Hydrogen – Fundamental for green power fuel markets

Heiko Ammermann, Roland Berger

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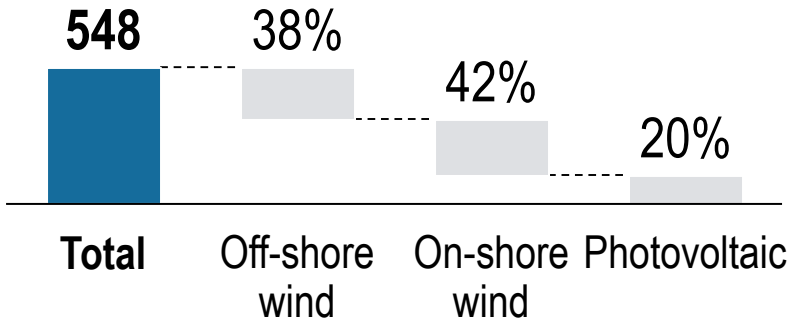
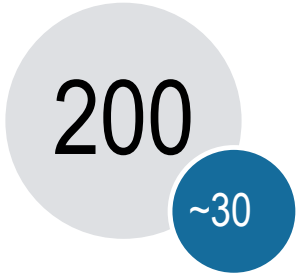
The "Energiewende" is driven politically and **hydrogen is required to enable it** – It's versatile as an energy carrier

Electricity mix, 2050 projection
[TWh][1)]

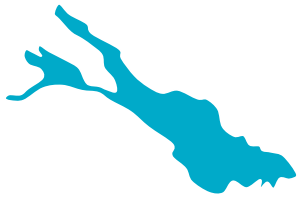


Expected storage requirements
for overcapacity [TWh]



