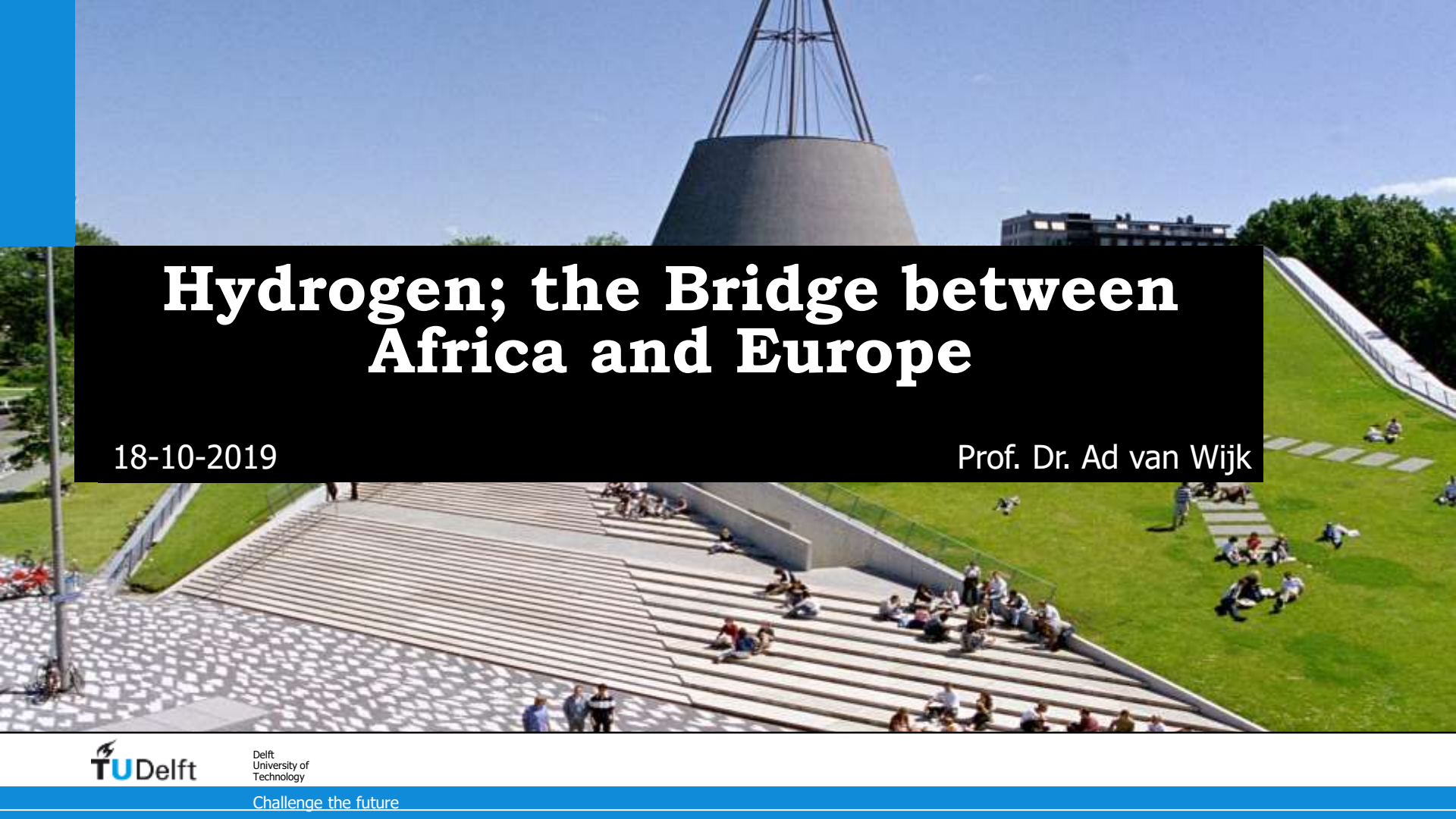


The background image shows a large, modern architectural structure with a prominent, conical, grey, ribbed tower rising from a green lawn. In the foreground, there are wide, light-colored stone steps where many people are sitting and walking. To the right, a grassy slope leads up to a building. The sky is clear and blue.

