Pathways to decarbonize energy-intensive industries in Europe

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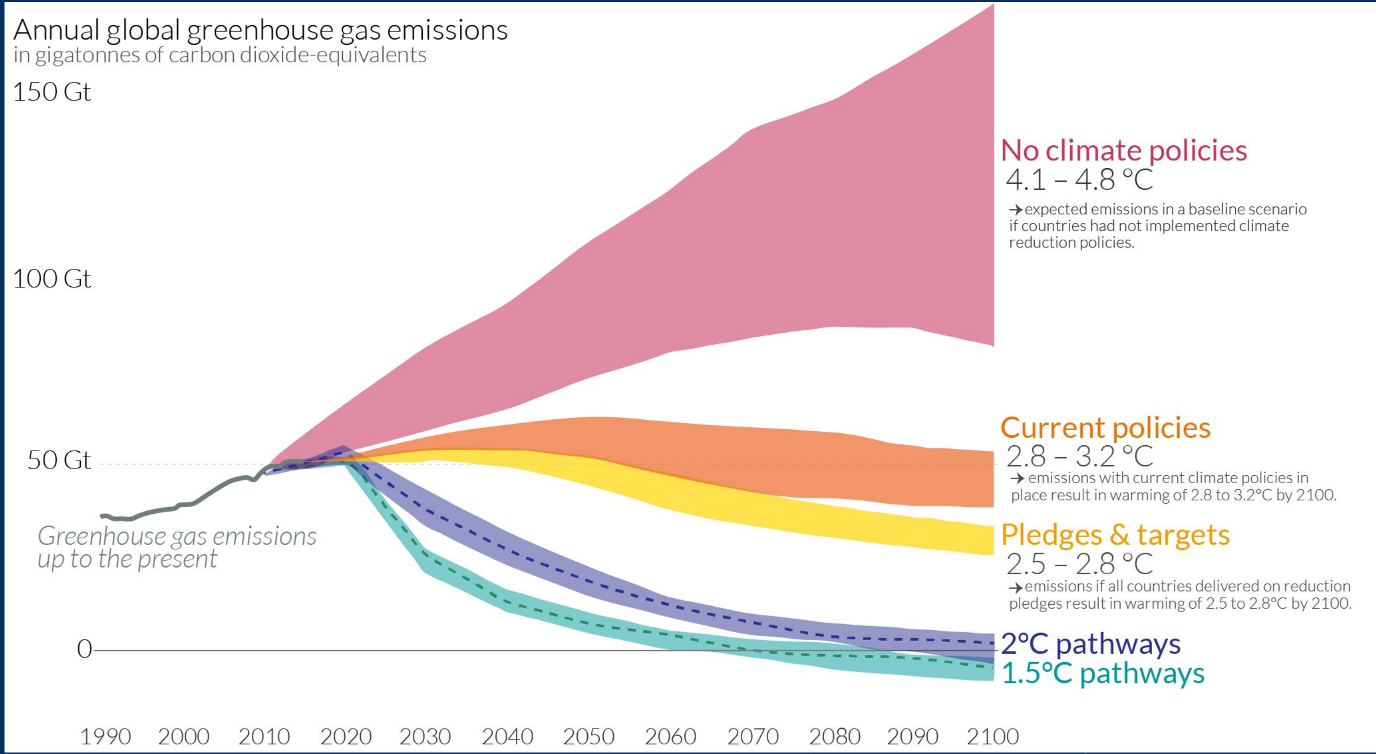
Air Liquide