For transport, assuming that 75% of vehicles are powered electrically

15x
the mass of Lake Constance for 200 TWh



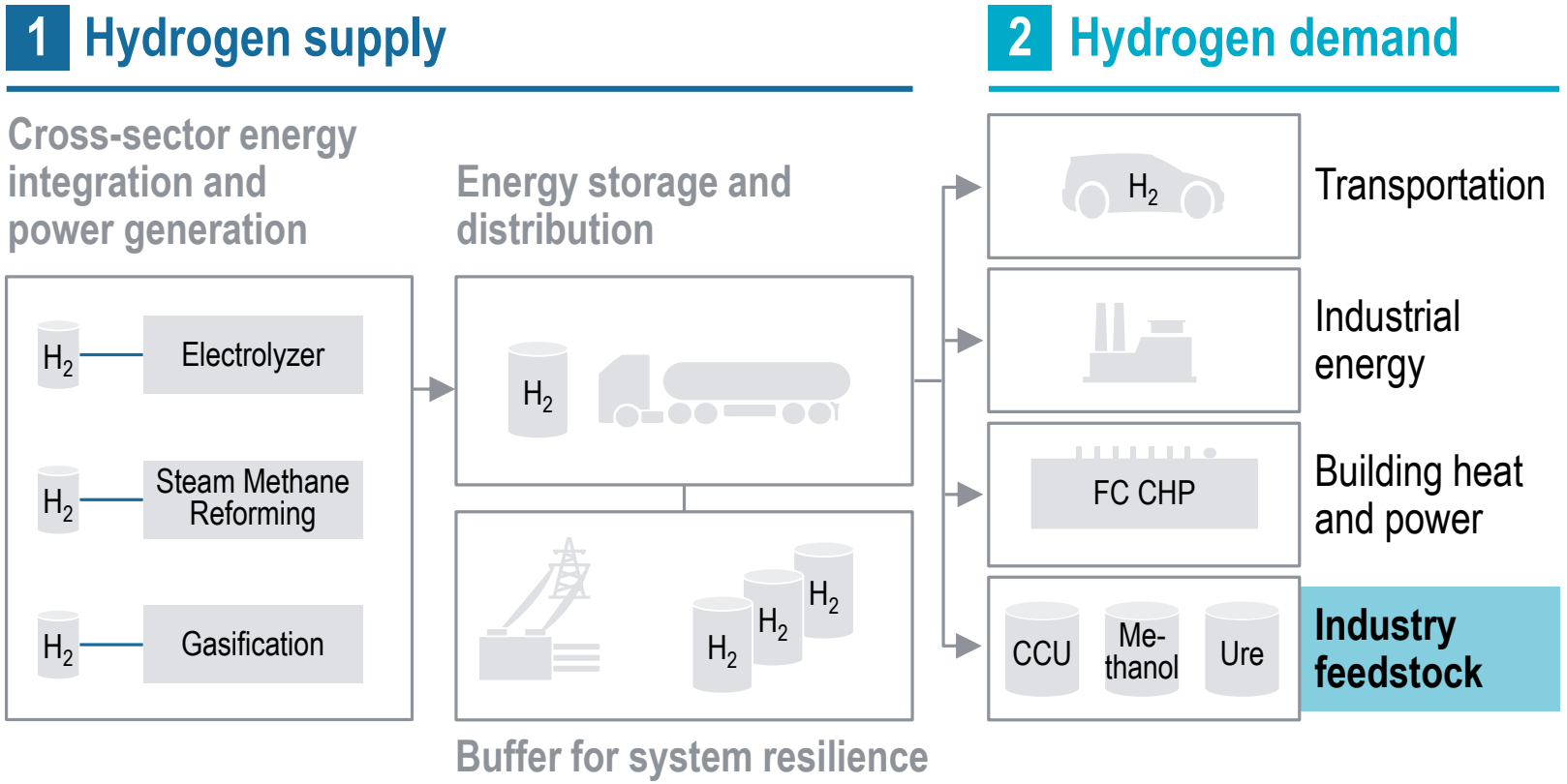
- **Massive increase of energy storage needs**
- **Hydrogen is required** in one way or the other to balance supply and demand
- **Different** natural, regulatory and commercial **frameworks will result in different technologies** chosen
- **Industry increasingly investing in H_2 storage** & transport applications