# Hydrogen; the Bridge between Africa and Europe

18-10-2019

Prof. Dr. Ad van Wijk

# Hearing Frans Timmermans 9-10-2019



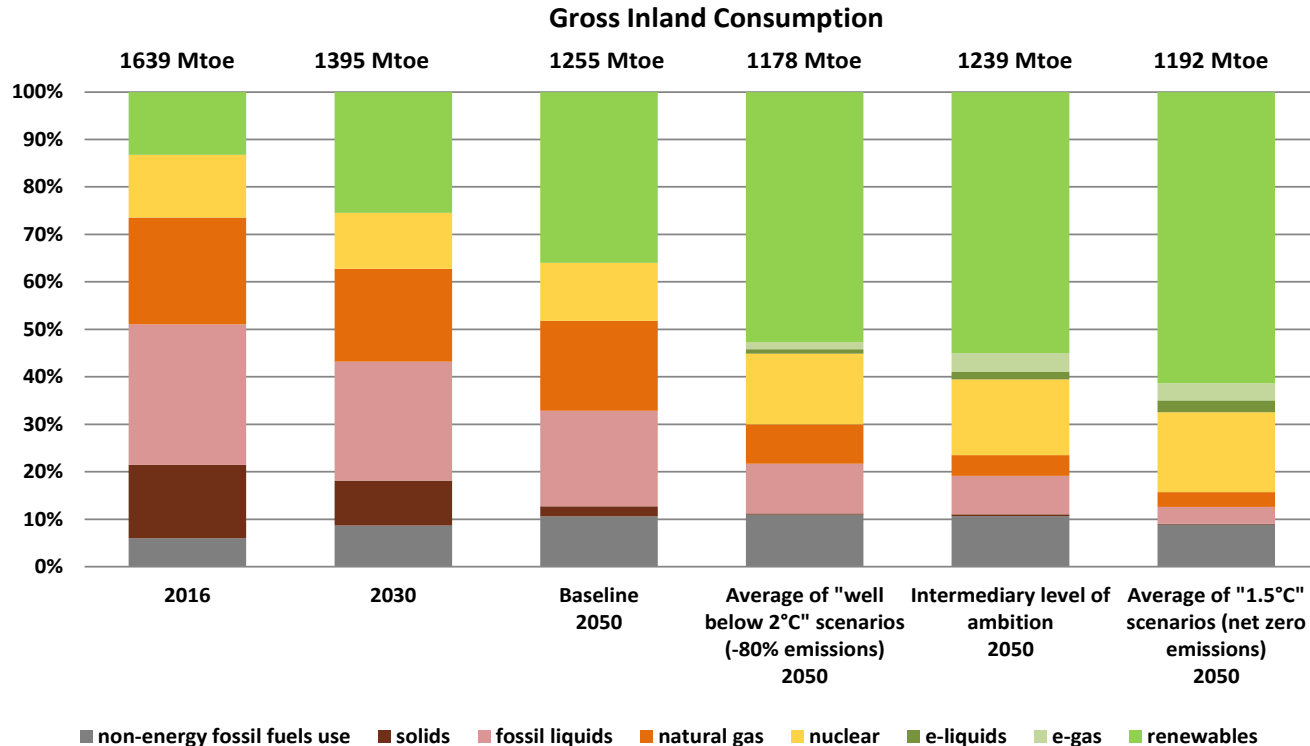
# Energy Consumption EU in 2017

| 2017 EU 28                        | Mtoe         | TWh           |
|-----------------------------------|--------------|---------------|
| <b>Gross Available Energy</b>     | 1,719        | 19,993        |
| - International Maritime Bunkers  | - 45         | - 523         |
| <b>Gross Inland Consumption</b>   | 1,663*       | 19,341        |
| - Feedstock                       | - 102        | - 1,191       |
| <b>Primary Energy Consumption</b> | 1,561        | 18,150        |
| - Conversion losses energy sector | - 438        | - 5,094       |
| <b>Final Energy Consumption</b>   | <b>1,123</b> | <b>13,056</b> |

\*Ambient heat (11 Mtoe) is also subtracted

Figures from Eurostat 2019

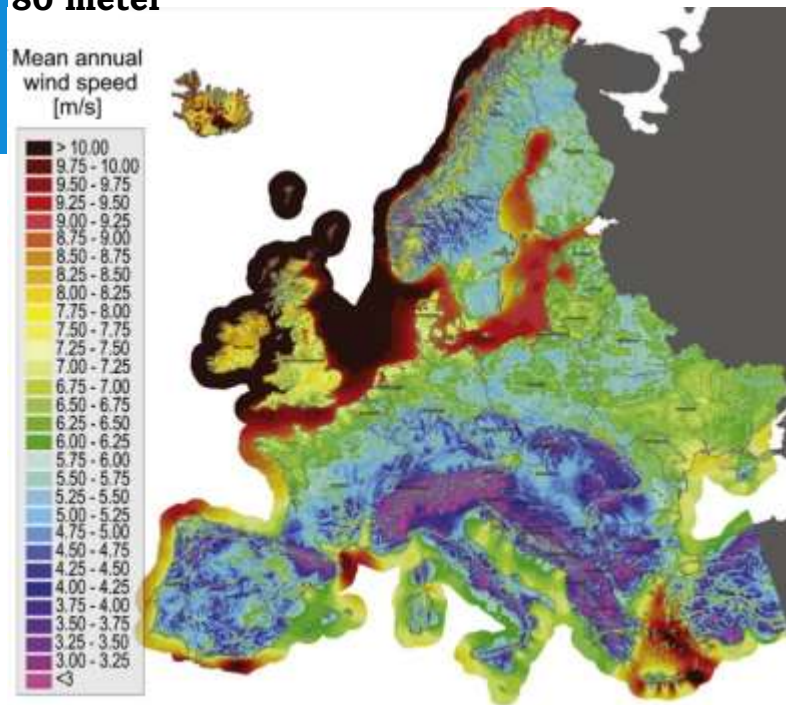
# A Clean Planet for All



Fuel mix for Gross Inland Consumption EU28, projected for 2050, for different scenarios from the EU document 'A clean planet for all' (European Commission 2018)

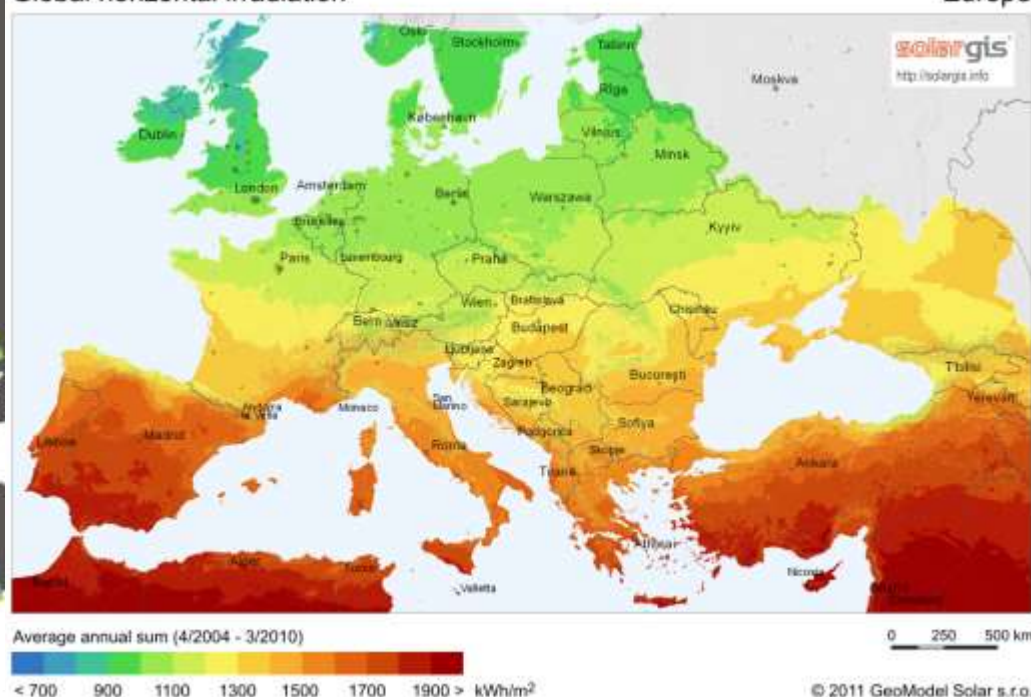
# European Wind Speed

80 meter



# European Solar Energy

Global horizontal irradiation



# EU Solar and Wind Energy in 2050

| Scenario                              | Solar Energy<br>[TWh/a] | Wind Energy<br>[TWh/a] | Solar Capacity<br>[GW] | Wind Capacity<br>[GW] |
|---------------------------------------|-------------------------|------------------------|------------------------|-----------------------|
| Shell Sky Scenario                    | 3,472                   | 3,089                  | 2,300                  | 1,000                 |
| DNV GL Energy Transition Outlook 2018 | 1,077                   | 1,662                  | 718                    | 554                   |
| LUT/EWG                               |                         |                        | 2,000                  | 560                   |