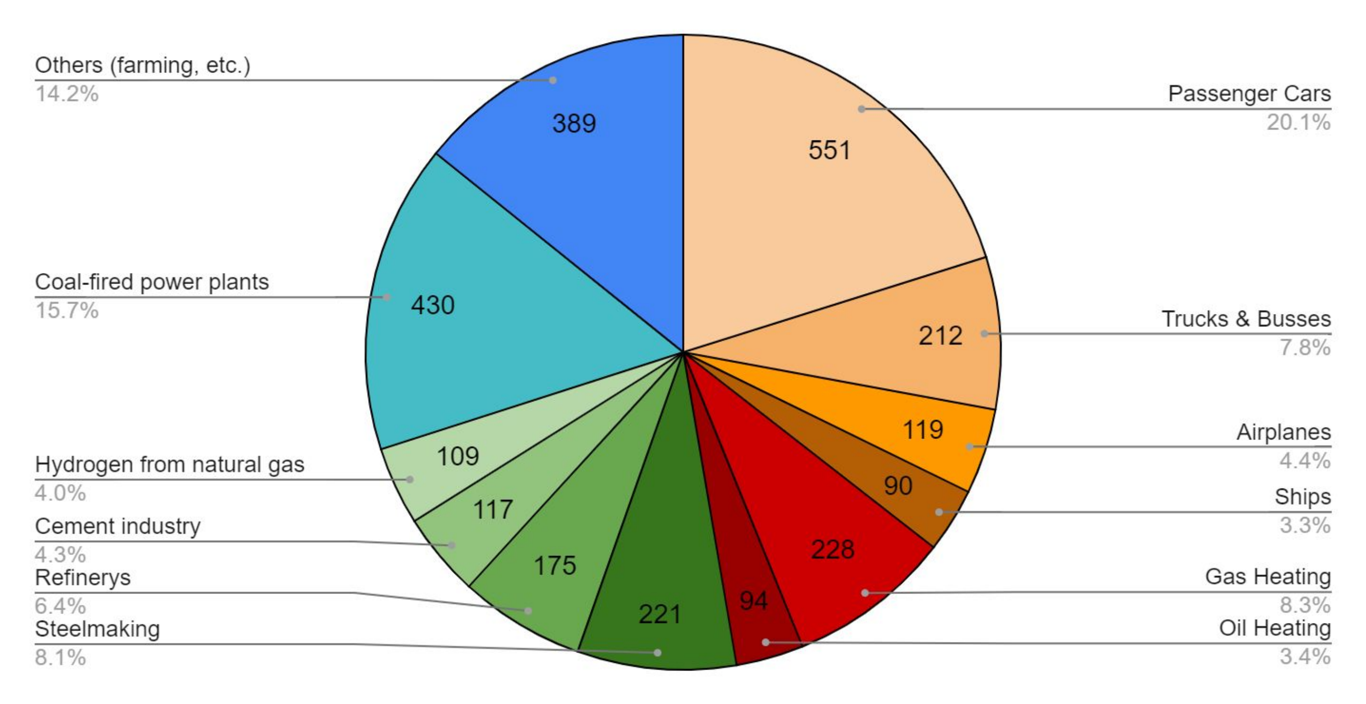
Limiting global warming requires significant efforts to lower global GHG emissions.



