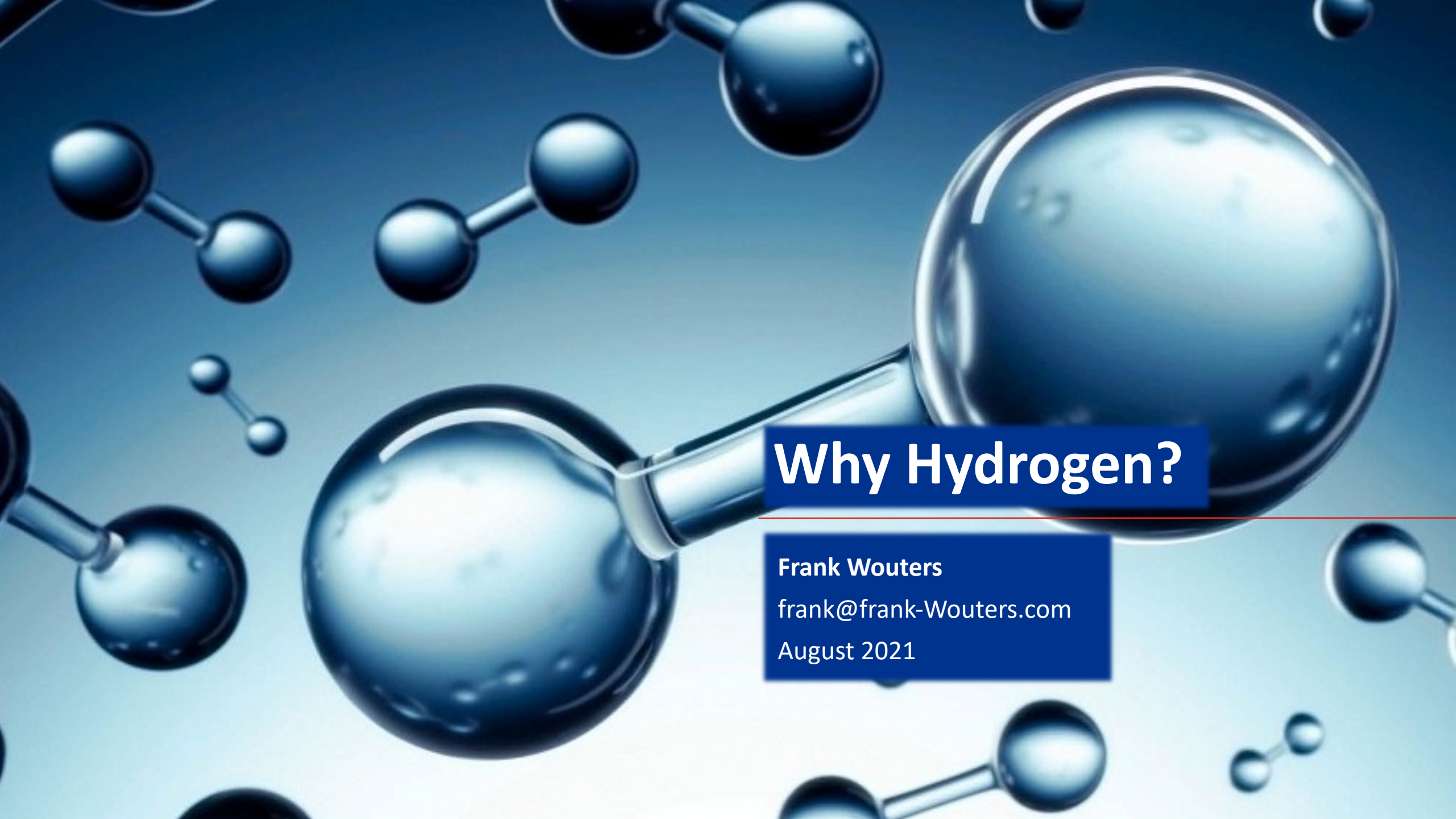


Why Hydrogen?

Frank Wouters
frank@frank-Wouters.com
August 2021

Frank Wouters

30 years energy transition experience

- MSc Mechanical Engineering
- SVP Energy Transition at Reliance Industries
- Director EU-GCC Clean Energy Technology Network
- Chairman MENA Hydrogen Alliance
- Chairman Dii Desert Energy Advisory Board
- Director Gore Street Capital – London
- Director VAST Solar – Australia
- Fellow Payne Institute, Colorado School of Mines

Past:

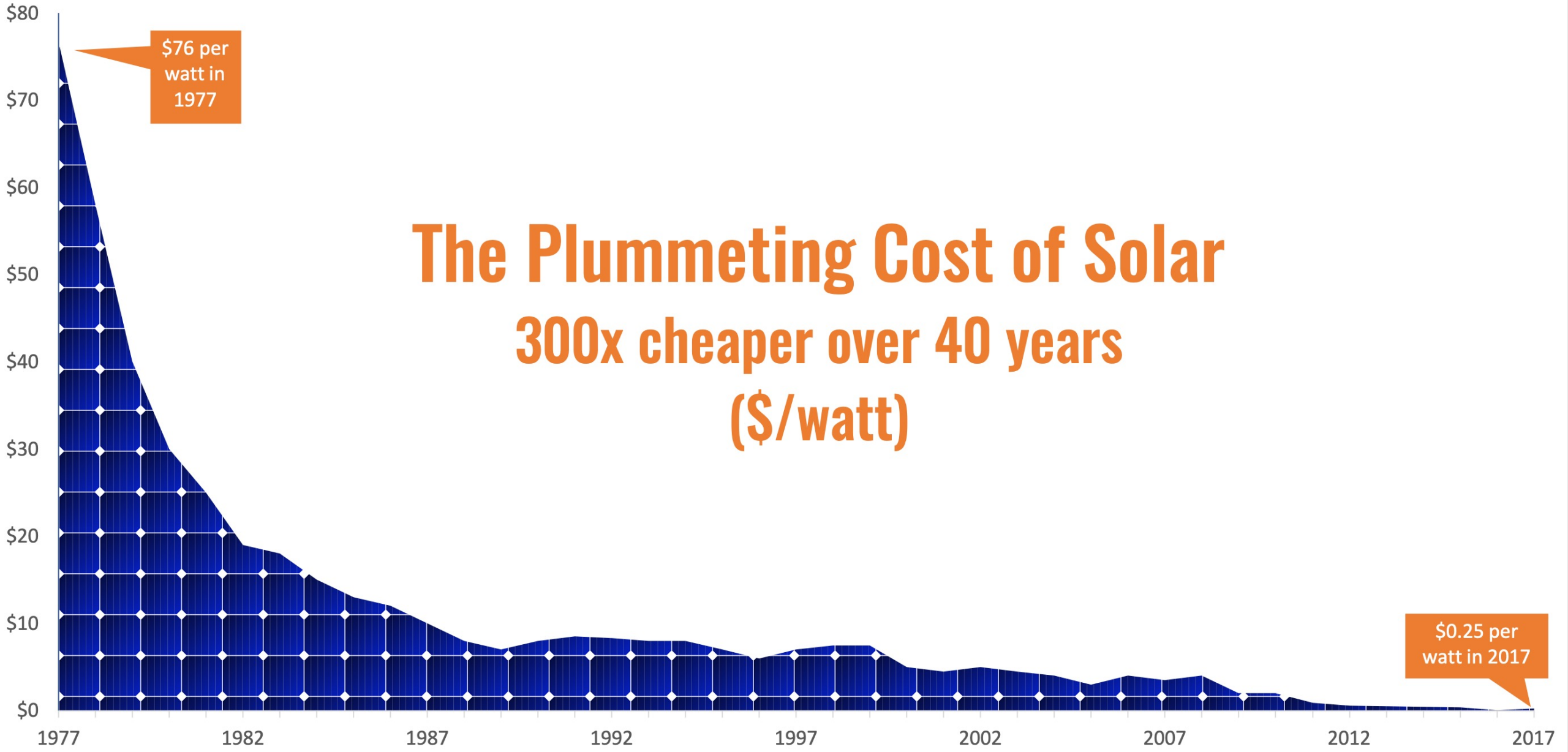
- 2017 – 2021: Global Lead Clean Hydrogen at Worley
- 2012 – 2014: Deputy Director-General of IRENA
- 2009 – 2012: Director of Masdar's Clean Energy Business Unit
- 1993 – 2009: various roles within ECONCERN, last as CEO of Evelop
- 1990 – 1993: TDAU at University of Zambia

Flow

1. The energy transition
2. Hydrogen in the energy transition
3. Hydrogen in Europe
4. System aspects of hydrogen
5. Hydrogen: the market
6. Projects

1

The energy transition - electricity



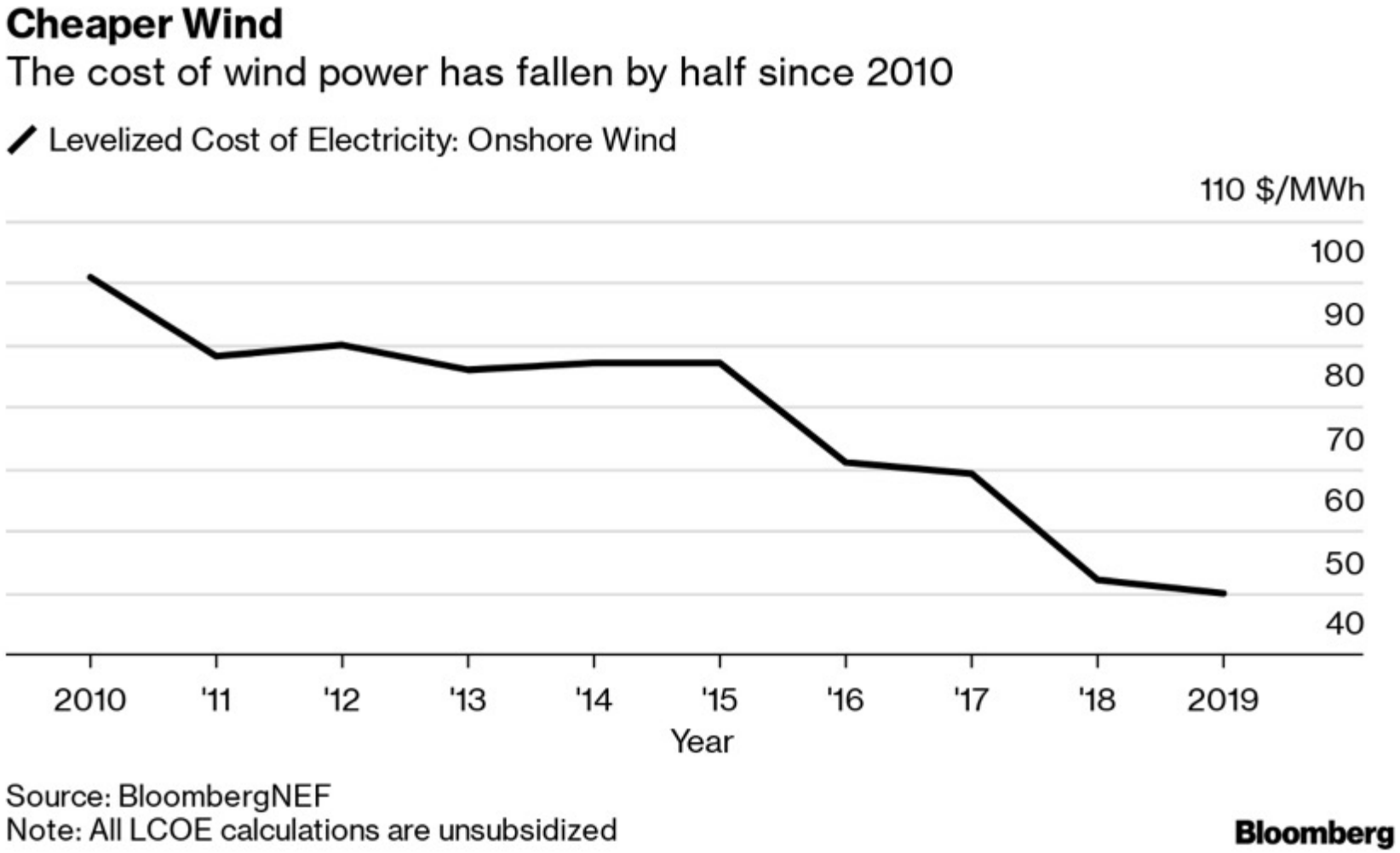
The Plummeting Cost of Solar

300x cheaper over 40 years

($/watt)