Solar and wind energy in the European Union in 2050, according to several scenario's

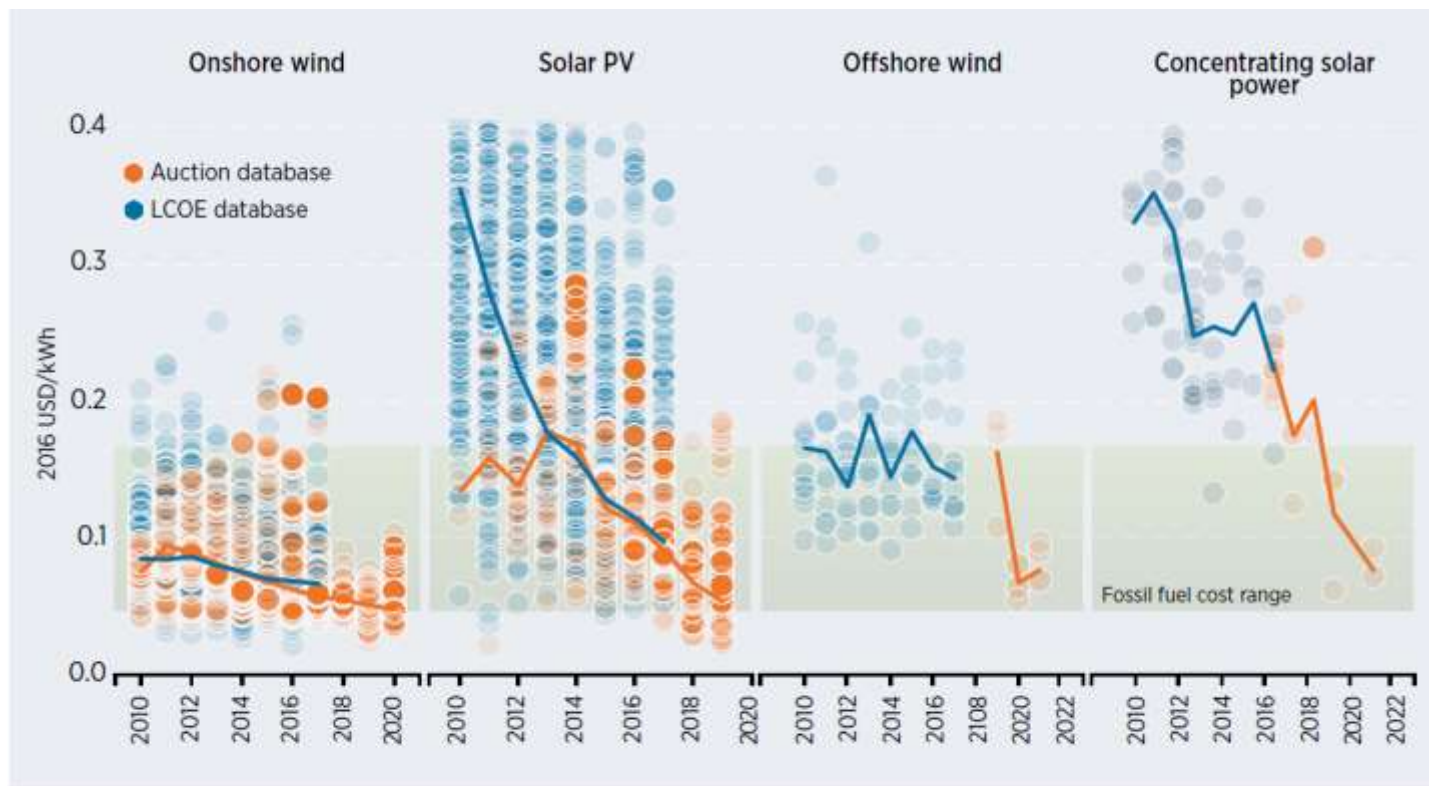
# **EU 2050;**

## **100% renewable energy supply**

1. Final energy demand in 2050 = 12.000 TWh
  - 50% electricity
  - 50% hydrogen
2. Re-use and expand gas infrastructure and storage
  - For hydrogen transport
  - For hydrogen storage
3. Europe and North Africa join hands in green hydrogen