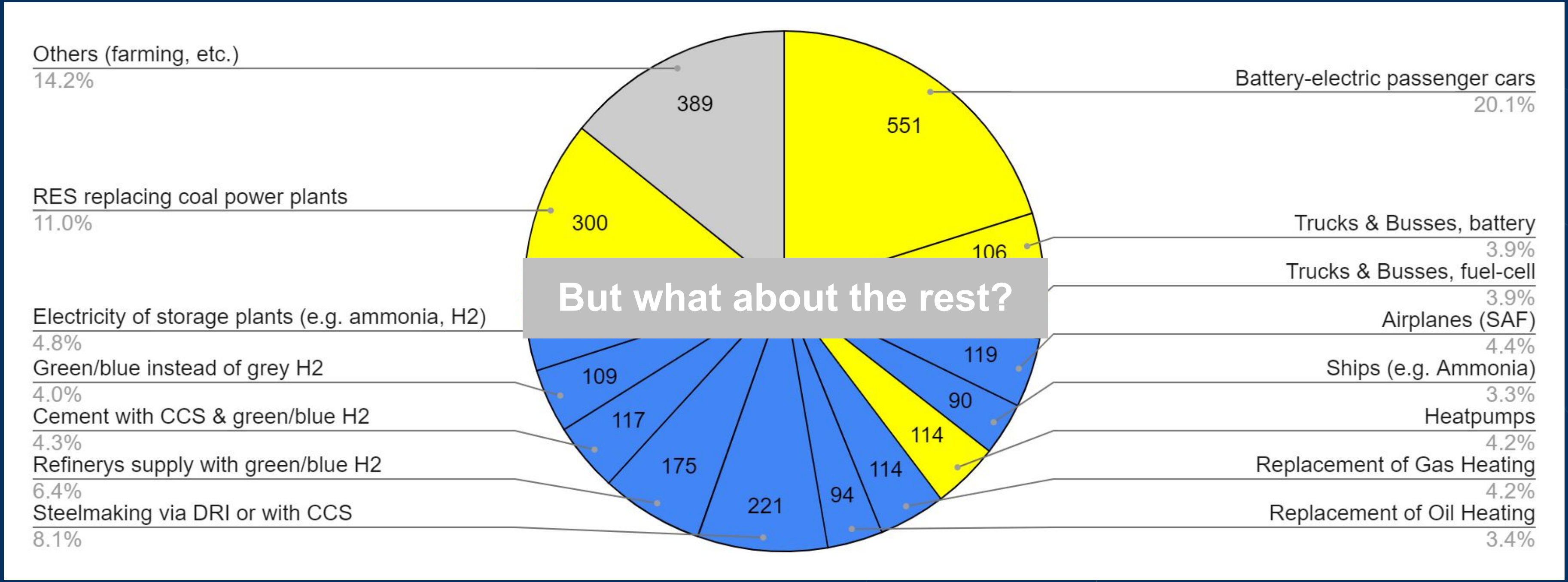
Source: OurWorldinData.org - Climate Action Tracker Licensed under CC BY by Hannah Ritchie & Max Roser

CO_2-Emissions in Europe by sector: How can we decarbonize?

In total 2019: ~3,000 Mio. t/pa.



Electrification can solve some problems, e.g. passenger cars, heatpumps, RES for Power Gen



Example no. 1 - Steelmaking

Status quo

- Producing 1 t of steel emits 1.8 t of CO_2
-
- EU27 produce 123 mio.t Steel per year
  → Total emissions in EU27: 221 Mio. t

Decarbonization path

- Direct reduction to iron sponge using Hydrogen
- Carbon capture of blast furnace exhaust
- 60 kg of H_2 required per 1 t of steel
  → 7.4 Mio. t Hydrogen per year for EU27
  → Electricity demand 370 TWh p.a.
  (50 MWh per t H_2)
- Air Liquide solution:
  → Water electrolyzer plants
  → Carbon capture with amine wash
  → Carbon capture with Cryocap™

Example no. 2 - Cement industry

Status quo

- Yearly emission of 117 mio. t of CO_2
- 60% of emissions are process-related → Inevitable CO_2 emissions
- 40% of emissions due to process heat, supplied by natural-gas and other carbon-intensive fuels

Decarbonization path

- Hydrogen as fuel gas (ca. 5 Mio. t of Hydrogen p.a.)
- Carbon capture of 70 Mio. t of CO_2 p.a.
- Air Liquide solution:
  → Water electrolyzers
  → CCS with Cryocap™ / Amine wash