1) Government installation plans; for a CO2 reduction of 80 – 95% based on 1990

Source: FZ Jülich, Fraunhofer, COP21 agreement, Roland Berger

Hydrogen enables **decarbonization**, **system flexibility** and **sector coupling**

Schematic



> Hydrogen is a **flexible energy carrier** that can **cater to all energy needs**

> **Hydrogen inevitably required to reduce emissions**, e.g.

- Ammonia, methanol synthesis
- Hydrotreatment of hydrocarbons
- Steel production

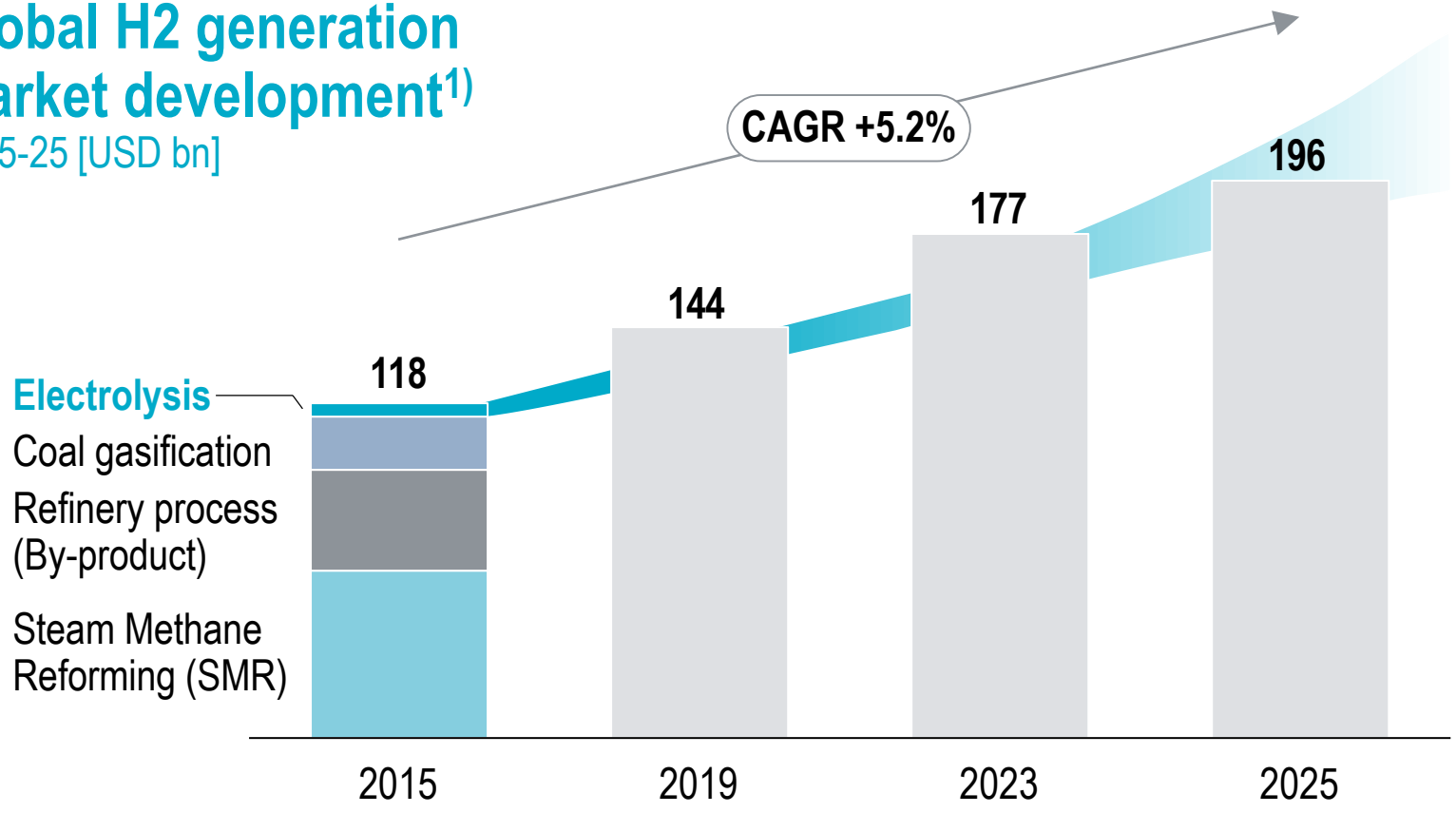
Use of H_2 for other green power fuels

Source: Shell (2017), Hydrogen Council (2017), Roland Berger

The market for hydrogen is expected to grow continuously – growing share for renewable H_2

Global H2 generation market development[1)]

2015-25 [USD bn]