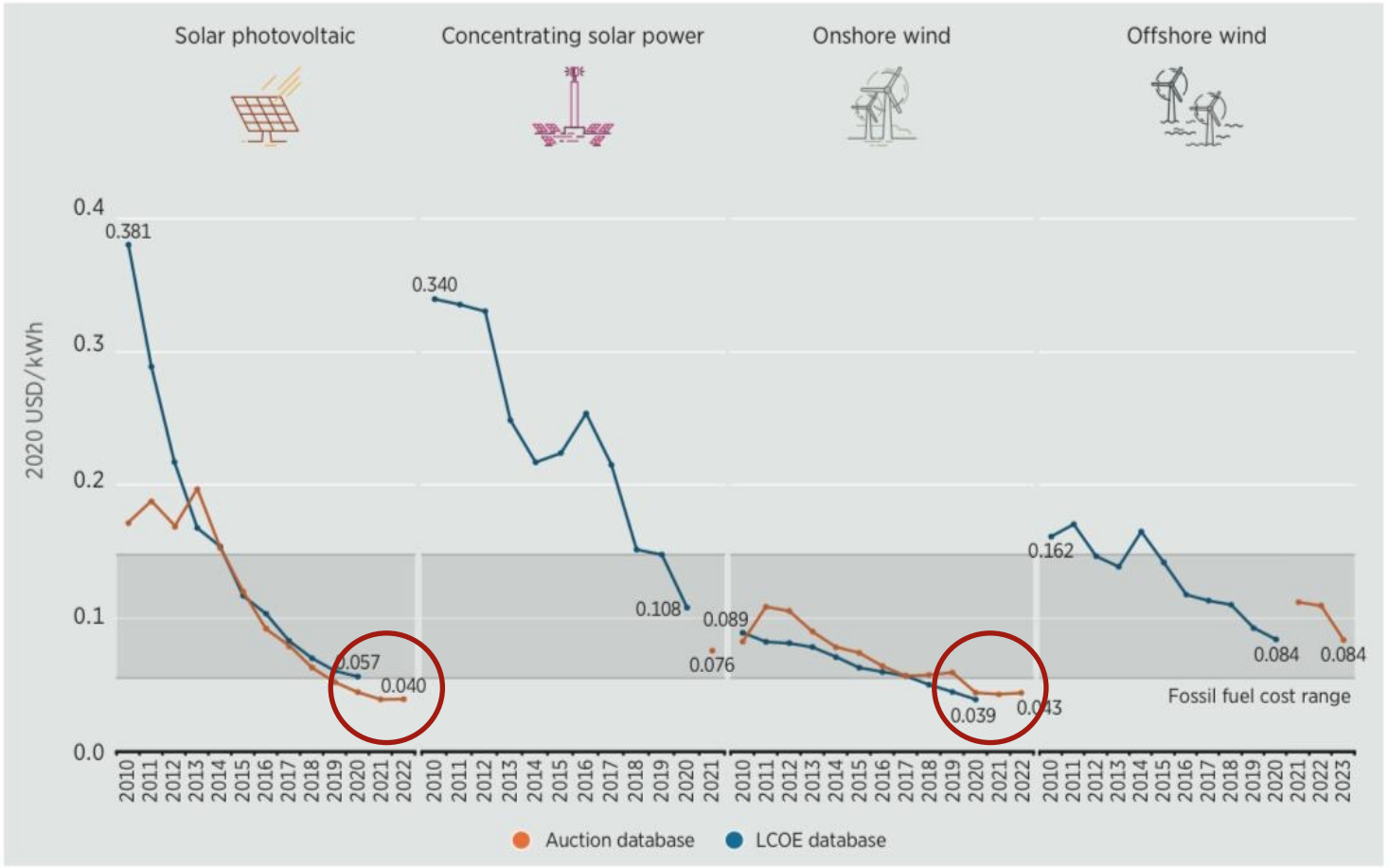
Sources: Bloomberg New Energy Finance, National Renewable Laboratories, Freeing Energy

But also wind is cheap now



IRENA Cost Study June 2021 – Cost of electricity per resource

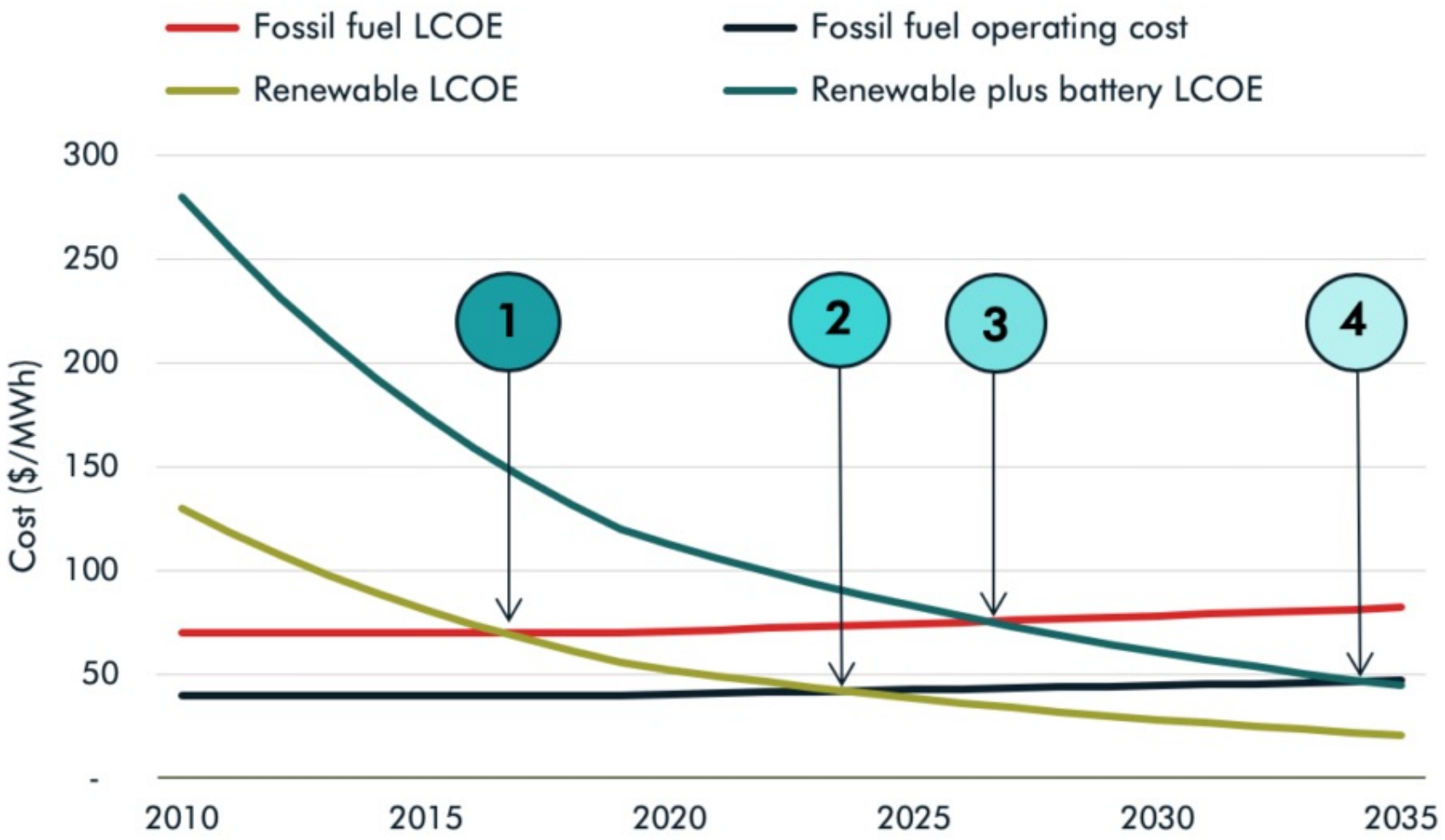
Figure ES.3 The global weighted-average LCOE and PPA/auction prices for solar PV, onshore wind, offshore wind and CSP, 2010-2023



Source: IRENA Renewable Cost Database

Note: The thick lines are the global weighted average LCOE, or auction values, by year. For the LCOE data, see Figure ES2 note. The band that crosses the entire chart represents the fossil fuel-fired power generation cost range.

