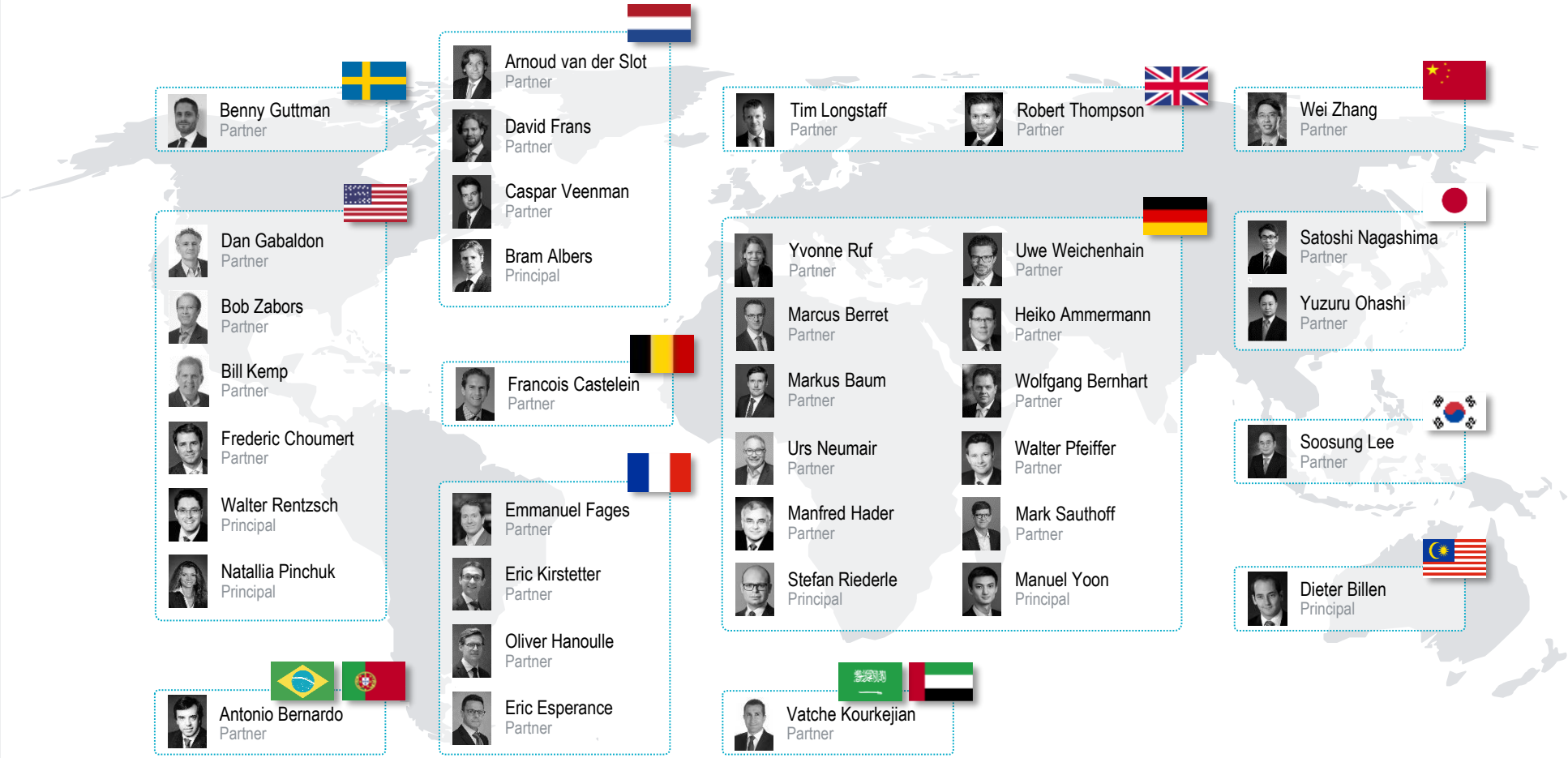
- Analysis of global integrated H_2 projects, so-called "H_2 valleys"
- H_2 strategy for German state

Clients and project-based network | Typical projects | 2020 project examples

Source: Roland Berger

Our worldwide network of hydrogen experts contributes insights to our project work, covering developments from all key markets

Roland Berger's hydrogen experts around the world



Source: Roland Berger

Along projects, we have built a strong H_2 knowledge base and toolbox which enable us to accelerate our delivery

Roland Berger tools & differentiators

Worldwide H_2 trends, 2030 market forecasts

> Modelling and 2030 forecasts of the hydrogen value chain and size of end use markets, with a specific focus on hydrogen
> Database and proprietary modelling on the cost competitiveness evolution by 2030 of technologies (green H_2, other H_2, biogas, CO_2/CCU)