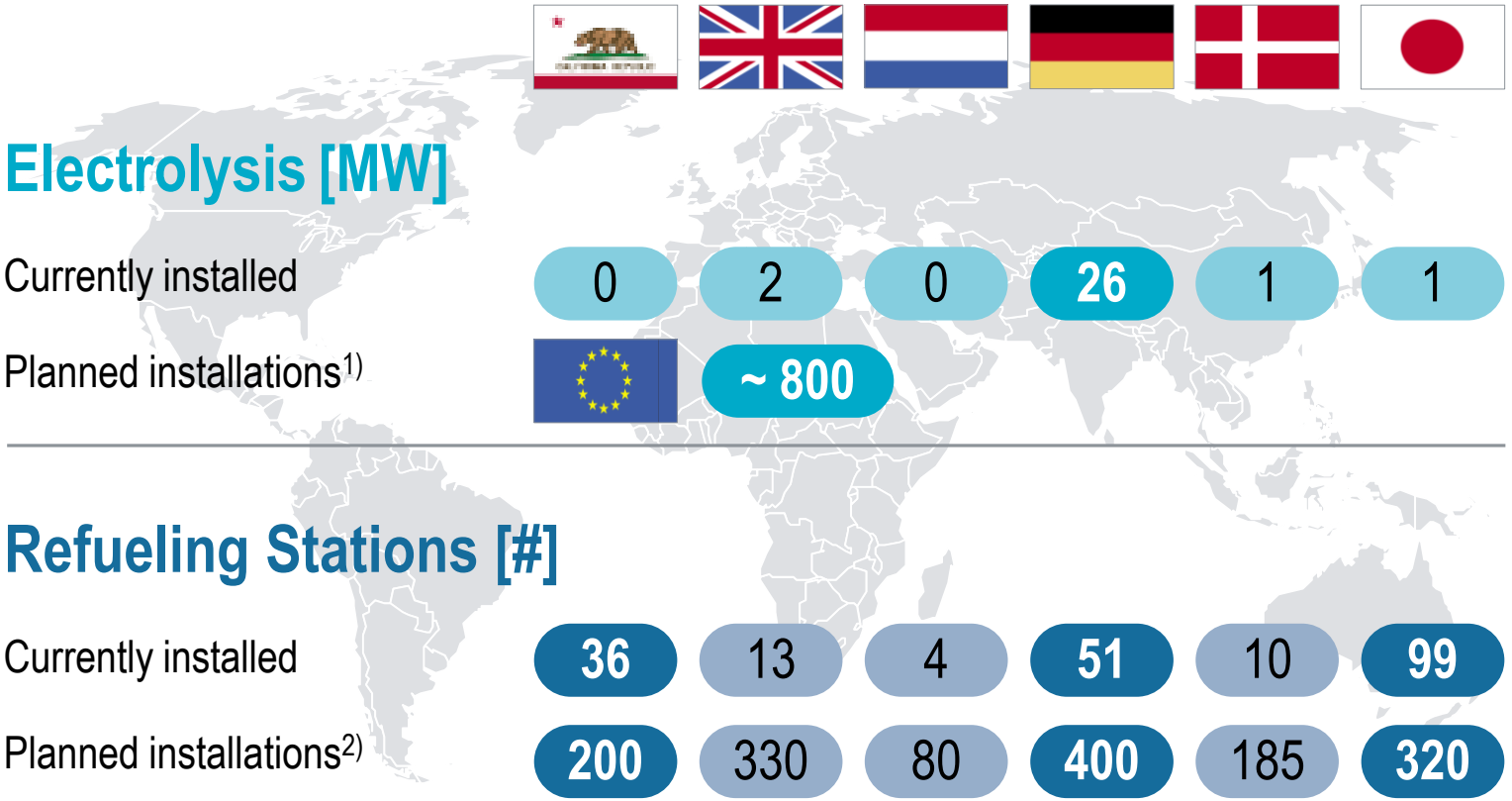


- **Global hydrogen market is expected to grow** continuously
- **Large opportunity for power-to-gas** to substitute SMR as dominant technology
- **Primarily driven by** investment in **Europe**

1) Global estimate of Hydrogen generation market including both captive & merchant Hydrogen and all major applications incl. industrial ones

Source: MarketsandMarkets, Roland Berger

Infrastructure for the use of hydrogen **increasingly envisaged – Germany** global **leader**



Electrolysis [MW]

Currently installed	0	2	0	26	1	1
Planned installations[1)]		~ 800				

Refueling Stations [#]

Currently installed	36	13	4	51	10	99
Planned installations[2)]	200	330	80	400	185	320