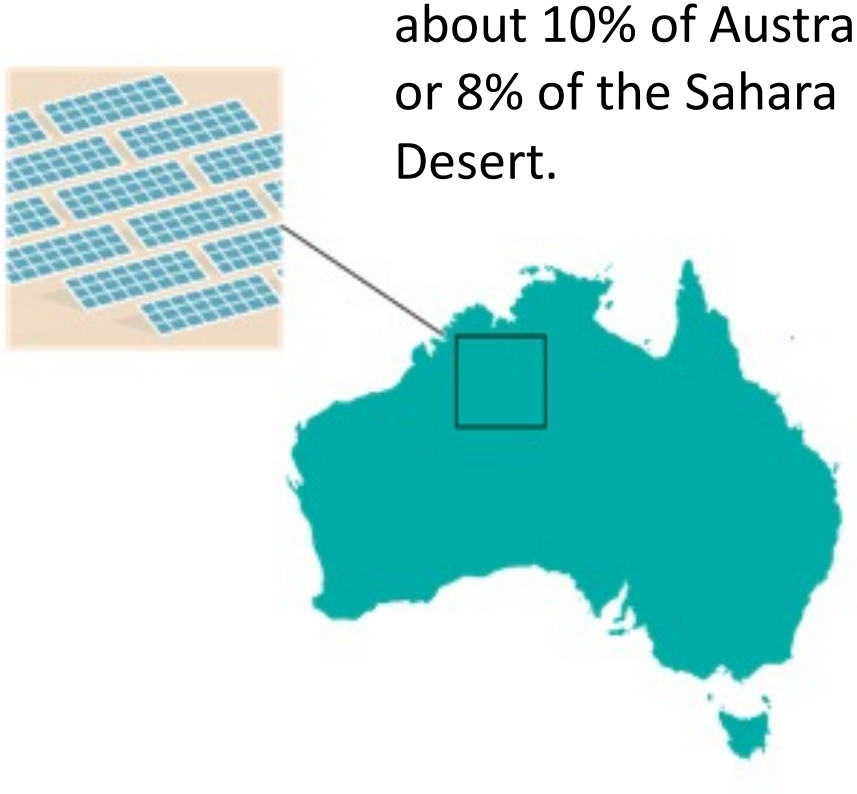
Tipping points



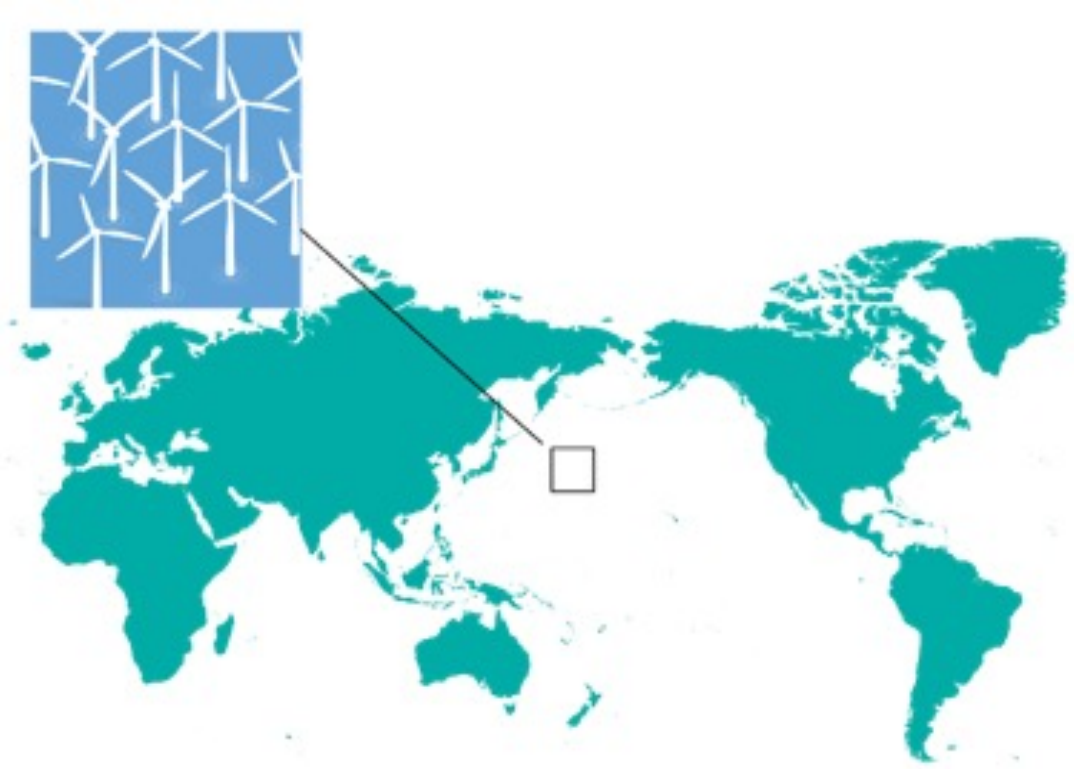
Source: Carbon Tracker

Worldwide energy demand: 155,000 TWh/a

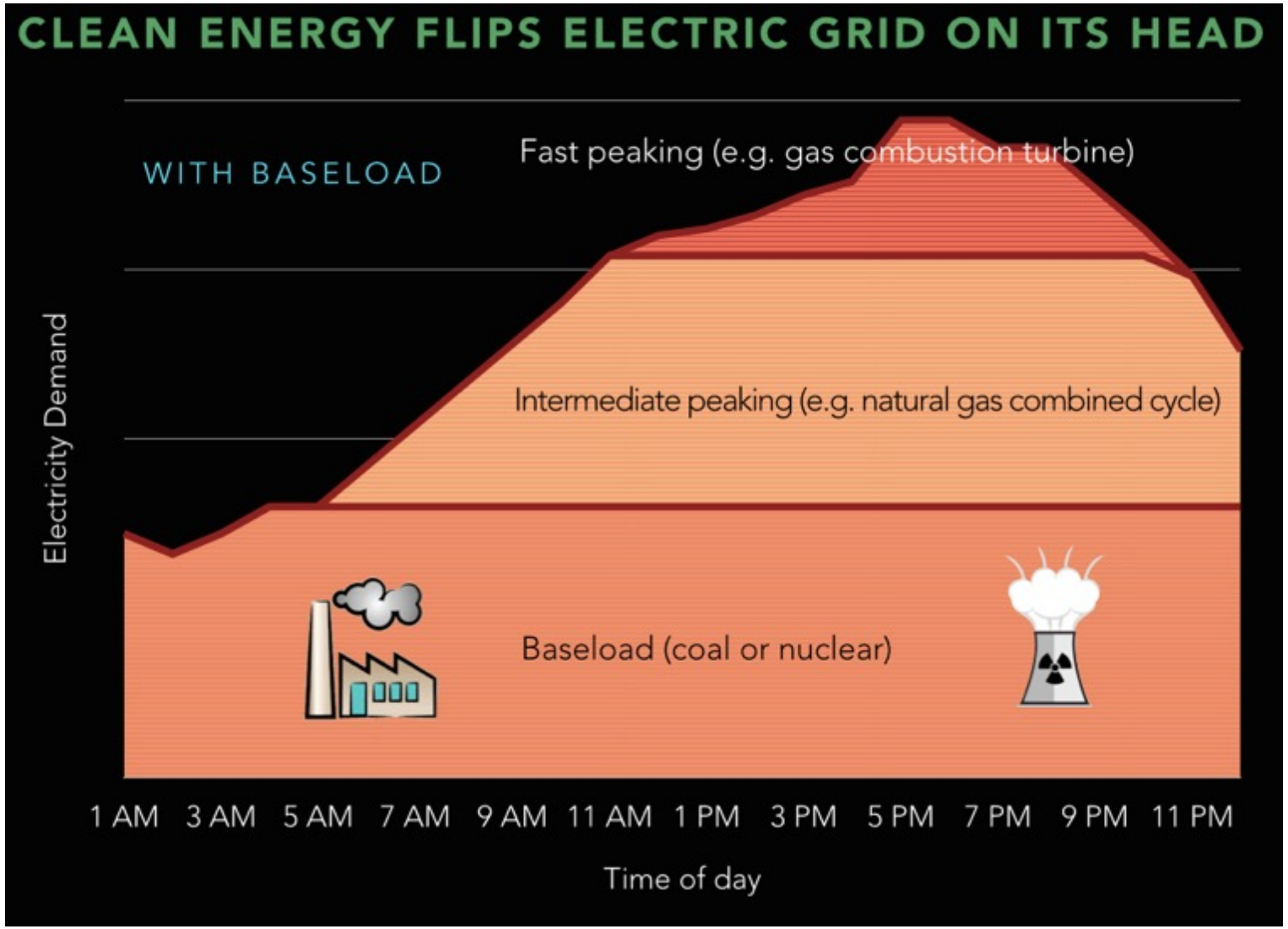
With solar panels only, it would require a surface area covering about 10% of Australia or 8% of the Sahara Desert.



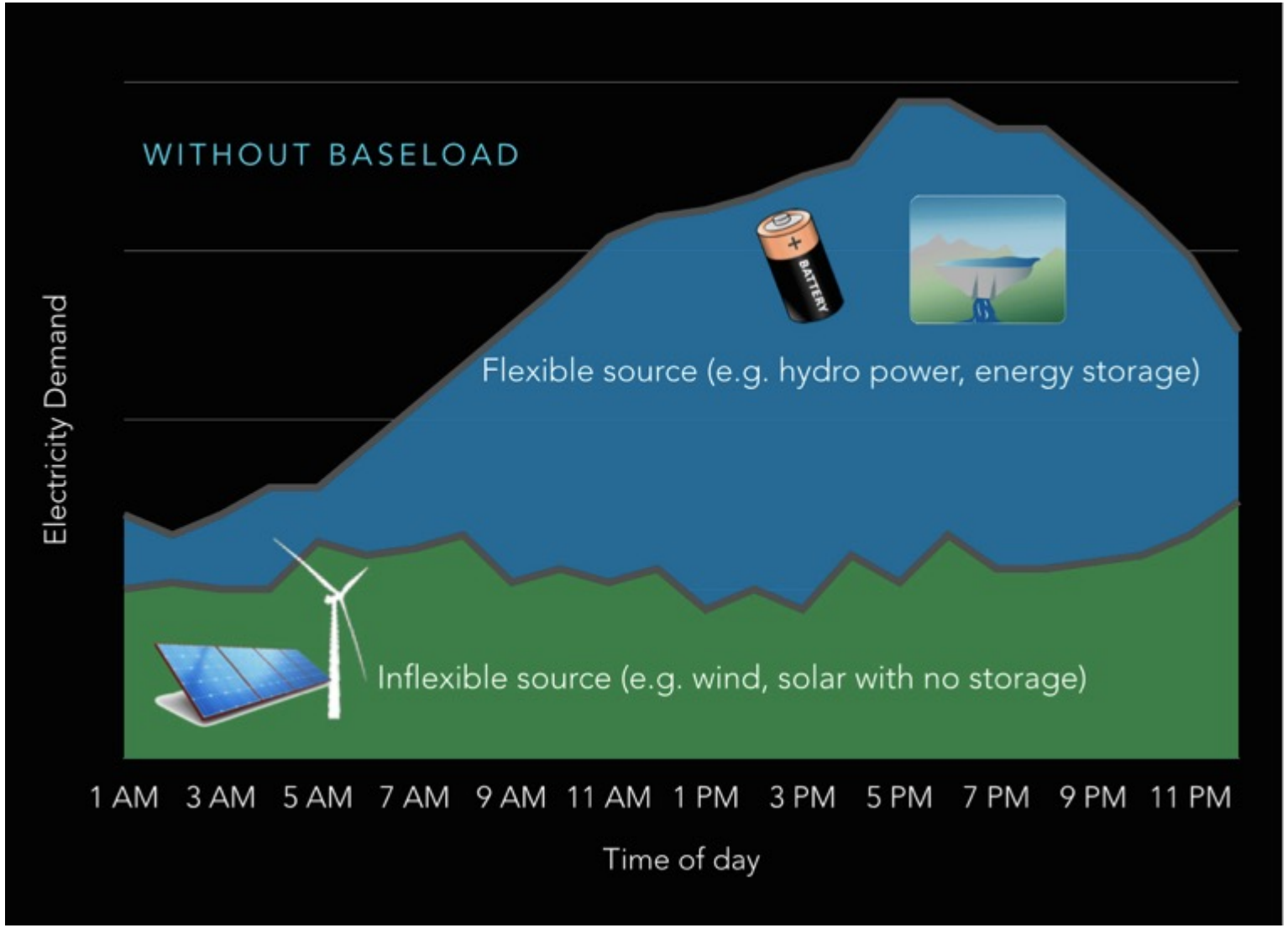
In a scenario with only wind turbines, it would require an area of 1.5% of the Pacific Ocean.



From the old system

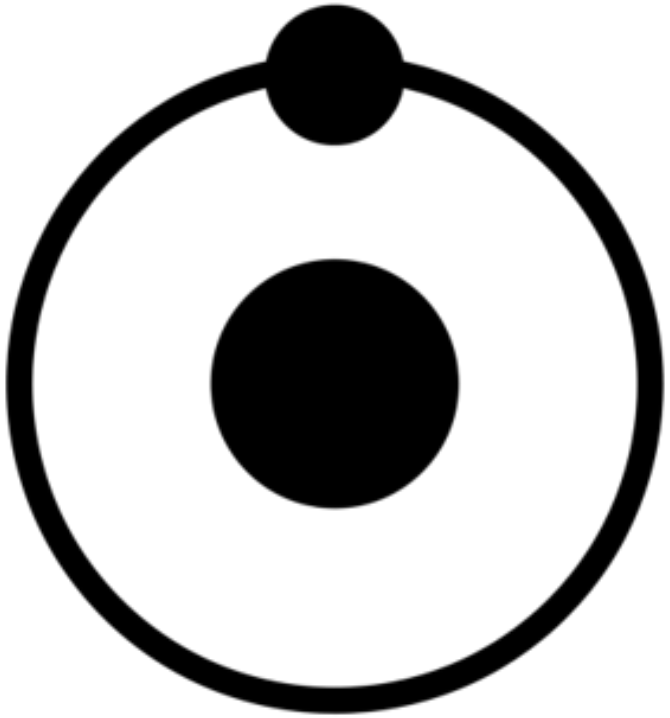


To the new


WITHOUT BASELOAD
Electricity Demand
Flexible source (e.g. hydro power, energy storage)
Inflexible source (e.g. wind, solar with no storage)
1 AM
3 AM
5 AM
7 AM
9 AM
11 AM
1 PM
3 PM
5 PM
7 PM
9 PM
11 PM
Time of day

2

Hydrogen in the energy transition

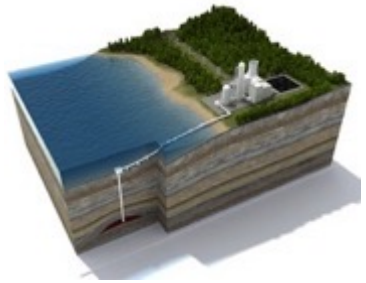


How do we make hydrogen?