Example no. 3 - Hydrogen for refineries and chemical industries

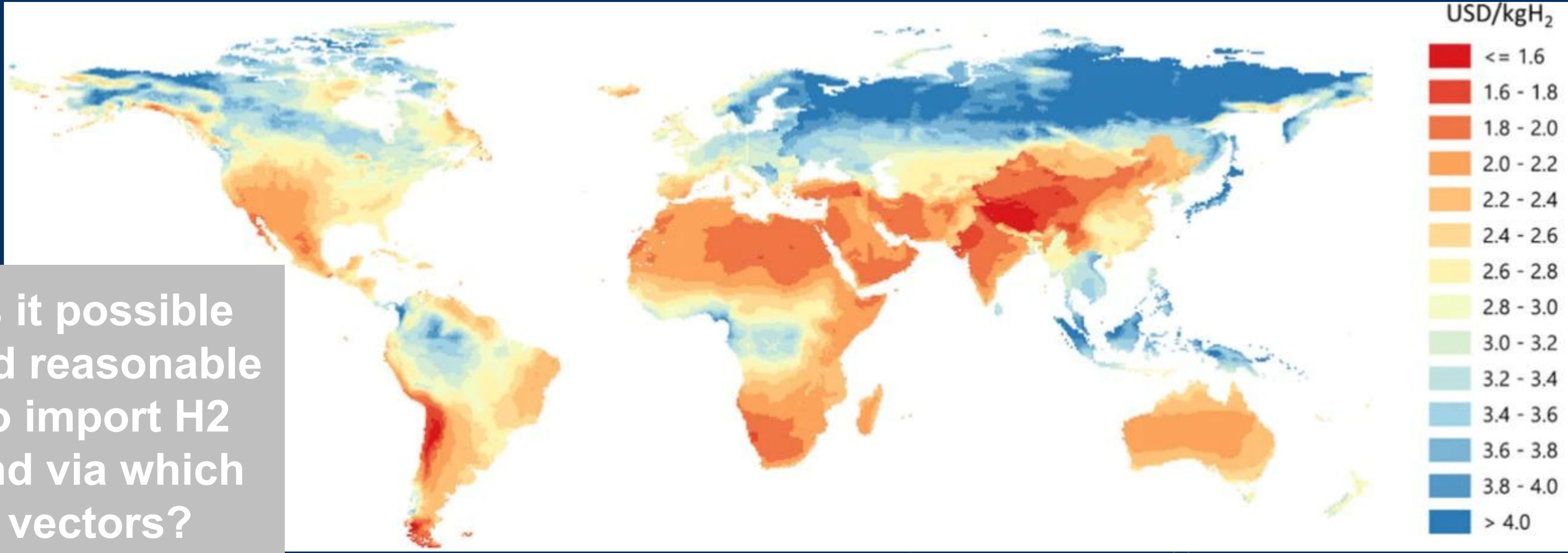
Status quo

- EU27 consumes 10 Mio. t of Hydrogen per year as a chemical
- Vast majority from natural gas via steam reformer (SMR)
- Total emissions of 109 Mio. t CO_2 per year

Decarbonization path

- Hydrogen from electrolyzer, fed from RES
- Carbon capture for SMR/ATR
- Air Liquide solution:
  → Water electrolyzer plants
  → SMR + Cryocap / Amine wash
  → ATR + ASU + Cryocap

Examples 1 to 3 combined require 22 Mio. t of green Hydrogen p.a. - but where from?



Is it possible and reasonable to import H2 and via which vectors?

Source: The Future of Hydrogen, Report by IEA, June 2019
Assumptions: ELY efficiency 74%, CAPEX 450 US$/kW (ELY), 400 - 1,000 US$/kW (PV), 900 - 2,500 US$/kW (onshore wind)
Hybrid plants combining wind and PV

Options to transport Hydrogen

Pipelines

- New, dedicated H_2 pipelines
- Retrofitted natural gas pipelines
- Blending green H_2 into natural gas & H_2 extraction using membranes and PSA

Liquid Hydrogen

- High CAPEX but high efficiency and low energy demand for release
- Liquefiers needs to be scaled up (SK 50 tpd)
- Ships under construction (KHI 90 t/vessel)