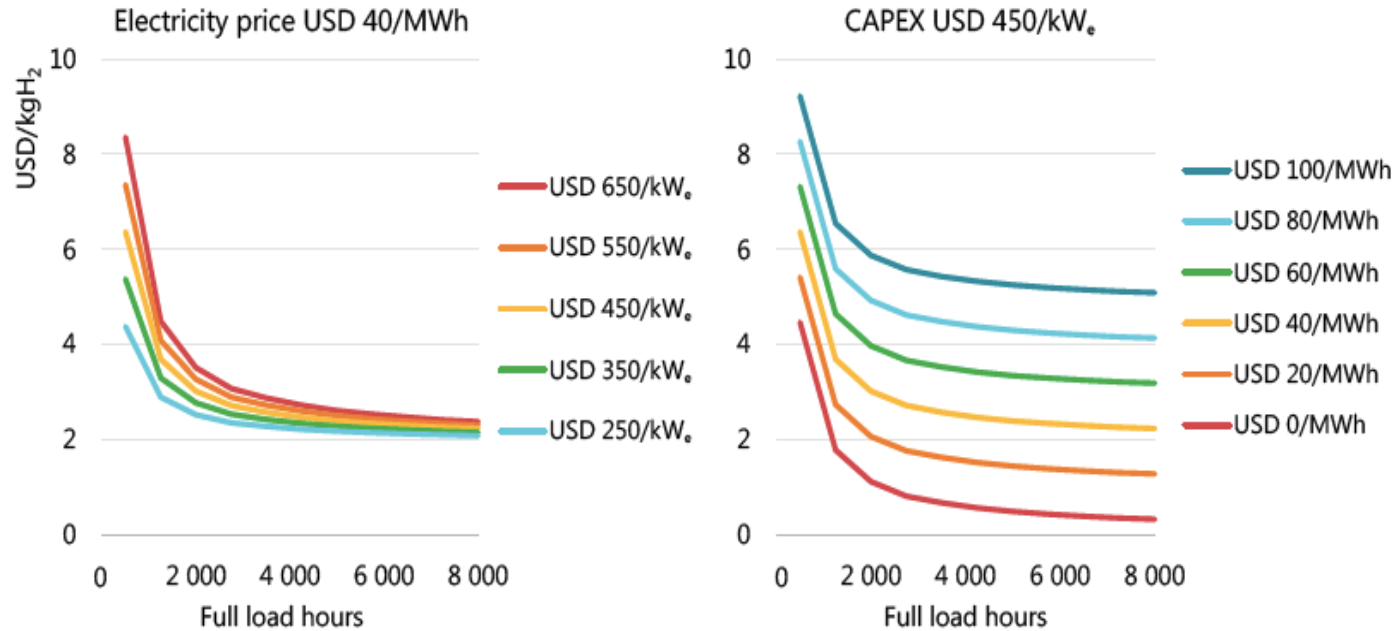
# Levelized Cost of Electricity



Source: IRENA Renewable Cost Database and Auctions Database.

IRENA, January 2018, Renewable Power Generation Costs 2017

# Hydrogen production cost; LCoH



Notes: MWh = megawatt hour. Based on an electrolyser efficiency of 69% (LHV) and a discount rate of 8%.

Source: IEA 2019. All rights reserved.

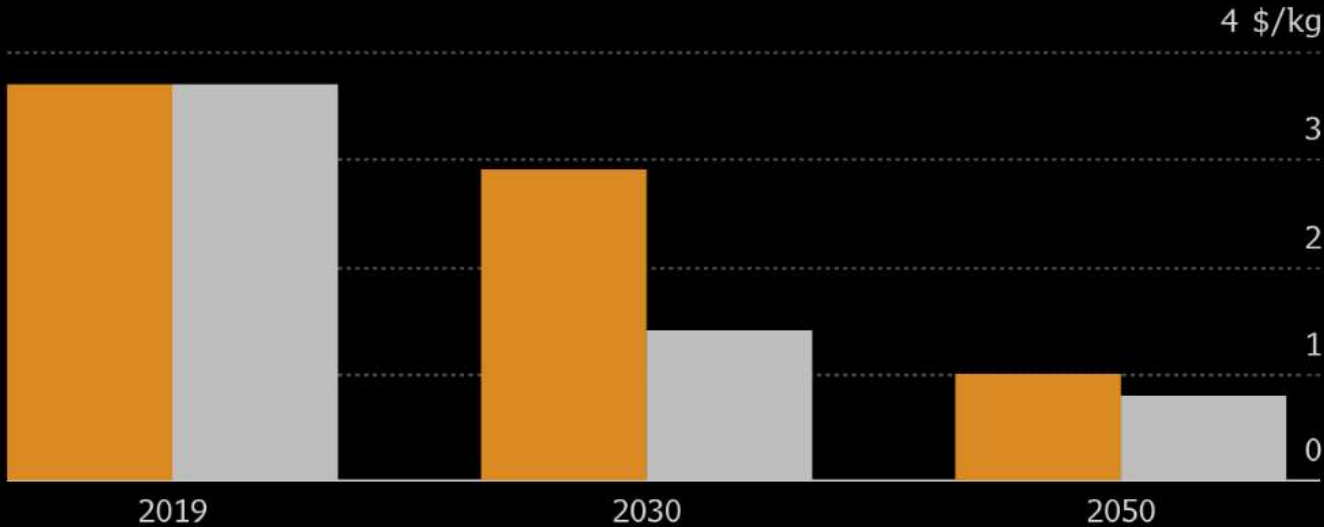
Future levelized cost of hydrogen production by operating hour for different electrolyser investment costs (left) and electricity costs (right), from The Future of Hydrogen (IEA 2019) (LHV efficiency 69% is HHV efficiency 81%)