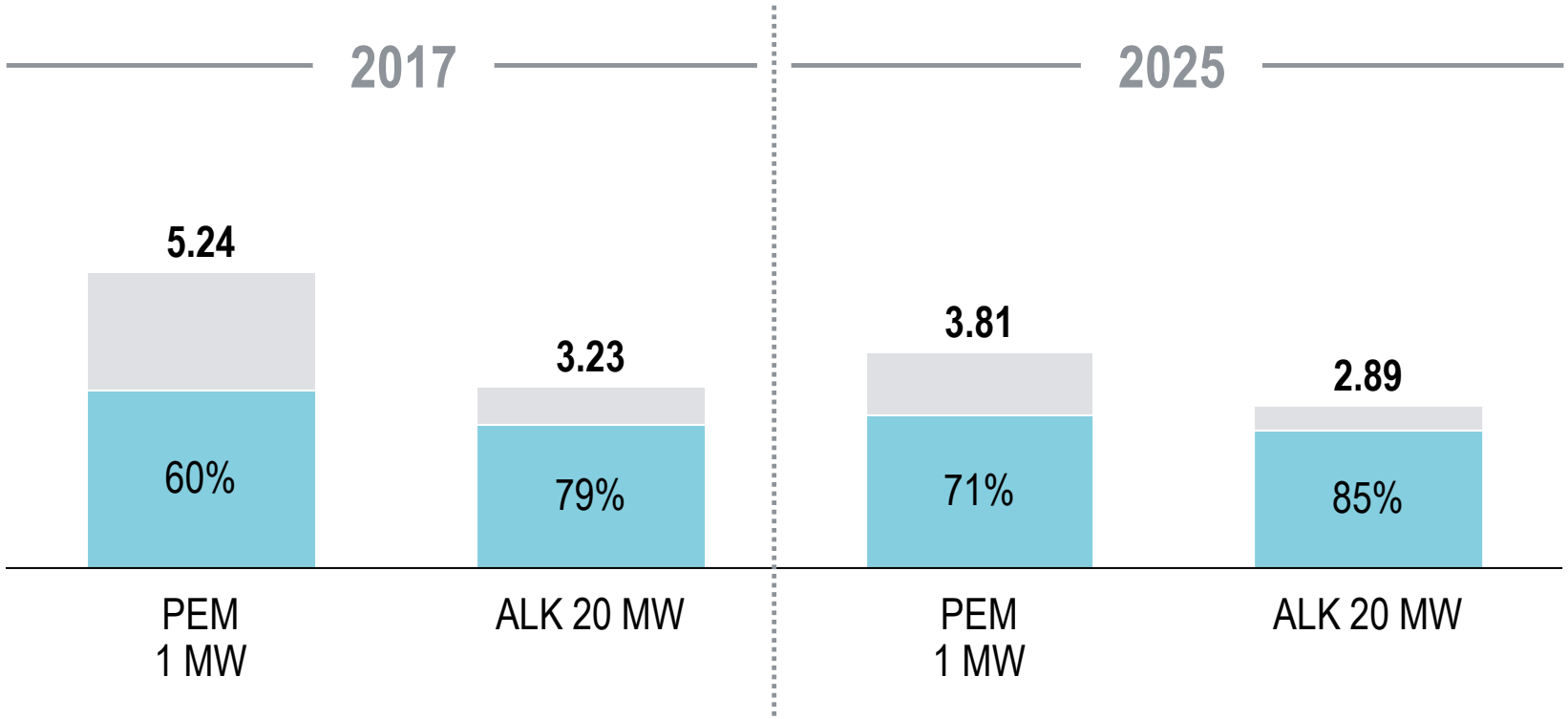
- **Technological leadership** still **in Europe** today
- **Germany has positioned itself well** with new infrastructure (P2G, HRS)
- **Growth of renewables** and **more applications critical** required
- **Long-term success has** to **come** from **commercial** applications, not subsides

Note: Status and publicly stated ambitions of deployment of FCH technology (selected countries); 1) Planned by Cities and Regions until 20230 (FCH JU Regions Study); 2) Multiple sources, through 2025

Source: Public reports and databases, Desk Research

Electricity is largest cost component for electrolytic hydrogen– **Advantage** for **low cost** energy **locations**

Electrolytic hydrogen production [EUR/kg]



> **Price of electricity is the key driver** of electrolytic hydrogen

> **Low cost renewable** electricity countries are **best equipped to produce** hydrogen at scale **cheap**