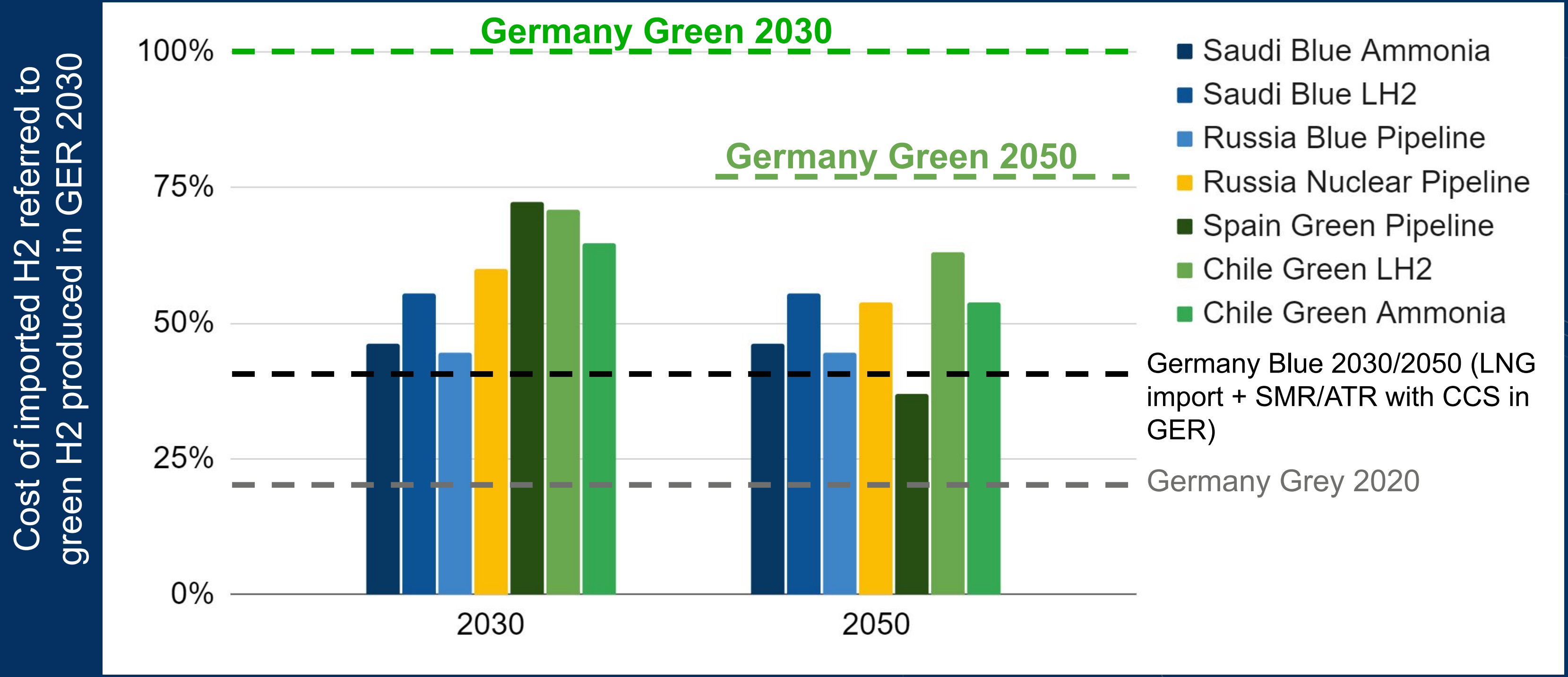
Ammonia

- Existing infrastructure can be used → lower CAPEX
- Large ships available
- High energy demand for cracking (use as H2)
- Possible direct use, e.g. in power gen.