# Bloomberg NEF, August 2019

## Cost of Hydrogen

Hydrogen is set to decrease in price powered by green electricity

■ Conservative estimate ■ Optimistic



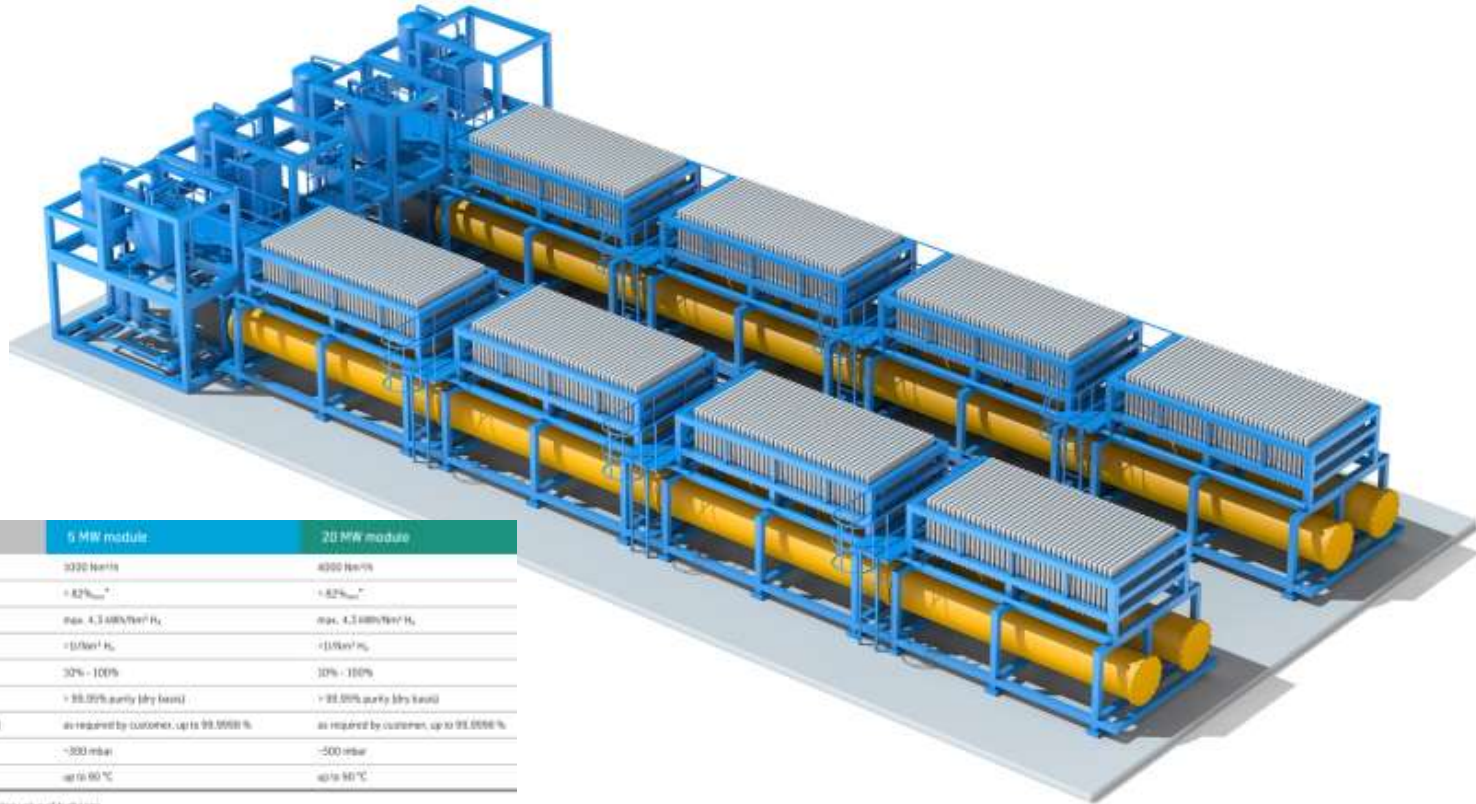
Source: BNEF

Refers to hydrogen produced from alkaline electrolysis

Bloomberg

$$1 \text{ \$ / kg} = 0,025 \text{ \$ / kWh}$$

# 20 MW Alkaline Electrolyser

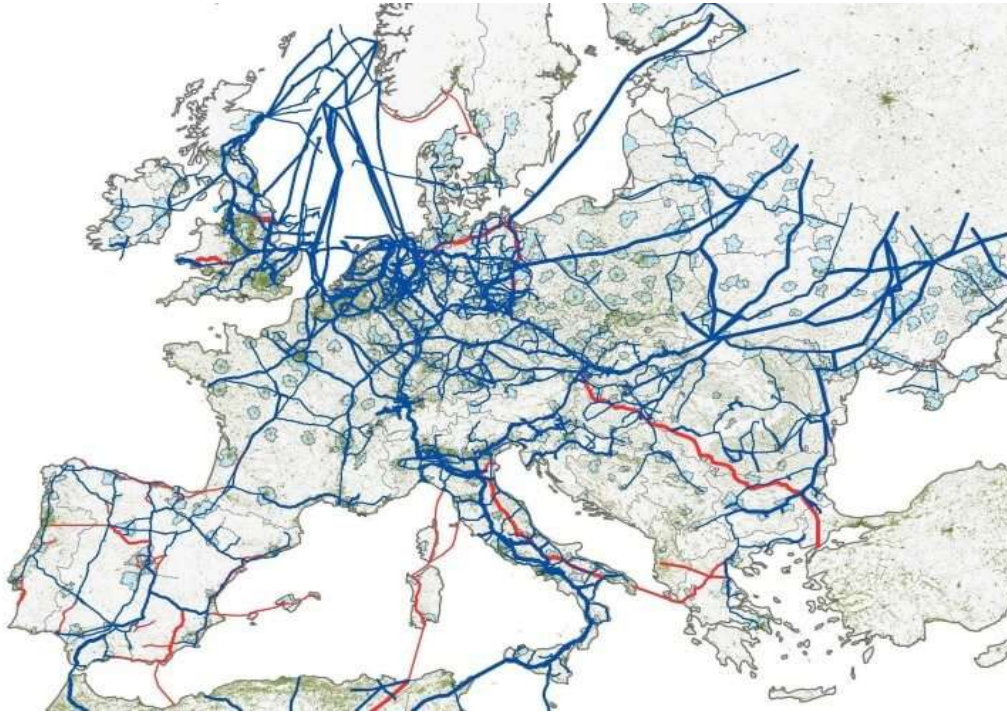


|                                                  | 5 MW module                             | 20 MW module                            |
|--------------------------------------------------|-----------------------------------------|-----------------------------------------|
| Design capacity $H_2$                            | 3330 Nm <sup>3</sup> /h                 | 4000 Nm <sup>3</sup> /h                 |
| Efficiency electrolyser (EQ)                     | > 82% <sub>HHV</sub> *                  | > 82% <sub>HHV</sub> *                  |
| Power consumption (EQ)                           | max. 4.3 kWh/Nm <sup>3</sup> $H_2$      | max. 4.3 kWh/Nm <sup>3</sup> $H_2$      |
| Water consumption                                | < 0.9 Nm <sup>3</sup> $H_2$             | < 0.9 Nm <sup>3</sup> $H_2$             |
| Standard operation window                        | 30% - 100%                              | 30% - 100%                              |
| $H_2$ product quality at electrolyser outlet     | > 99.99% purity (dry basis)             | > 99.99% purity (dry basis)             |
| $H_2$ product quality after treatment (optional) | as required by customer, up to 99.9999% | as required by customer, up to 99.9999% |
| $H_2$ product pressure at module outlet          | ~300 mbar                               | ~500 mbar                               |
| Operating temperature                            | up to 90 °C                             | up to 90 °C                             |