> **Hydrogen** is also **chance to reduce** import **dependency**

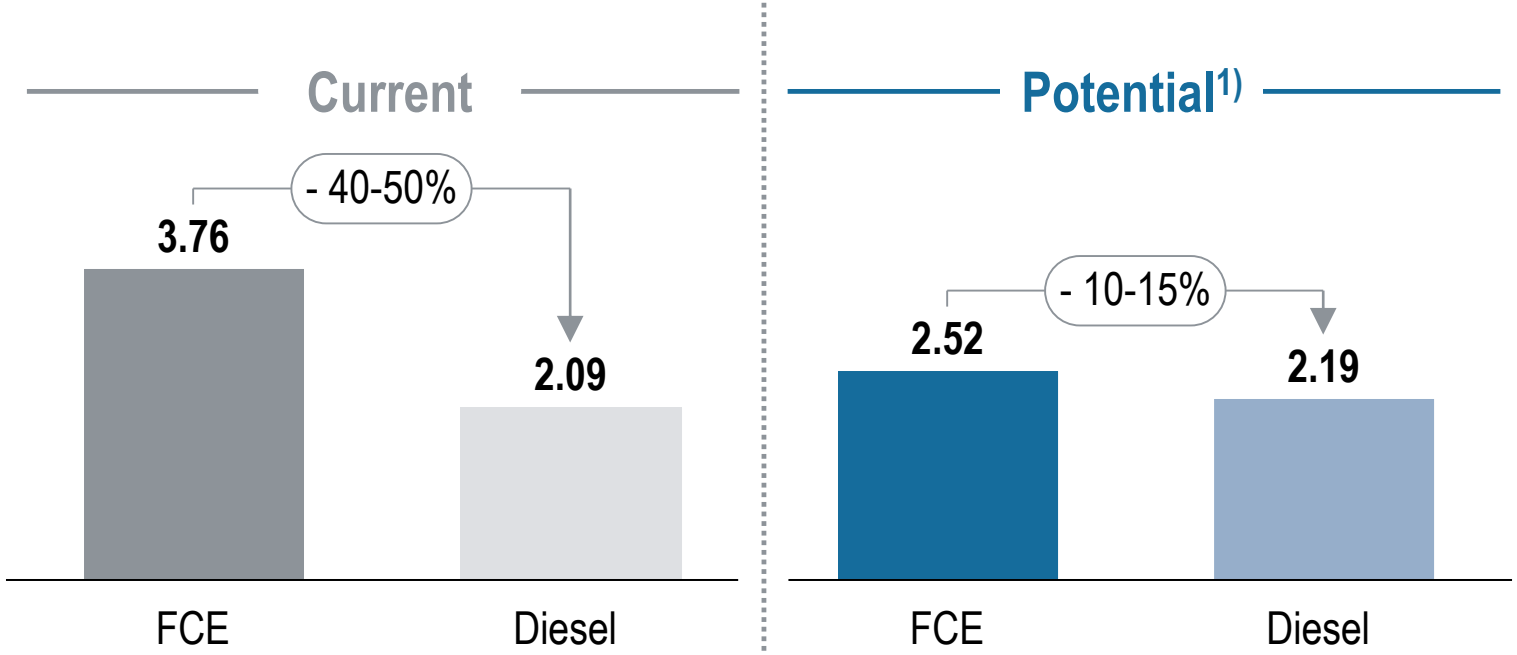
Note: 7,000 full load hours p.a., 50 EUR per MWh effective electricity cost, indicative cost break-down, cost reductions through the provisions of grid services are not included

Source: FCH2 JU, Roland Berger

Costs for fuel cell applications will reduce and are expected to be in a closer range with diesel

Example: Fuel cell bus

Total Cost of Ownership [EUR/km], annualized at 2017 prices



1) In production at large volumes scenario 2) Depending on hydrogen production mix

Source: FCH2 JU, Roland Berger

Potential in heavy-duty & fleets

> **Heavy-duty and fleet** operated fuel cell vehicles **become commercial**

> Key applications are **trains**, **buses**, **trucks** & **vans**

> **Some cases superior performance and cost levels** to batteries expected

> Some applications have **to move to synthetic fuels** (e.g. planes)