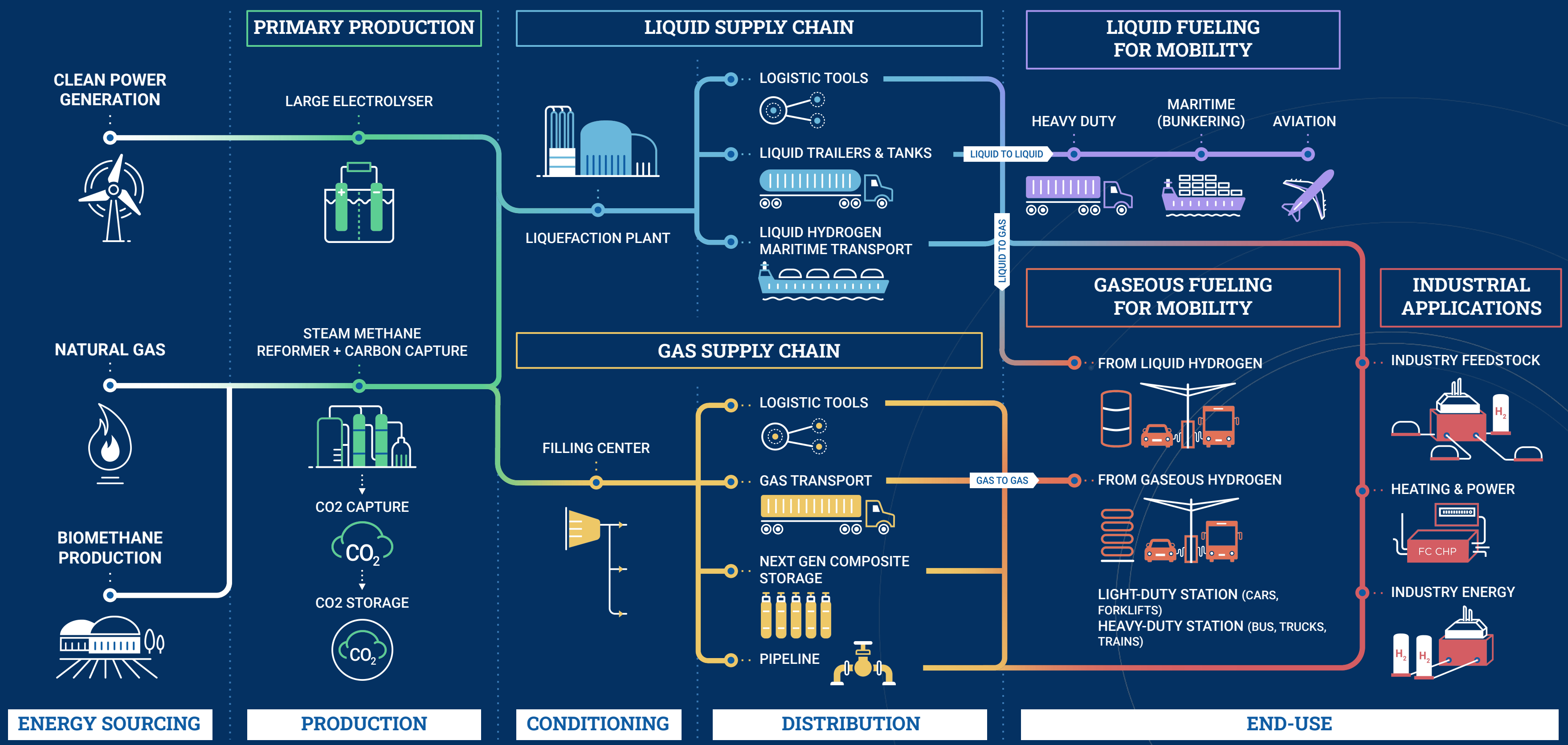
LOHC

- Liquid Organic Hydrogen Carrier
- Technology needs significant Scale-up. (Covestro 5 tpd Dormagen)
- Today: Conversion efficiency quite low
- Very large ships (supertankers) can be used.

Case study: How can we get the cheapest low carbon Hydrogen to Germany?



HYDROGEN VALUE CHAIN



A steep learning curve

HYBALANCE 1.25 MW
PEM
In operation

< 2017

2018

more than 35 electrolyzers in operation worldwide

usual range: 50 - 100 Nm^3/h H_2

Mainly Alkaline technology

ONSITE

2019

BECANCOUR 20 MW
Largest PEM project
In operation

Air Liquide invests in the world's largest membrane-based electrolyzer to develop its carbon-free hydrogen production

February 25, 2019

Air Liquide completes the first phase of ultra-high purity low-carbon H2 electrolyzer plants in Taiwan

2020

25 MW in Taiwan
Start-up

Air Liquide transforms its network in Germany by connecting a large electrolyzer producing renewable hydrogen

Paris, France, July 29, 2021

2023

OBERHAUSEN
Phase 1 20 MW
Phase 2 10 MW
Siemens PEM
Under execution

Towards 100+MW scale

Air Liquide's 200 MW electrolyzer project in the Netherlands enters the final selection round of European Innovation Fund