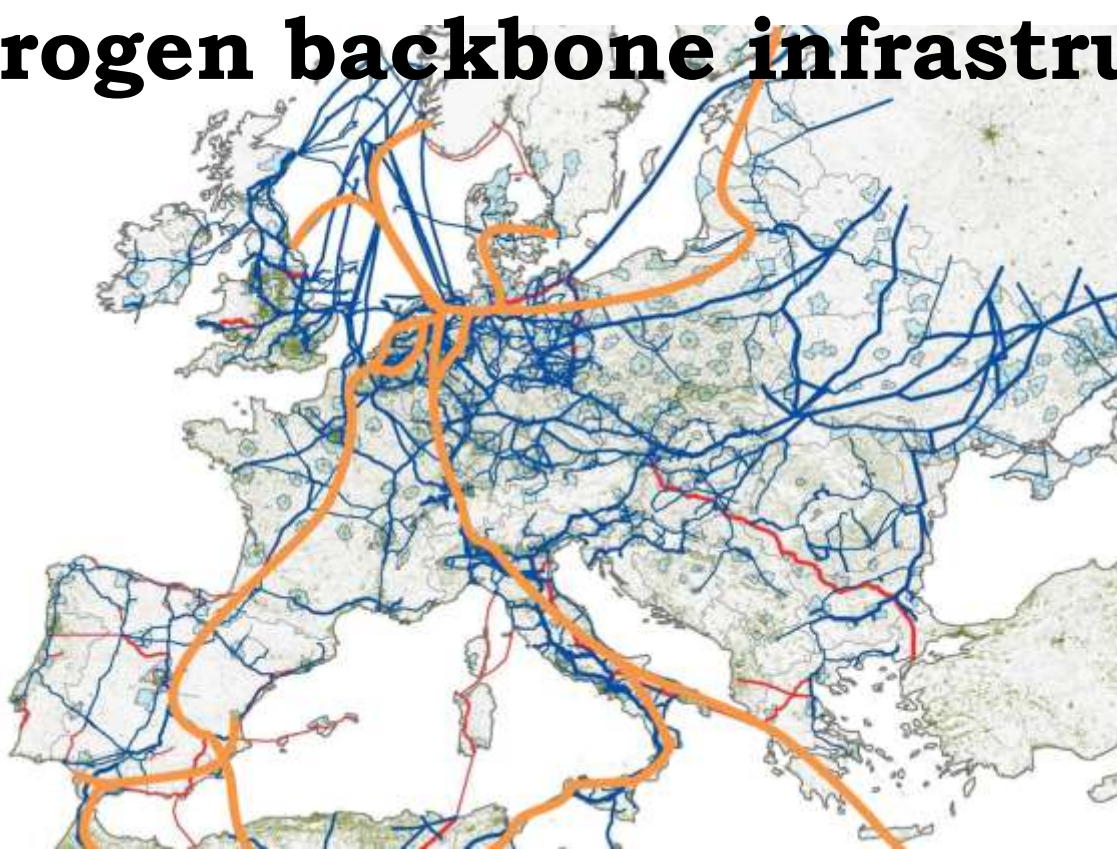
\* HHV = calculated with reference to higher heating value of  $H_2$  (gJ/g).

All values may vary depending on operating conditions.