SMR: grey hydrogen

- Steam methane reforming (SMR) of natural gas
- 95% of all current H_2 production
- 9-10 kg of CO_2 emissions for each kg of H_2
- SMR: TRL 9

SMR + CC(U)S: blue hydrogen

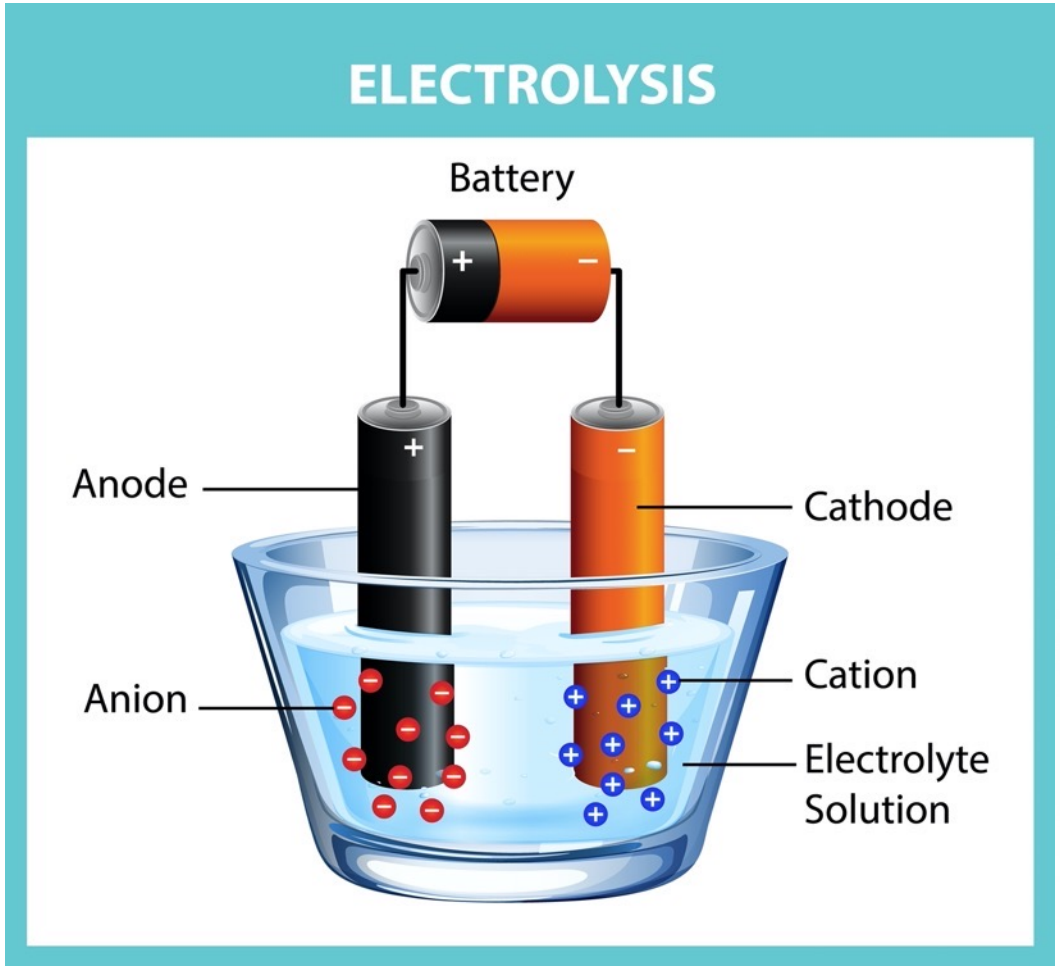


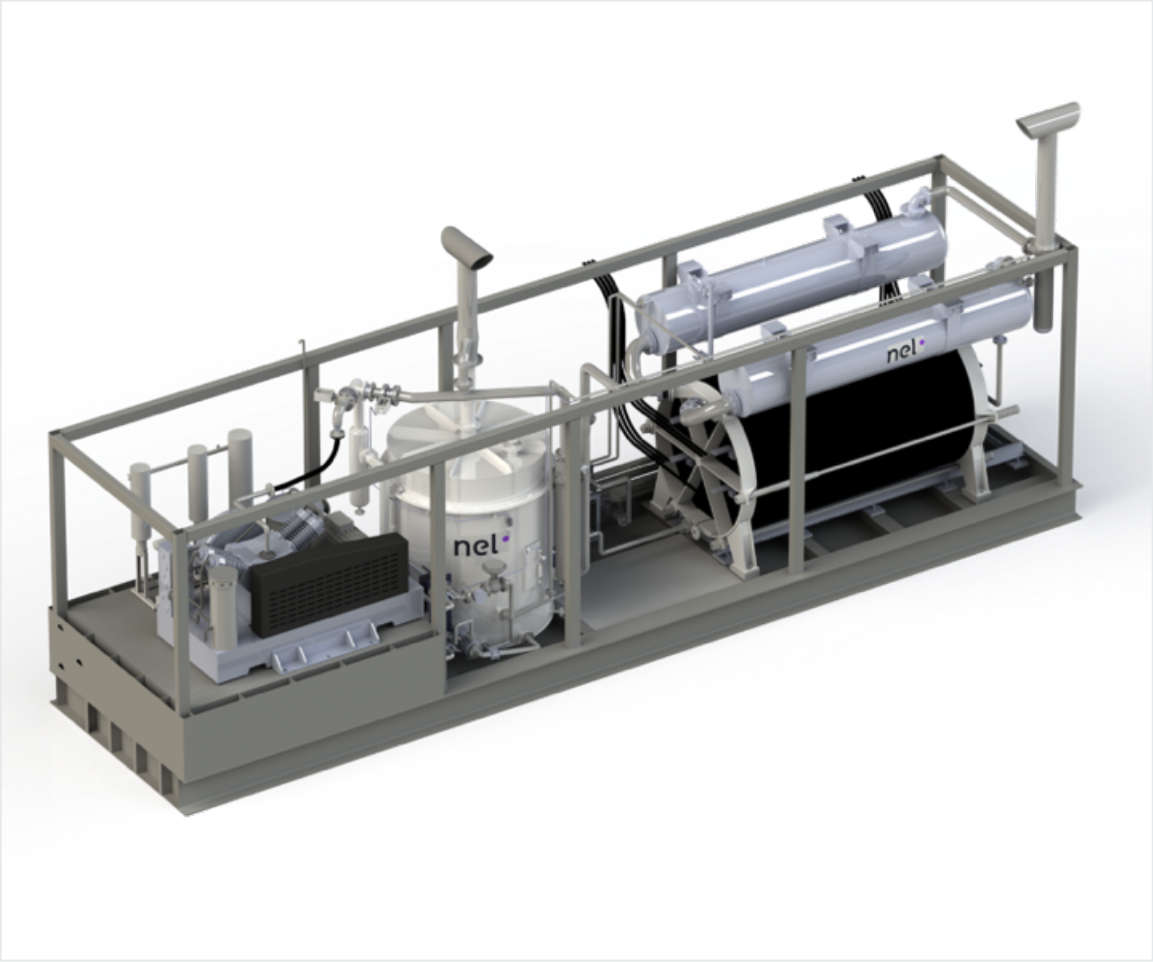
- Not yet practiced, but significant attention lately
- CC(U)S: TRL 8

Electrolysis: green hydrogen

- Water electrolysis is a derivative of proven chlorine electrolysis, with decades of experience