ELYgator
An Air Liquide Solution

2023/4

H2V NORMANDY 200 MW
Largest ELY project
Under conception

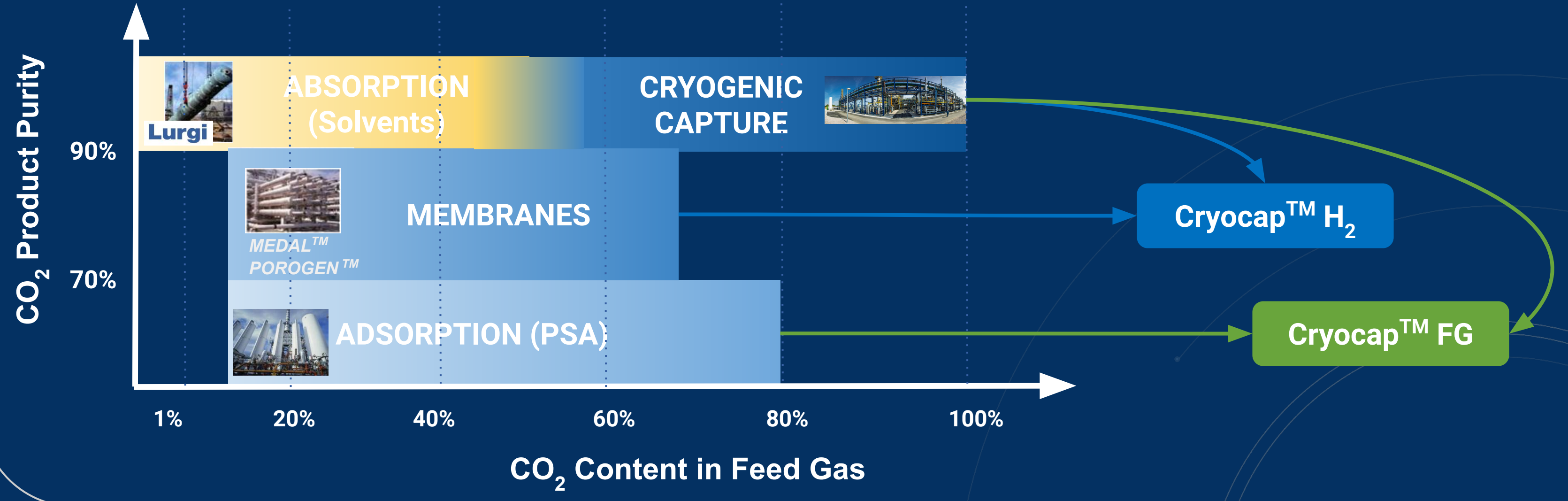
Air Liquide makes a strategic investment to support large scale renewable hydrogen production in France

Paris, France, January 20, 2021

A complete range of products for carbon capture and liquefaction

CRYOCAP™						ABSORPTION	
H_2 Production	Oxycombustion	Steel Production	>15% Flue Gas (Cement, Refineries, H2…)	Natural Gas	CO_2 Liquefaction	Syngas Flue gas	Syngas
							
CRYOCAP™ H_2	CRYOCAP™ OXY	CRYOCAP™ Steel	CRYOCAP™ FG	CRYOCAP™ NG	CRYOCAP™ XLL	MDEA 2G amines	Recticap™ Rectisol™
Adapted to concentrated sources Electricity powered CO_2 produced gaseous or liquid						Steam driven	Large scale ATR/POX