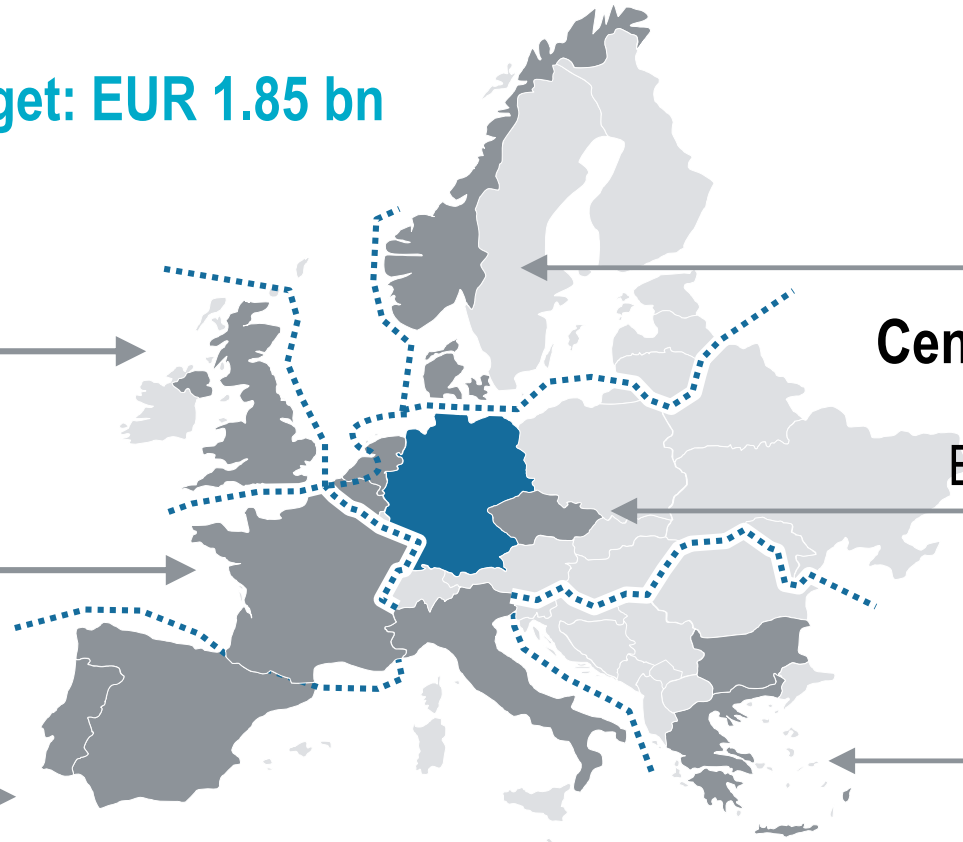
Demand for FCH in Europe still largely **driven by public sector**, aiming to invest **EUR 1.8 bn until 2022**

FCH JU Regions project
total planned project budget: EUR 1.85 bn

UK
5 projects
EUR 66 m

France
4 projects
EUR 133 m

Iberia + Italy
6 projects
EUR 168 m



Nordics + Baltics
3 projects
EUR 53 m

Central Europe thereof **Germany**
12 projects **6 projects**
EUR 1,207 m **EUR 971 m**

South East Europe
6 projects
EUR 223 m

Countries with regions that indicated a project budget

Notes: Sum of investment plans for 36 projects in Europe
Source: Cities & Regions Roadmaps, FCH 2 JU, Roland Berger

Countries in **Asia and North America support the fuel cells and hydrogen sector** with dedicated policies

North America

Regulatory intervention paired with **advantages for FCH technology** (e.g. FC cars) and infrastructure investment[1)]

Policies with FCH technology focus

Europe

Fragmented/ diverse approaches with large budgets for public activities, but **no long-term incentives** for hydrogen

Policies generally zero emission technology neutral

Asia

Strict public price and performance requirements for the technology generate more attractive product supply

Policies focused on building a competitive FCH industry

Learnings for Germany:
> Dedicated FCH strategy and policy provides stable framework for investment
> Regulation/incentives for industry investment in FCH strengthens supply side

1) Esp. in California

Hydrogen and fuel cells are key success factors for the "Energiewende" and keeping Germany's status as innovator

- **Germany needs an integrated hydrogen strategy** in order to stand its ground in international technology competition
- **Electrolysis, hydrogen processing and handling equipment are key enabling technologies** for Germany that should be supported
- **Technology leadership still in Europe for H_2 generation**, however, Asians have taken over for applications – Industry needs to invest
- Judging on past performance, **some of Germany's key industries can improve their performance in zero emission topics** with some external guidance


Roland
Berger
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