Power to Gas: Electrolyzer





Electrolysis: not new

Rjukan, Norway; 1927 – 1970's

Glomfjord, Norway; 1953 – 1991

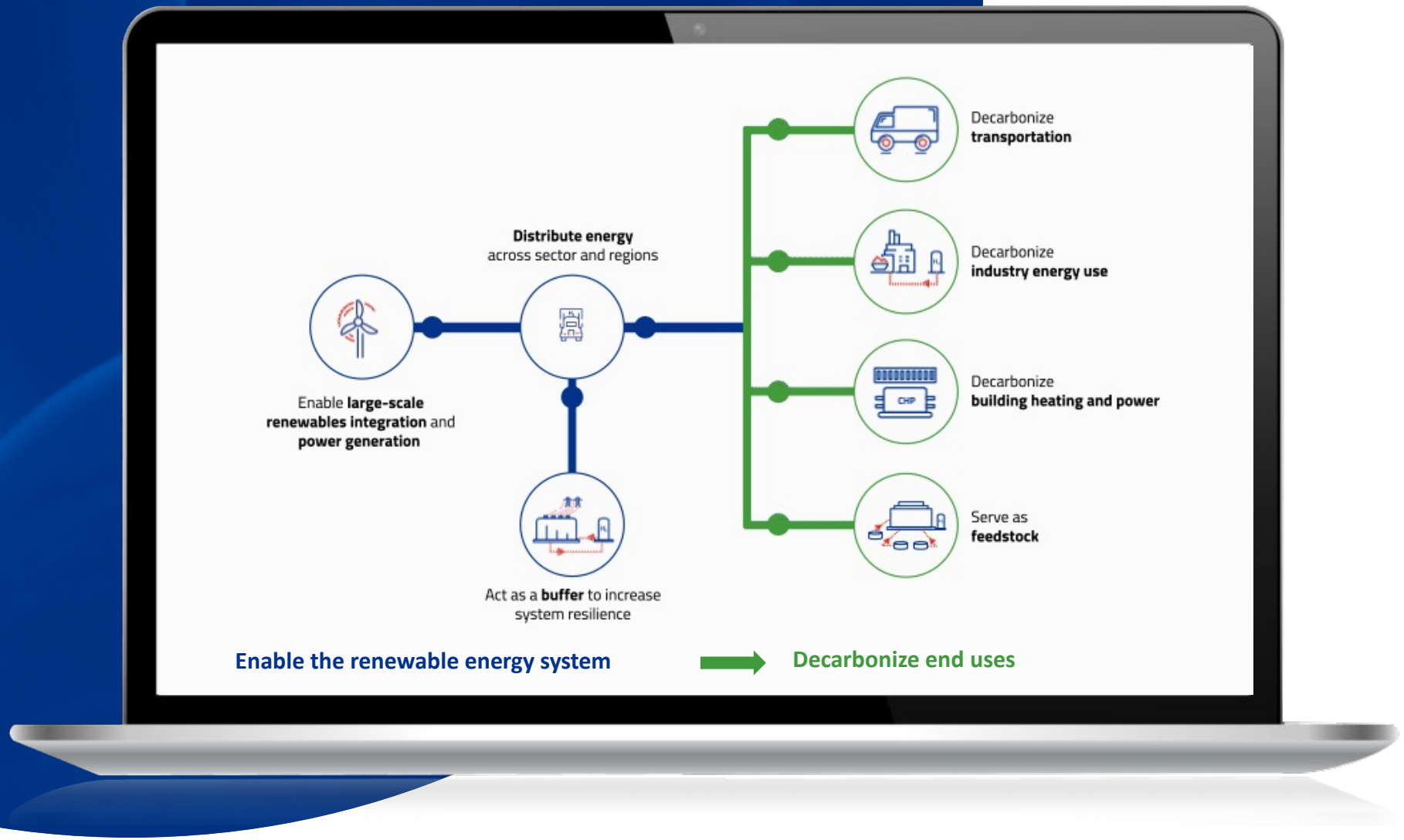
Source: NEL

Hydrogen will soon be competitive with natural gas

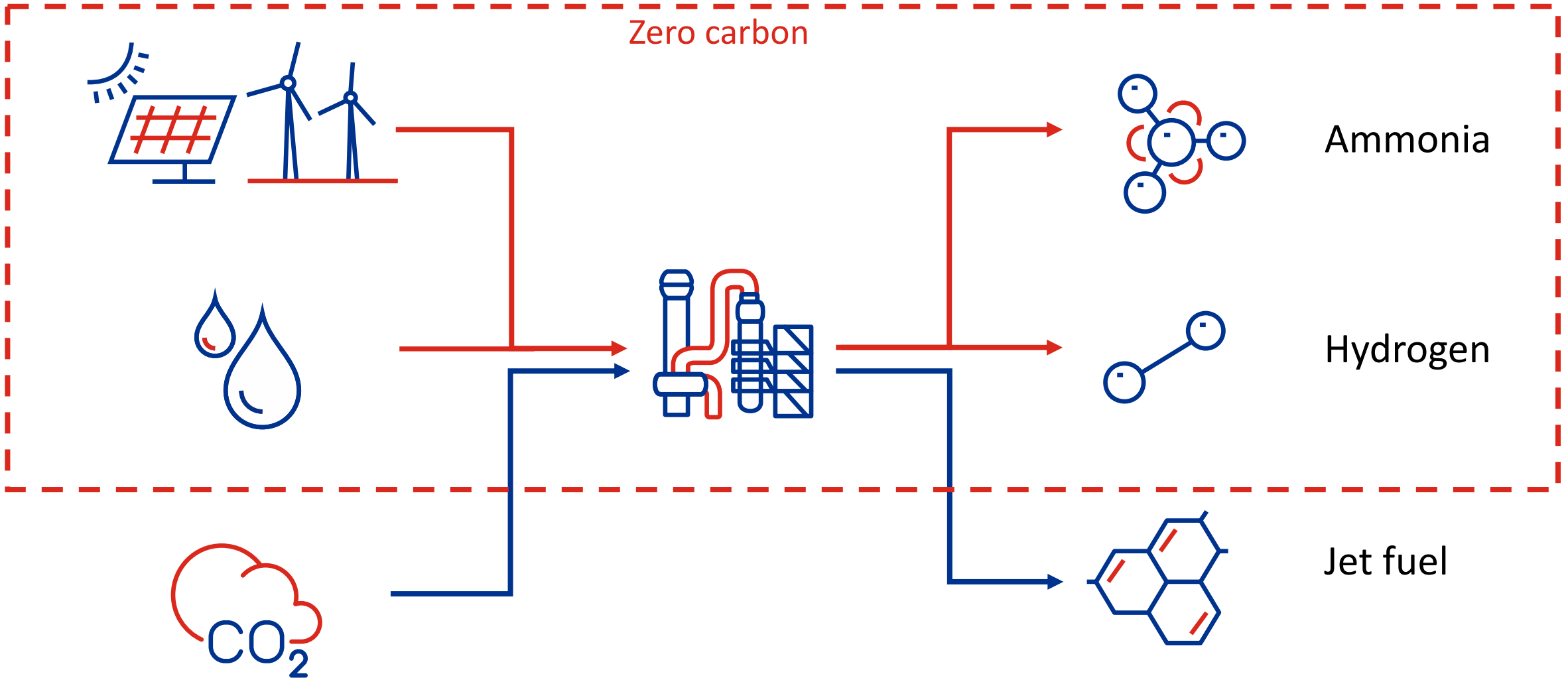
- IEA (June 2019)
  $1/kg by 2040
  which corresponds to
  $9/mmbtu for natural gas
- Bloomberg (August 2019)
  Hydrogen production cost down to
  $0.8/kg
  which corresponds to
  $6/mmbtu for natural gas.

With the declining **cost of electrolyzers and renewable electricity**, hydrogen will be competitive with natural gas

The role of hydrogen in the energy transition



How to make hydrogen fuels?



3

Hydrogen in Europe

Final energy in Germany 2020

Electrons

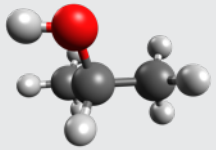
513 TWh

~20%

More RE

50 %
RE Power

Molecules



1987 TWh

Electrification

More clean molecules

Inter alia Biofuels 9 %

Final energy in Germany 2050

Electrons

50%

100 % RE Power

Molecules

50%

- Biofuels (limited)
- CCS (limited)
- Green H_2
- H_2 based substances
  - Ammonia
  - Methanol
  - Other e-fuels

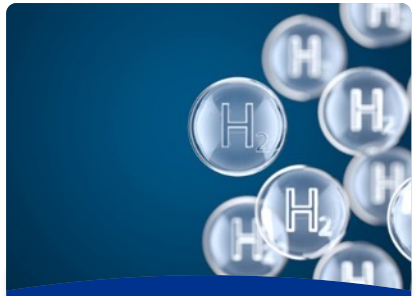
100% clean molecules

Frans Timmermans – November 2019

8 July 2020: European hydrogen strategy

Priority focus on **green** hydrogen, role for blue

At least **6 GW** of electrolyzers by 2024 at least **40 GW** installed by 2030.



But also 1 million ton by 2024 and 10 million ton by 2030

Role for **import** (40GW) from neighboring regions

By 2030, the Commission estimates that €13-15bn could be invested in electrolyzers across the EU*

*in addition to €50-150bn for a dedicated wind and solar capacity of 50-75GW.

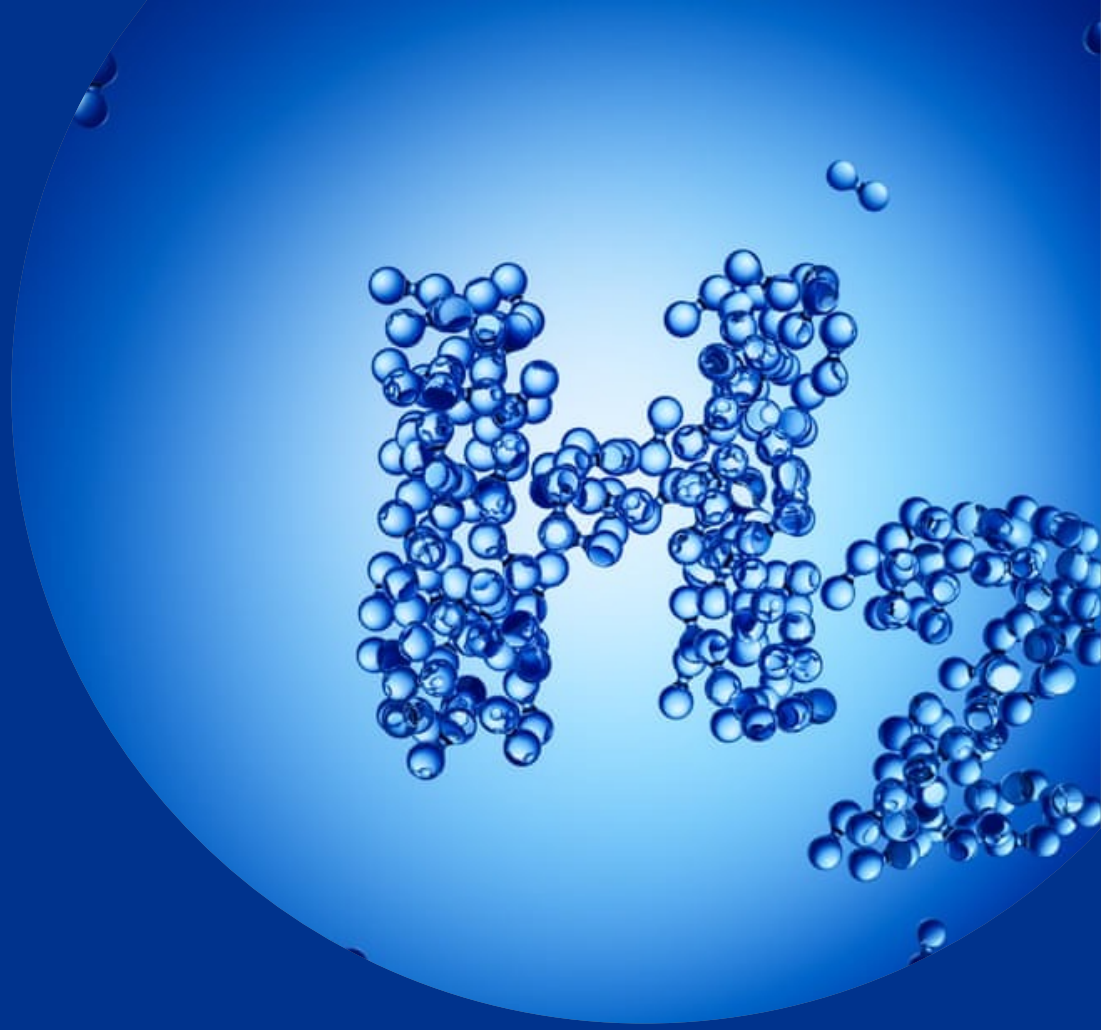
14 July 2021: Fit for 55 package

REDII now has two sub-targets for H_2:

- Transport: it will be 2.6% for H_2, corresponding to 3 million ton by 2030.
- Industry that use H2 now must have 50% green H2 by 2030, corresponding to 2.7 million ton.
- The 5.7 million ton corresponds to 40GW

4

System aspects of hydrogen



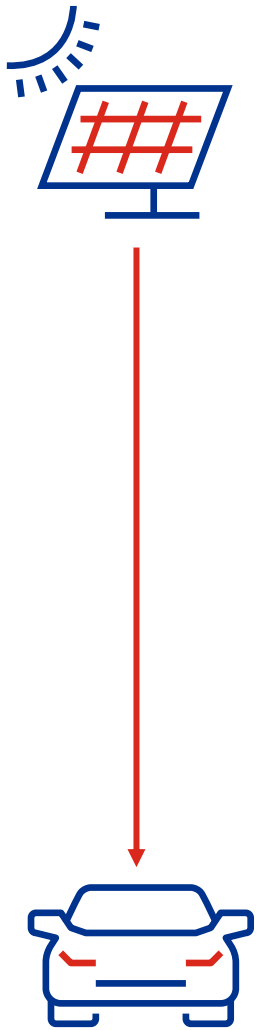
1. The efficiency fallacy
2. Infrastructure
3. Storage