# Hydrogen via Gas Infrastructure

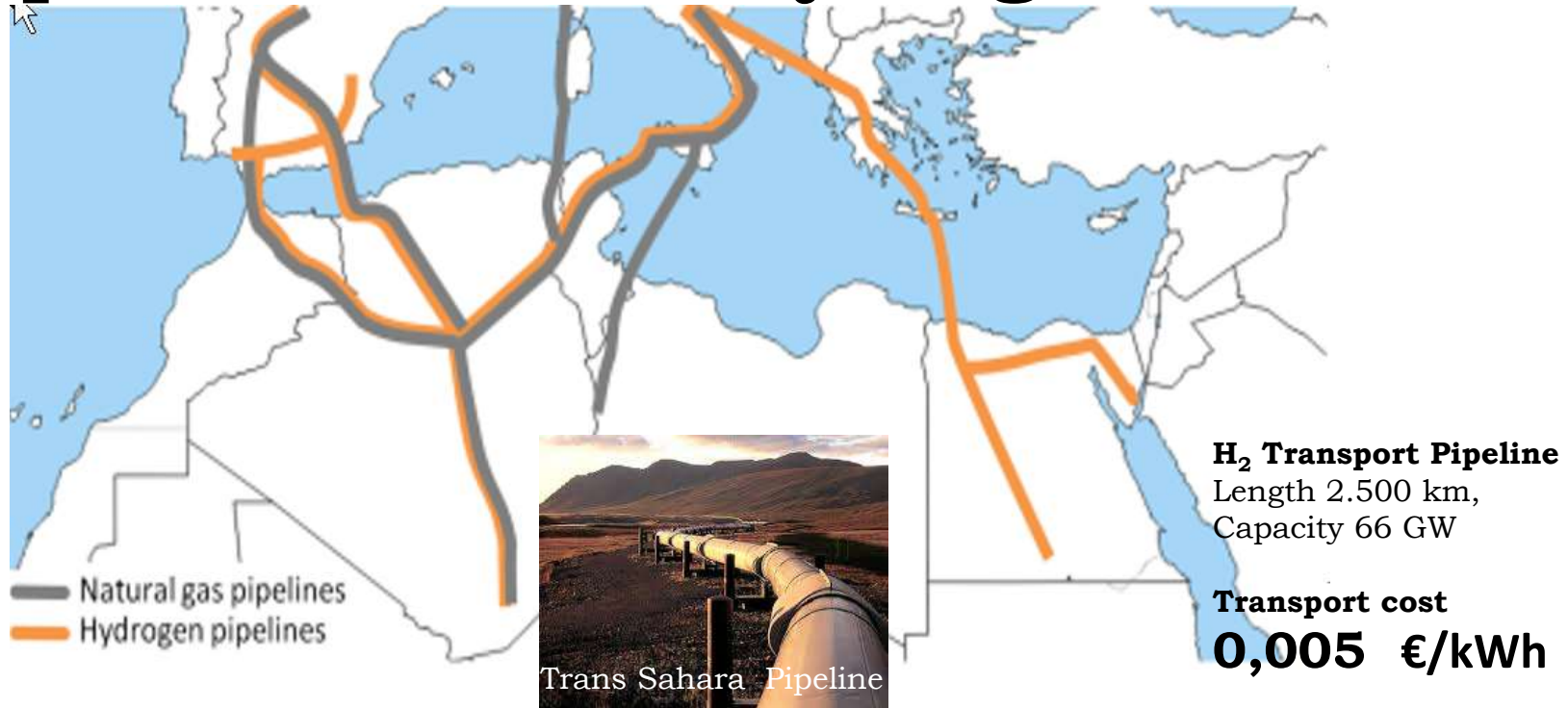


# Hydrogen backbone infrastructure



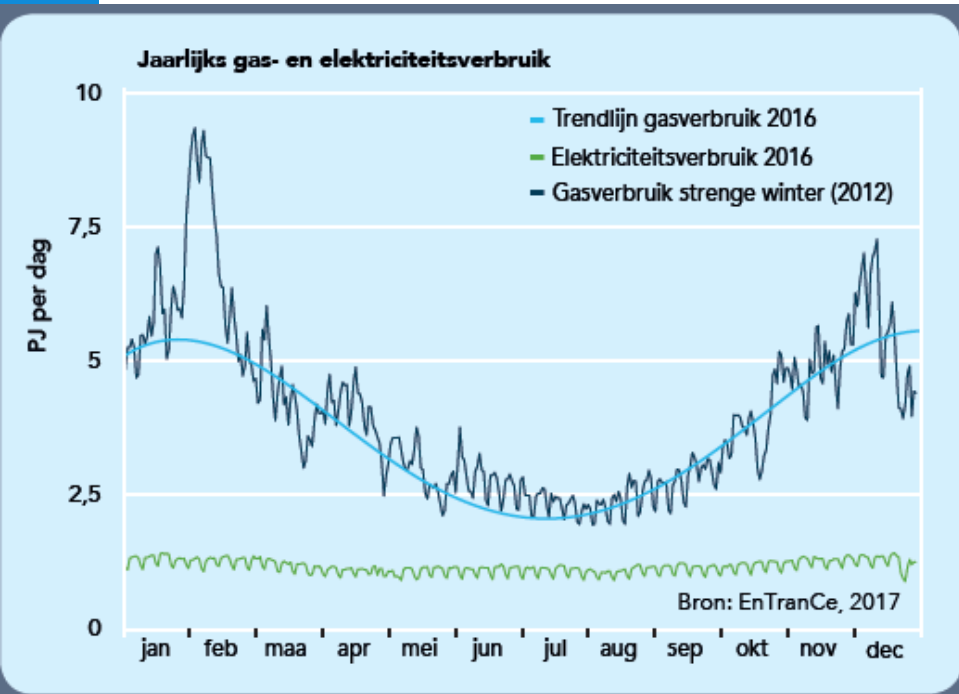
Natural gas infrastructure in Europe (blue and red lines) and first outline for a hydrogen backbone infrastructure (orange lines). The main part of the hydrogen backbone infrastructure consists of re-used natural gas transport pipelines with new compressors. A new pipeline from the solar and wind resource areas in Greece needs to be realized.

# Europe North-Africa Hydrogen backbone

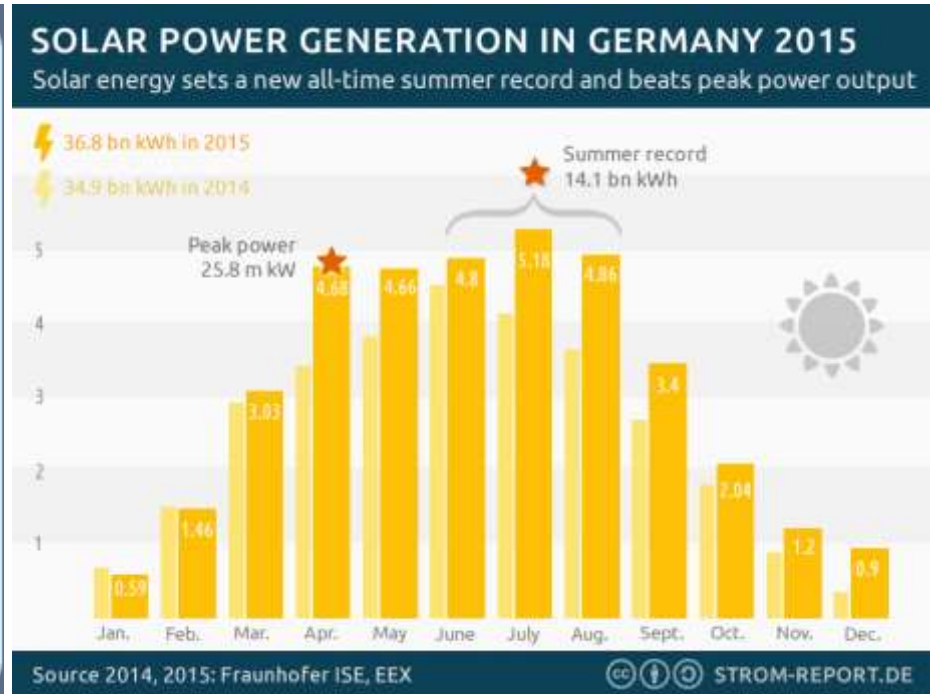


first outline for a hydrogen backbone infrastructure Europe-North Africa. An existing gas infrastructure from Algeria and Morocco could be converted to a hydrogen infrastructure (grey-orange lines). A “new” hydrogen transport pipeline must be realized from Italy to Greece, crossing the Mediterranean Sea to Egypt, which could eventually be extended to the Middle East (orange line).

## Gas and electricity consumption in the Netherlands



## Solar power production in Germany



# Gas storage capacity in Europe

|                                      | BCM  | TWh   |
|--------------------------------------|------|-------|
| Gas consumption EU 2017              | 493  | 4.820 |
| Gas storage capacity EU 2017         | 89,2 | 871   |
| Gas storage capacity Germany         | 21,8 | 213   |
| Gas storage capacity the Netherlands | 13,4 | 130   |
|                                      |      |       |
| EU gas storage capacity/consumption  | 18%  |       |
|                                      |      |       |