Long list of and access to H_2 market players

> Long list of market players active along the hydrogen value chain, worldwide
> Details of existing hydrogen clusters / valleys
> +100 1-pagers detailing most promising H_2 market players
> Direct access to most players for interviews and to test business hypotheses

Complete H_2 modelling toolbox

> Complete H_2 toolbox, ready to be used and tailored, covering in particular:
  – Policies per country
  – Financial modelling for business cases at each step of the value chain (production, conversion, transport)

Dynamic market watch tool

> "Market watch radar" (web-based), developed by our data scientists, aiming at capturing from multiple sources, on a regular basis, all H_2-related insights, projects, market players moves, regulation evolutions etc. – *will be customized and provided to Total at the end of the project*

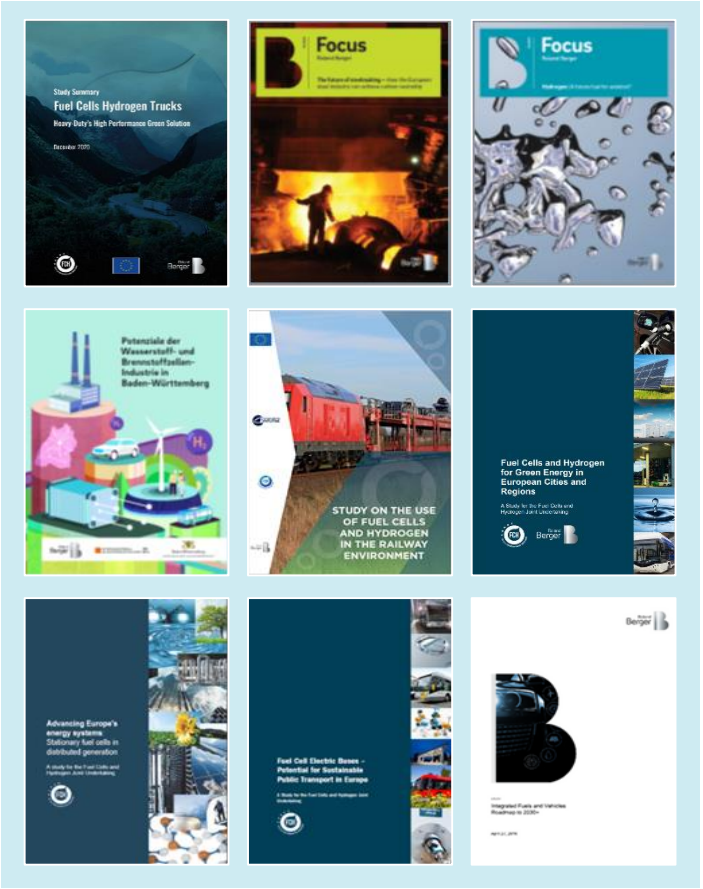
Tools, insights, development knowhow and contacts are constantly fuelled and updated thanks to our multiple projects delivered for H_2 market stakeholders worldwide

Source : Roland Berger

Our publications demonstrate our thought leadership in hydrogen and fuel cells and contribute valuable market insights to our projects

Our recent publications on hydrogen and fuel cell technology

- **Fuel Cells Hydrogen Trucks** – Business Cases and Technology Development Roadmap, FCH JU (2020)
- **The future of steelmaking:** How the European steel industry can achieve carbon neutrality, RB Focus (2020)
- **Hydrogen in aviation**, RB Focus (2020)
- **Economic potential of the hydrogen and fuel cells industry**, German State of Baden Württemberg (2020)
- **Use of Fuel Cell Hydrogen in the Railway Sector**, S2R JU / FCH JU (2019)
- **Business Cases for Fuel Cells and Hydrogen Applications** for European Cities and Regions, FCH JU (2018)
- **Integrated Fuels and Vehicles Roadmap 2030+** (2016)
- **Fuel cell electric buses**: potential for sustainable public transport in Europe, FCH JU (2015)
- Advancing Europe's energy systems: **stationary fuel cells** in distributed generation, FCH JU (2015)
- **Fuel Cells** – A realistic alternative for zero emissions? Study on the future role of fuel cells in the automotive sector, RB (2013)
- A roadmap for **financing hydrogen refuelling networks:** creating prerequisites for H2-based mobility, FCH JU (2013)
- Analysis of **commercialization of electric mobility based on hydrogen** and fuel cells in Germany, Federal Ministry of Transport (2013)



Source: Roland Berger

Roland Berger

Think:Act