Opposing views

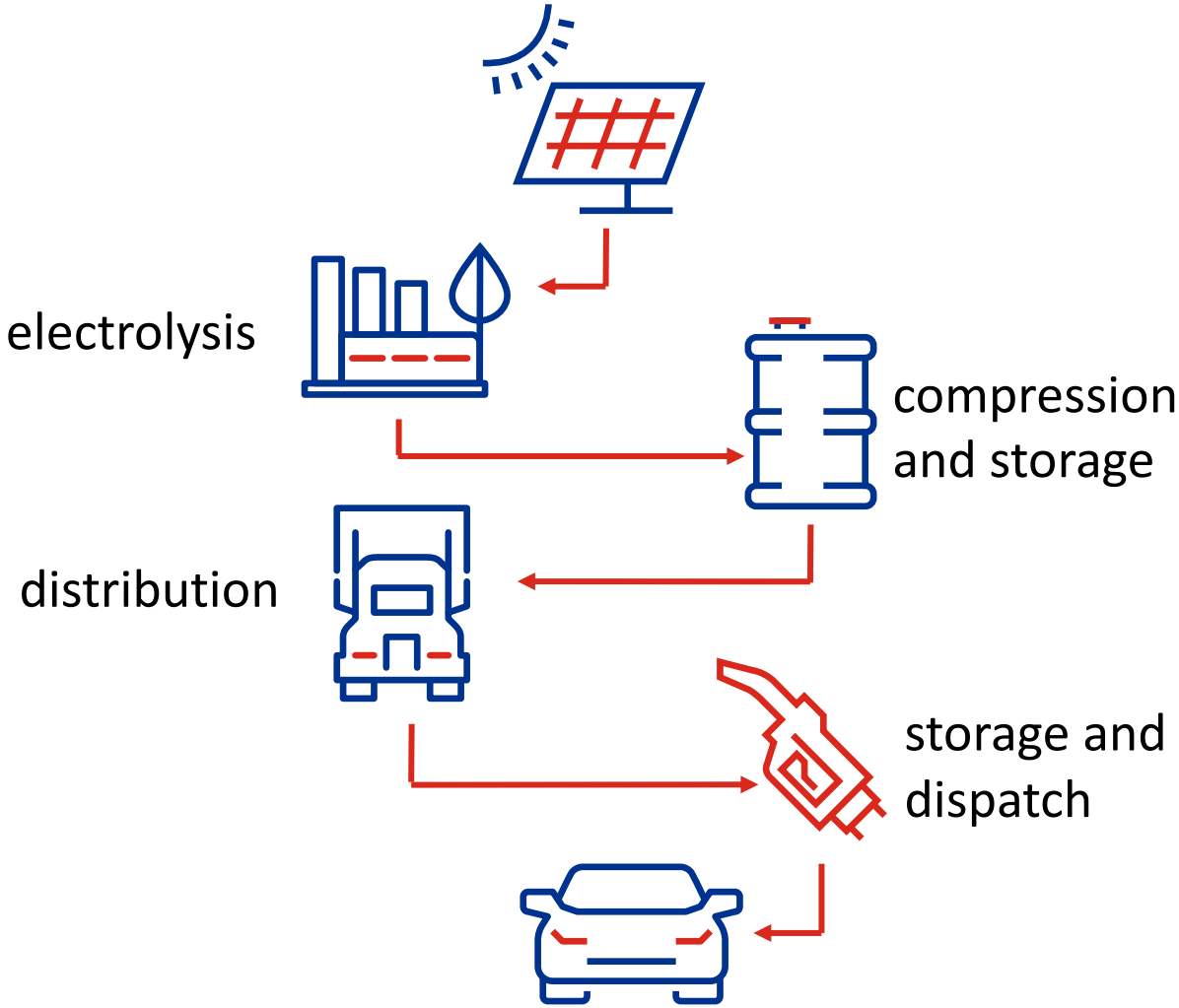
“Fuel cells = fool sells”
and "Staggeringly dumb”

”Hydrogen is the rock star for new energies all around the world, especially in Europe"

1. The efficiency fallacy



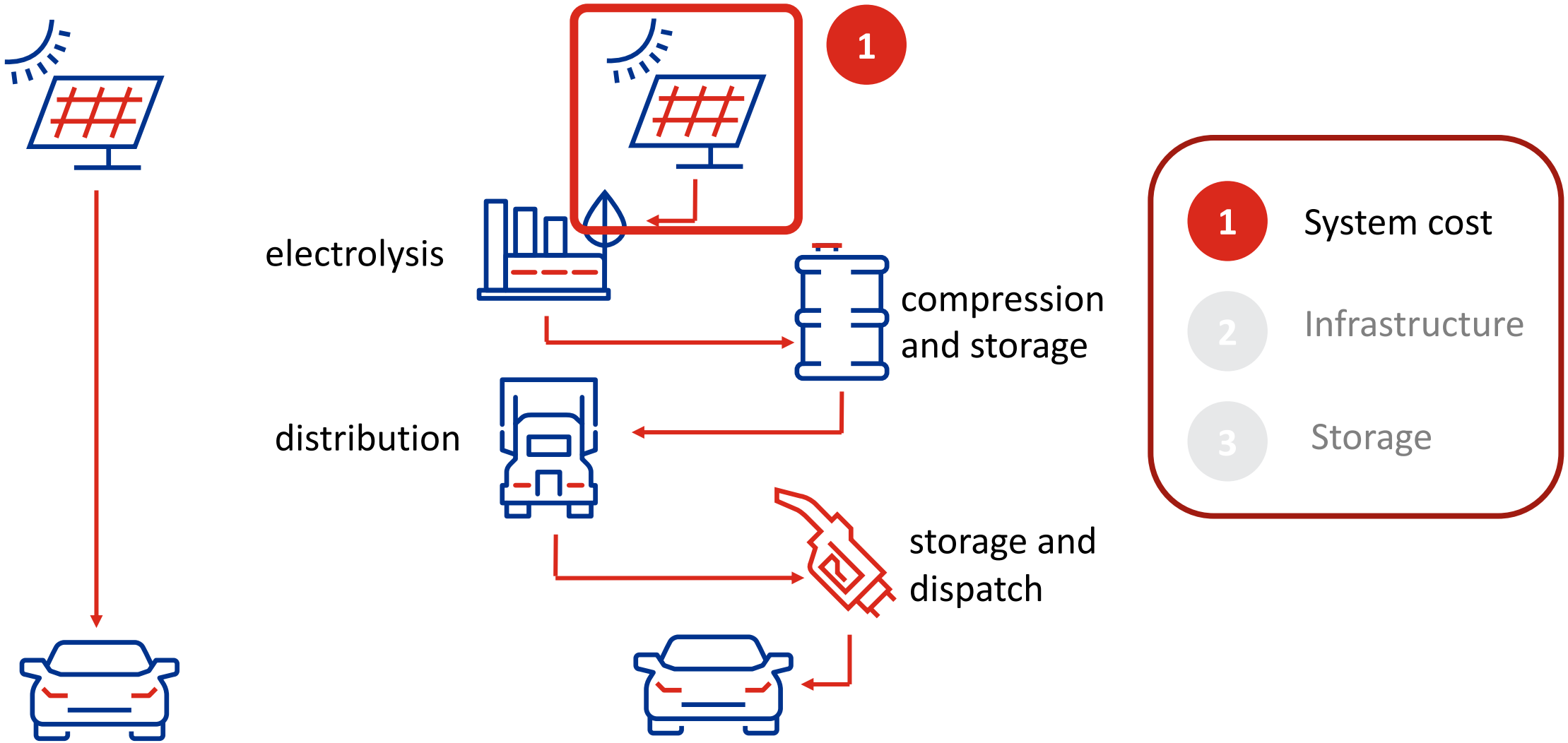
Battery Electric Vehicle



Fuel Cell Electric Vehicle

1. System cost
2. Infrastructure
3. Storage

1. The efficiency fallacy

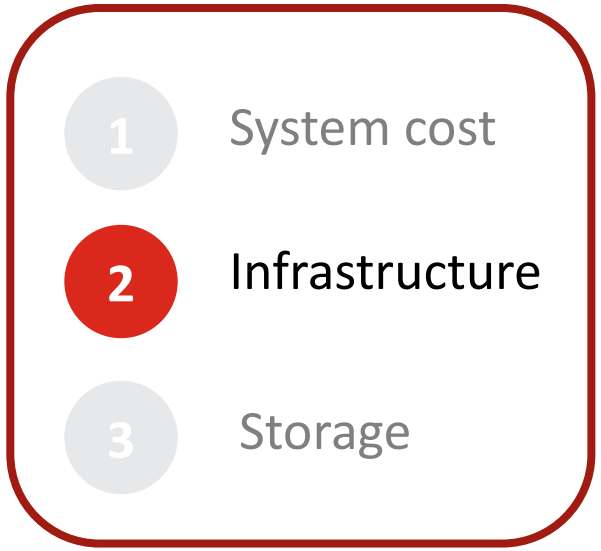


Battery Electric Vehicle

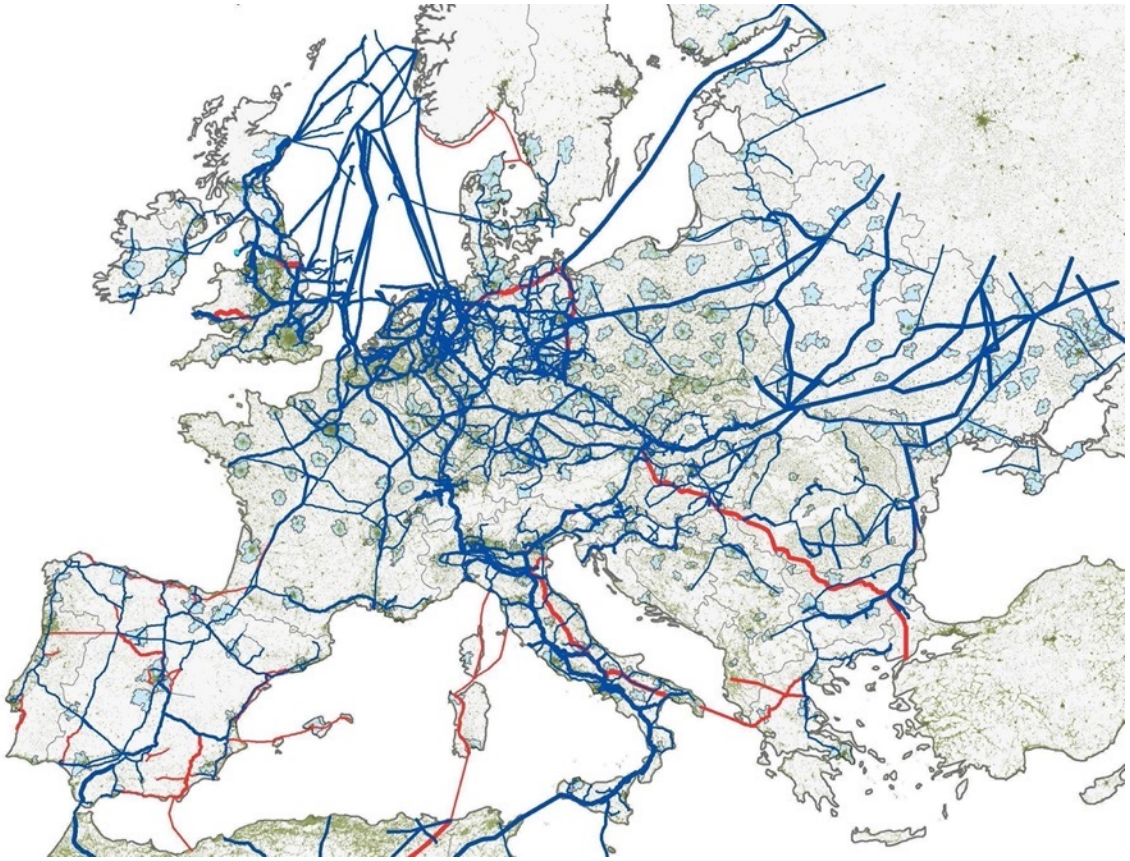
Fuel Cell Electric Vehicle

2. Infrastructure

	Cable (BritNed)	Pipeline (BBL)
Construction cost	€ 500 mln	€ 500 mln
Capacity	1 GW	15 GW
Volume (year)	8 TWh	120 TWh