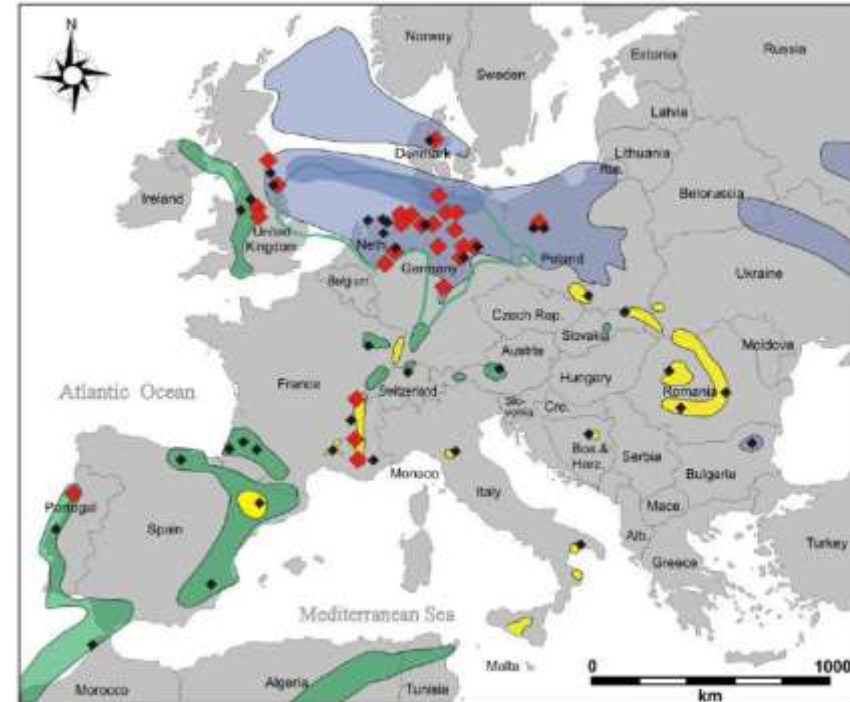
# Hydrogen storage in Salt Caverns



**1 salt cavern can contain 3,000-6,000 ton hydrogen  
(100 million Euro)**

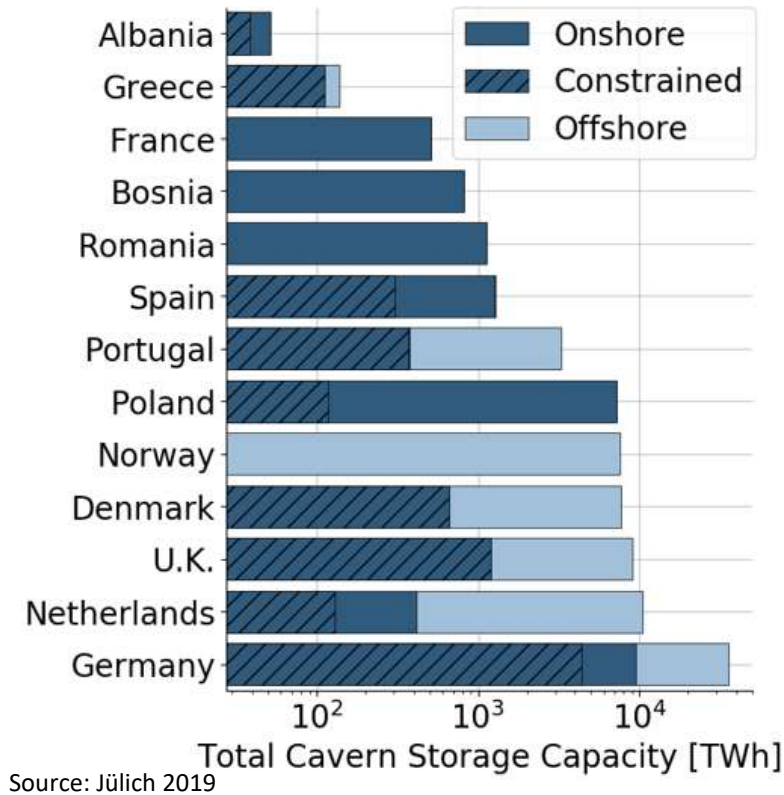
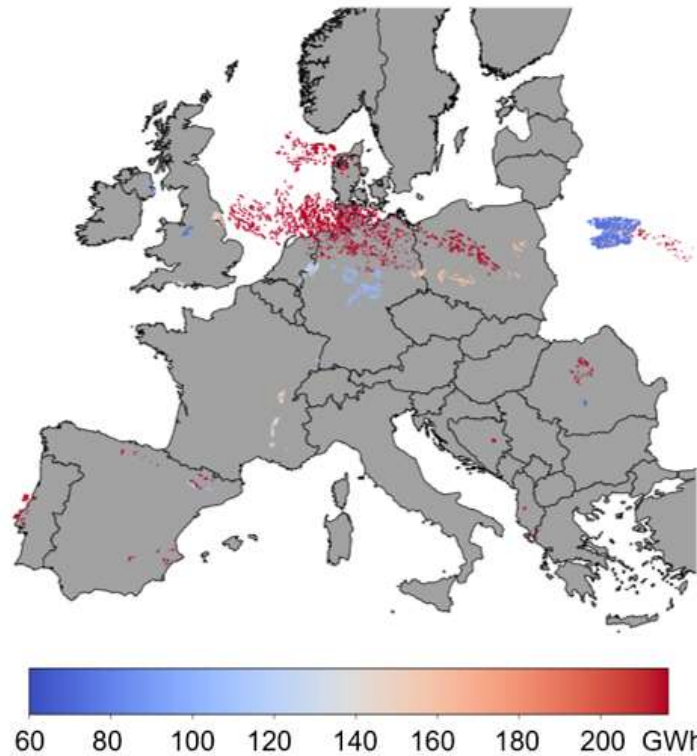
**Equivalent of 120-240 GWh or 8,5-17 million home batteries (14 kWh)  
(12-24 billion Euro)**

# Salt formations and caverns in Europa



**Red colored caverns in use for natural gas storage**

# Potential for Hydrogen Storage in Salt Caverns



Source: Jülich 2019

| EU 2050               | TOTAL<br>(GW)                           | Europe<br>(GW) | North Africa<br>(GW) |
|-----------------------|-----------------------------------------|----------------|----------------------|
| <b>Production</b>     |                                         |                |                      |
| Solar                 | 4,200                                   | 2,000          | 2,200                |
| Wind                  | 1,800                                   | 1,300          | 500                  |
| <b>Conversion</b>     |                                         |                |                      |
| Electrolyser          | 3,400                                   | 700            | 2,700                |
| Fuel cell             | 500                                     | 500            | --                   |
| <b>Infrastructure</b> |                                         |                |                      |
| Hydrogen Pipelines    | 1,000 GW pipeline between Africa-Europe |                |                      |
| <b>Storage</b>        |                                         |                |                      |
| Salt Caverns (number) | 15,000                                  | 10,000         | 5,000                |

# Further reading about hydrogen

[www.profadvanwijk.com](http://www.profadvanwijk.com)