2. Infrastructure



1 System cost

2 Infrastructure

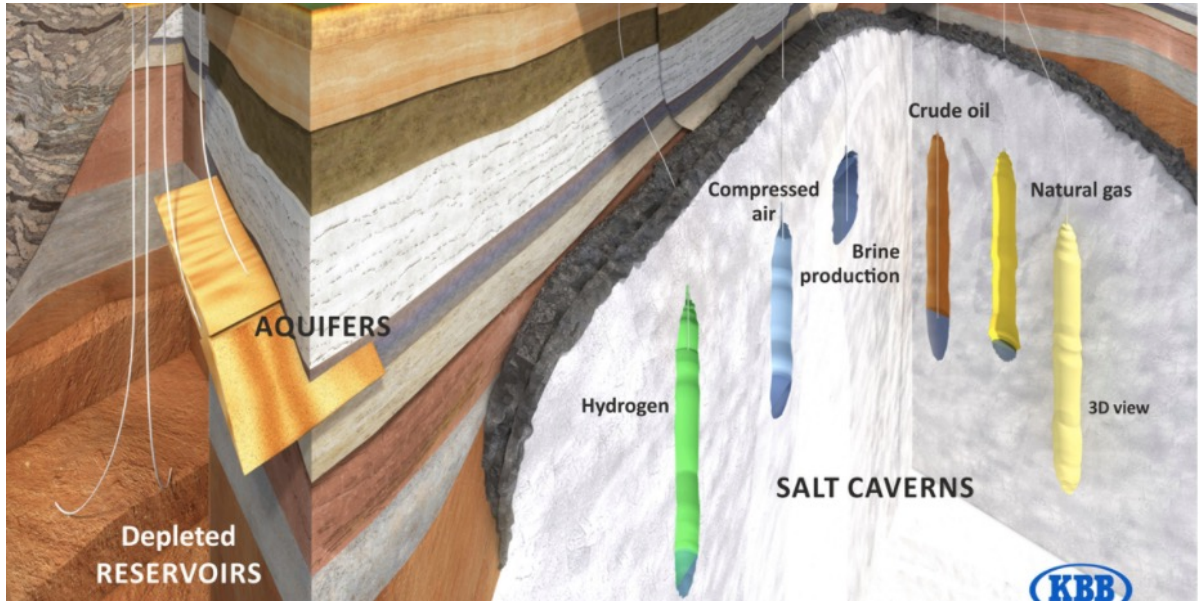
3 Storage

- Europe has 200,000 km of high-pressure gas grid, the bulk of which can be converted to accommodate hydrogen at very low cost

3. Seasonal energy storage

Considerations

We need a lot of hydrogen storage in our future energy system because of the seasonal gas demand patterns.



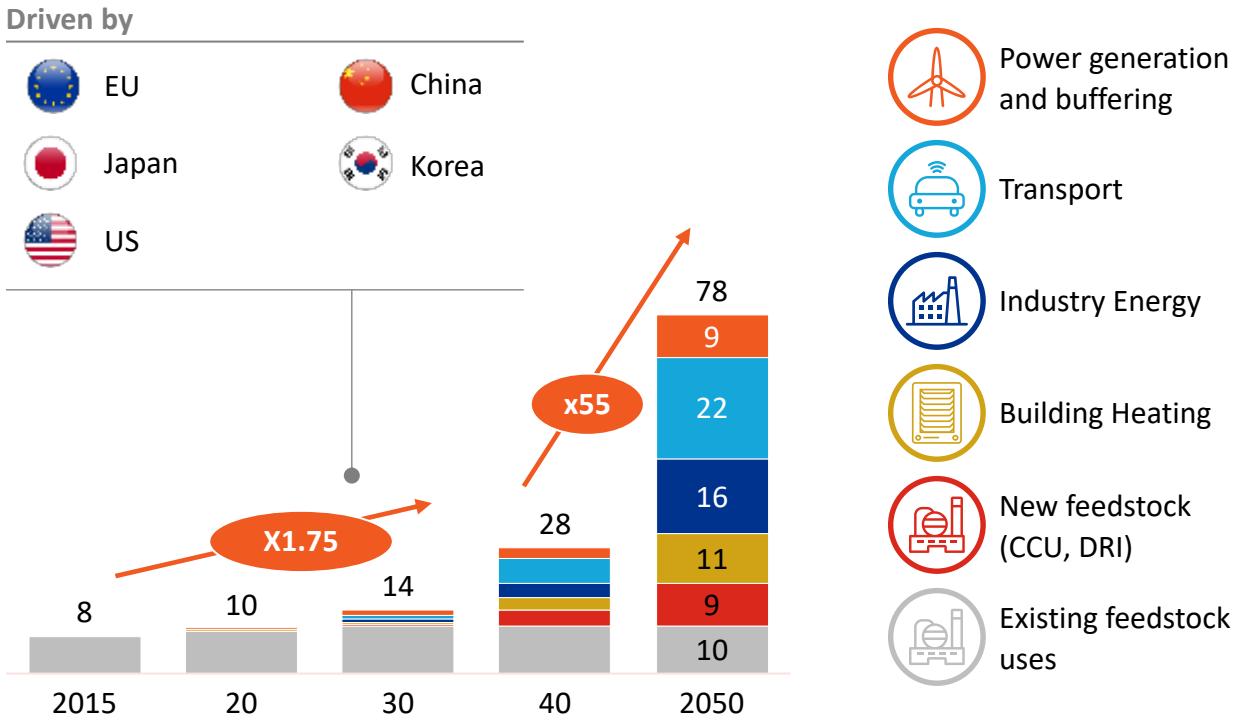
1. System cost
2. Infrastructure
3. Storage

5

Hydrogen: the Market

Hydrogen demand could almost double until 2030, then grow exponentially

Potential global energy demand supplied with hydrogen, Exajoule (EJ)

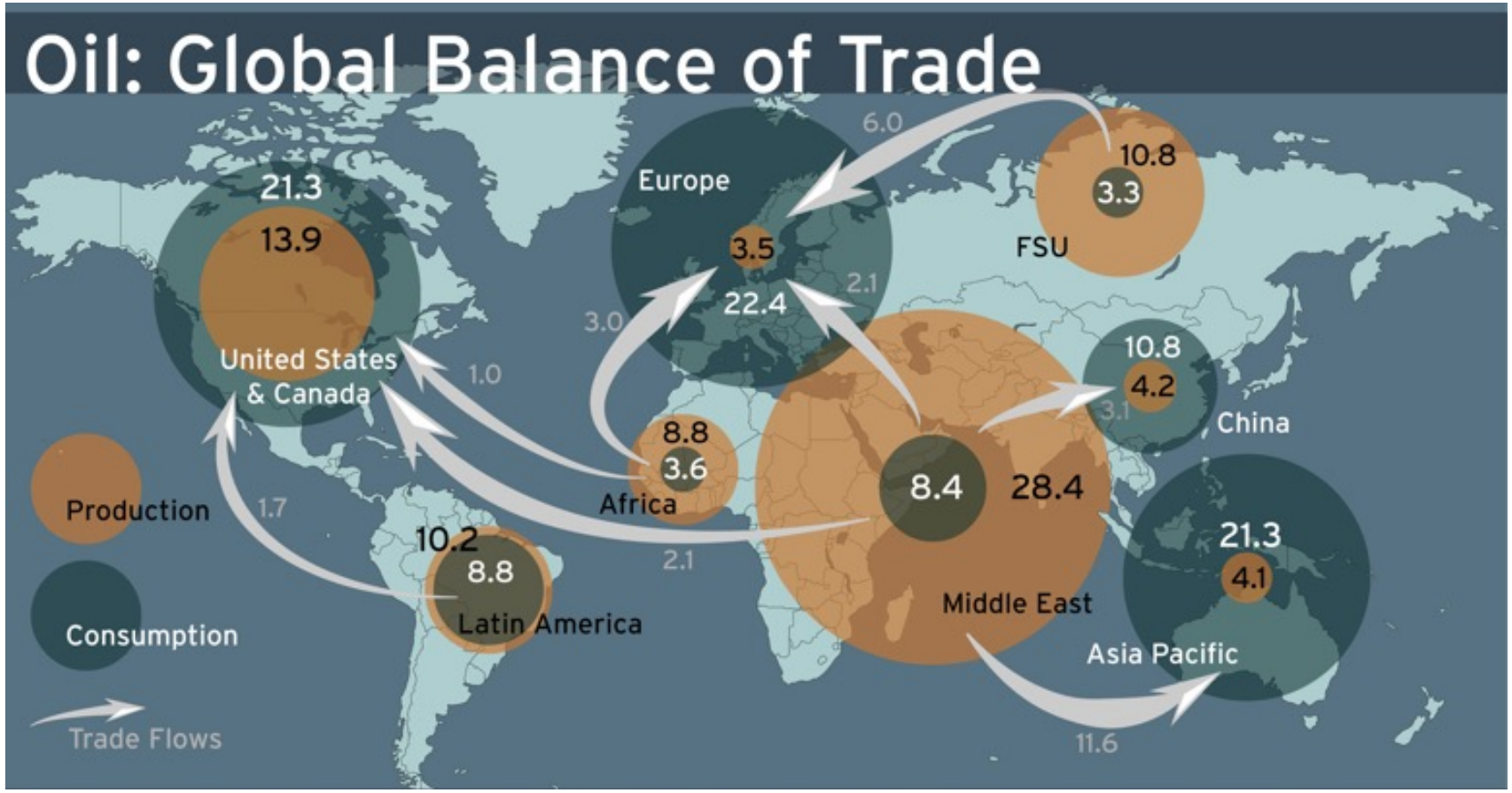


- Hydrogen demand could almost double between 2015 and 2030 to 14 EJ, then grow to ~78 EJ
- Growth driven by existing applications of hydrogen (feedstock for chemicals, refining) and new segments (until 2030 in particular transport, building heating, power generation)
- Growth until 2030 mostly driven by leaders in hydrogen adoption:
  - Europe
  - Japan, Korea
  - China
  - US

1 Final energy demand in 2050 is ~430 Exajoule
SOURCE: Hydrogen Council, World Economic Forum, Paris Agreement at the COP21 in Paris

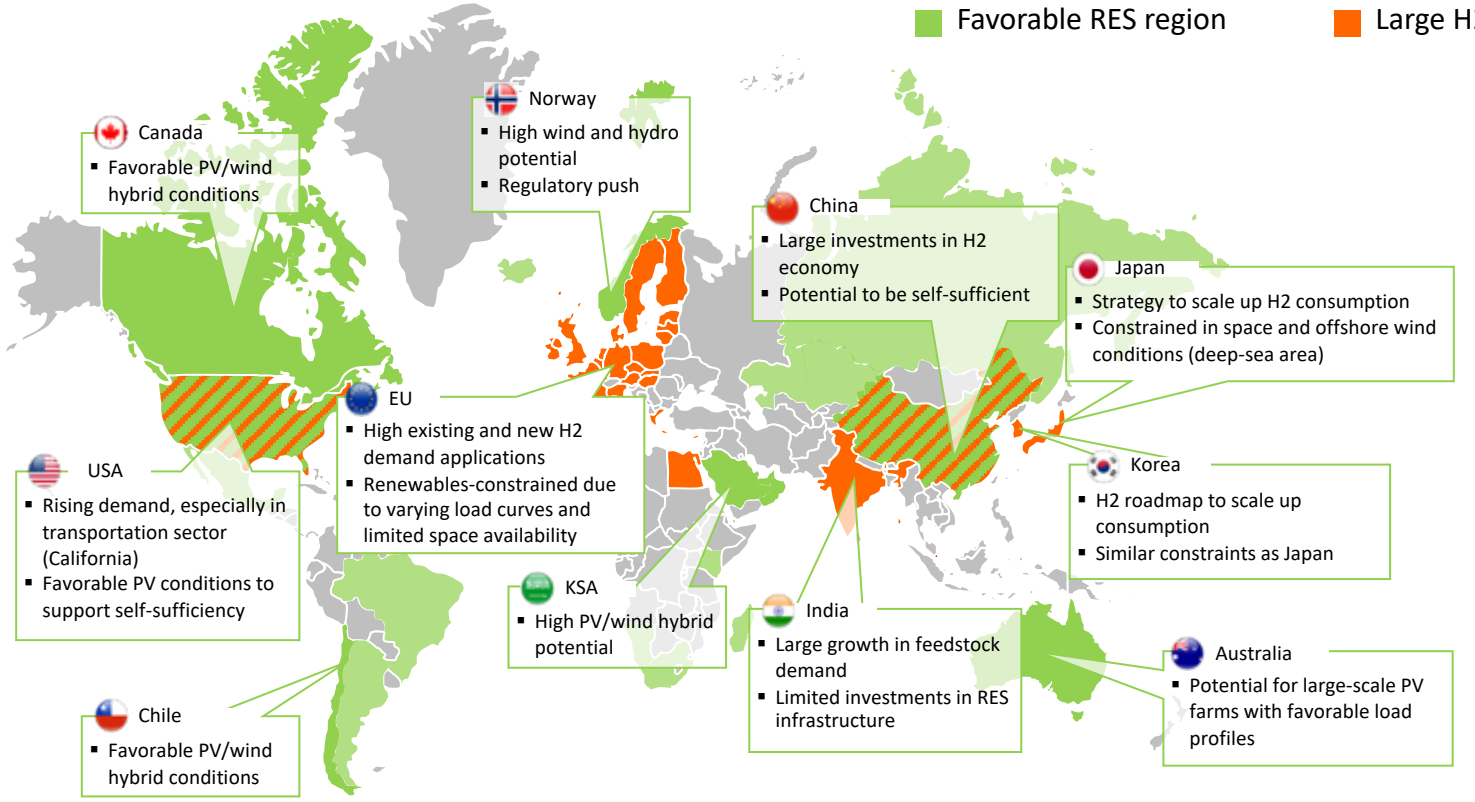
Source: McKinsey

Energy Trade



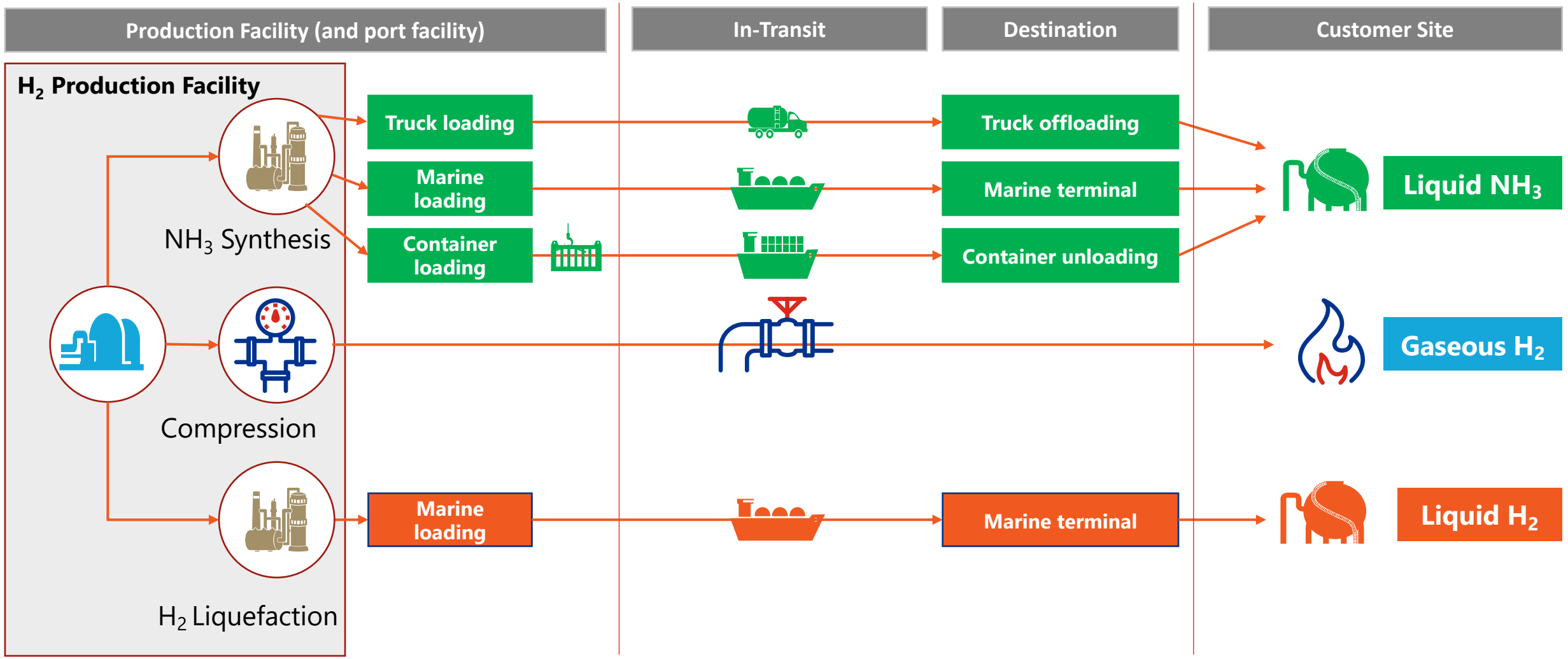
Regions with large potential H2 demand are renewables-constrained; regions with high renewable energy potential have an advantage to produce cheaply at scale

Major H2 offtake demand centers and regions with high potential for green H2 production



SOURCE: World Energy Council

Hydrogen export pathways



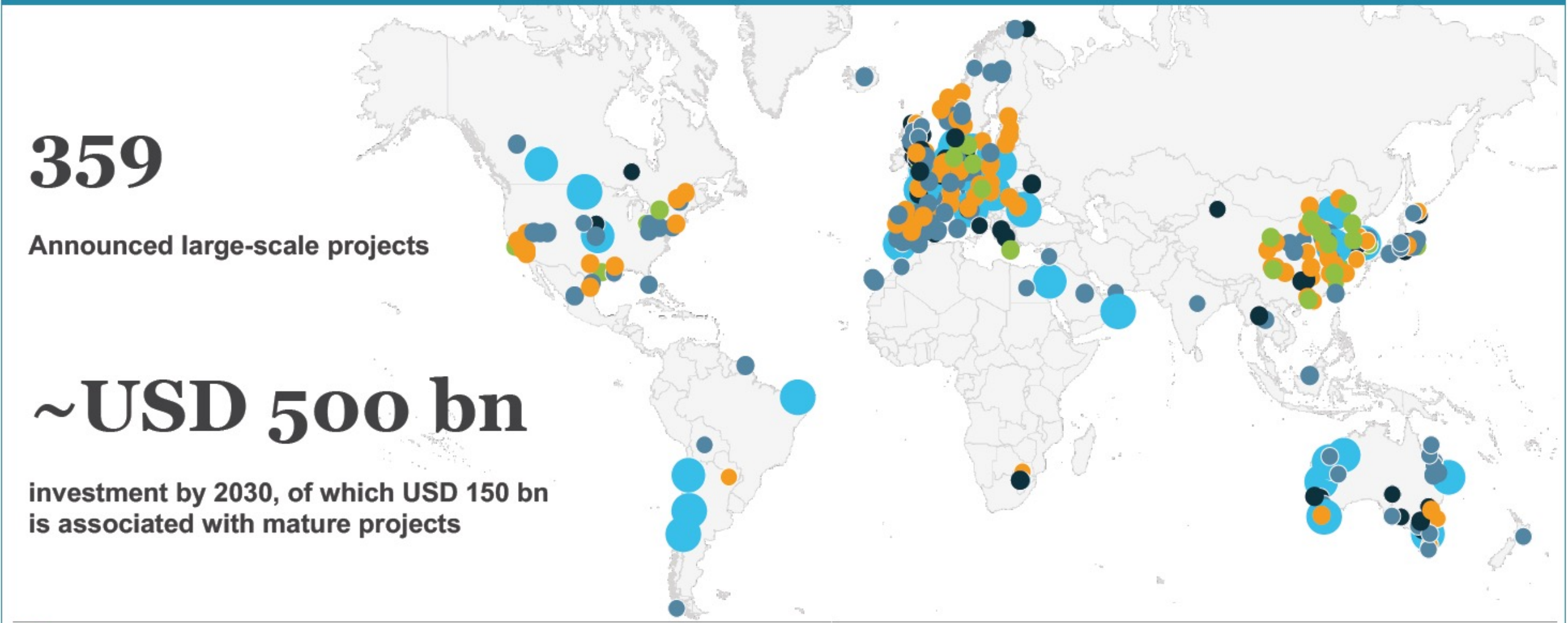
Sea transport of hydrogen and ammonia, also as marine fuels

6

Projects

McKinsey & Company

: Global hydrogen projects and investment across the value chain



359

Announced large-scale projects

~USD 500 bn

investment by 2030, of which USD 150 bn is associated with mature projects

28

Giga-scale production

Renewable hydrogen projects >1 GW and low-carbon hydrogen projects >200 ktpa

141

Large-scale industrial usage

Refinery, ammonia, methanol, steel, and industry feedstock

96

Transport

Trains, ships, trucks, cars, and other hydrogen mobility applications

56

Integrated hydrogen economy

Cross-industry and projects with different types of end uses

38

Infrastructure projects

Hydrogen distribution, transportation, conversion, and storage

1. Captive

- Refineries, ammonia production, steel plants
- In most cases replacement of SMR units

Typical investment: $100 – 300 million

2. Hydrogen Valleys

- A Hydrogen Valley is a regional ecosystem of production, distribution and use of hydrogen
- The Hydrogen Valley platform (H2V.EU) is a joint initiative by the Fuel Cells and Hydrogen Joint Undertaking and Mission Innovation.
- There are currently 36 registered Hydrogen Valleys in 19 countries

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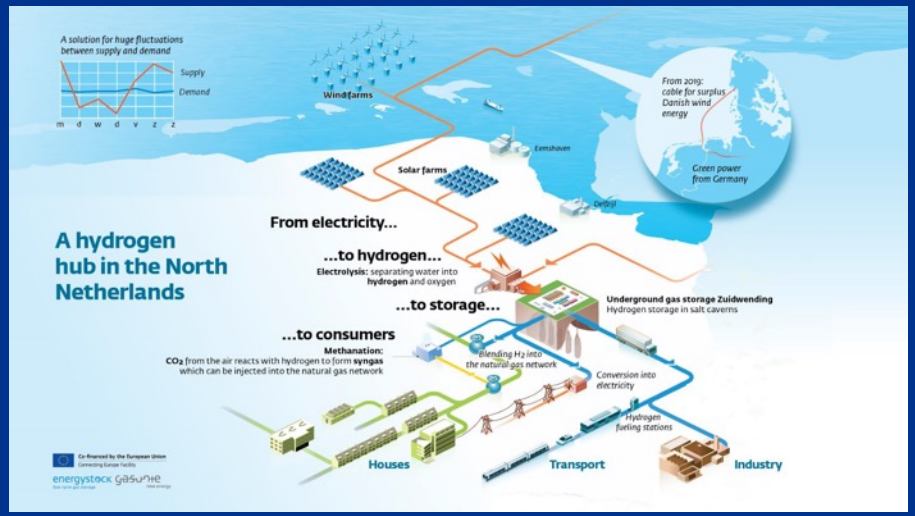
Typical investment: $1 billion



3. Pipelines

- Either new built or conversion of natural gas pipelines
- Blending or pure H_2
- Multiple production sites and offtakers several hundred km apart
- Several hydrogen backbones currently being studied: Netherlands, Germany, Spain, France

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Typical investment: $1 - $5 billion

4. International Trade

- Shipping from net exporter countries to net importer countries
- Modality:
  - liquid hydrogen
  - Ammonia
  - LOHC
  - Other

Typical investment: $5 - $15 billion