Air Liquide core technologies



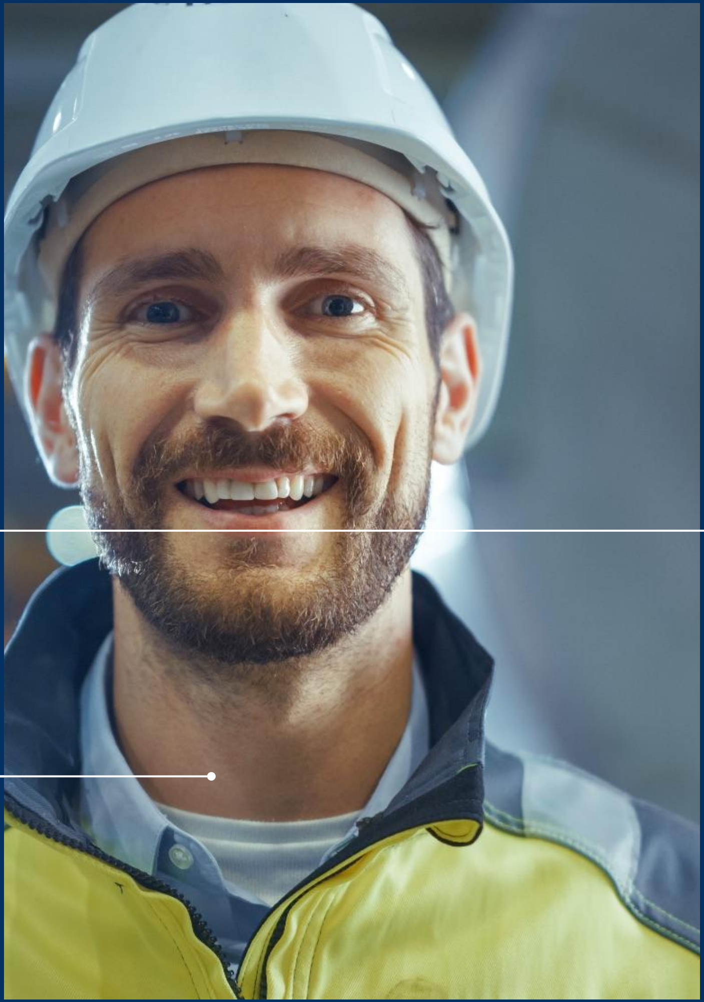
Absorption: The most suitable solution for low concentrated feed gas

Cryocap™ combines cryogenic with membranes & adsorption, addressing any CO2% > 15%, electrical power only.
Can produce HP CO_2 or Liquid CO_2 at marginal extra cost.

HP CO_2/Liquid CO_2: Looking for synergies between capture and compression / liquefaction steps is key

Key messages - Takeaways

- **Electrification** is one of the key solutions to decarbonize some significant sectors
- **Abt. 50% of CO2 emissions** can only be prevented directly or indirectly using **low carbon energy vectors such as Hydrogen/Ammonia**.
- Additionally, unavoidable CO2-emissions can be prevented using **CCS**
- Tomorrows **energy transport** will be carried out using **Liquid Hydrogen**, Ammonia and (Hydrogen) Pipelines
- **Air Liquide** has the **key-technologies inhouse** and will **play a major role** in the transition of our energy and industrial ecosystem.



Let's discuss!

AL Techno routes for low carbon Hydrogen & Syngas

FEEDSTOCK

Natural Gas

- Biogas
- Refinery Offgas
- LPG
- Naphtha

Residual Oil

REN Electricity

GAS PRODUCTION

SMR

Gas POx

ATR

MPG

Electrolyser

GAS CONDITIONING & PURIFICATION

CO Shift
HT-/
Mt-

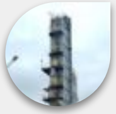
CO Shift
Isoth./
Mt-

CO_2 Removal
aMDEA/
Rectisol
Cryocap™
H2

Membrane

PSA

CO Cold Box



H2 Liquifier

Conditioning **Liquefaction**

PRODUCTS

H_2

CO

Syngas
H_2 +CO

CO_2

H_2 & O_2

Example no. 4 - Energy Transport

Status quo

- Limited transport capacity via power grid
- Fossil primary energy carriers transported by ship & pipeline (coal, oil, natural gas)

Decarbonization path

- Energy transport using liquid Hydrogen, Ammonia, LOHC or Hydrogen Pipelines
- Air Liquide solution:
  → Water electrolysis + Liquefaction
  → Water electrolysis + Ammonia loop
  → Pipelines + Membranes + PSA

Can we get 11,000 TWh of green energy in Europe?

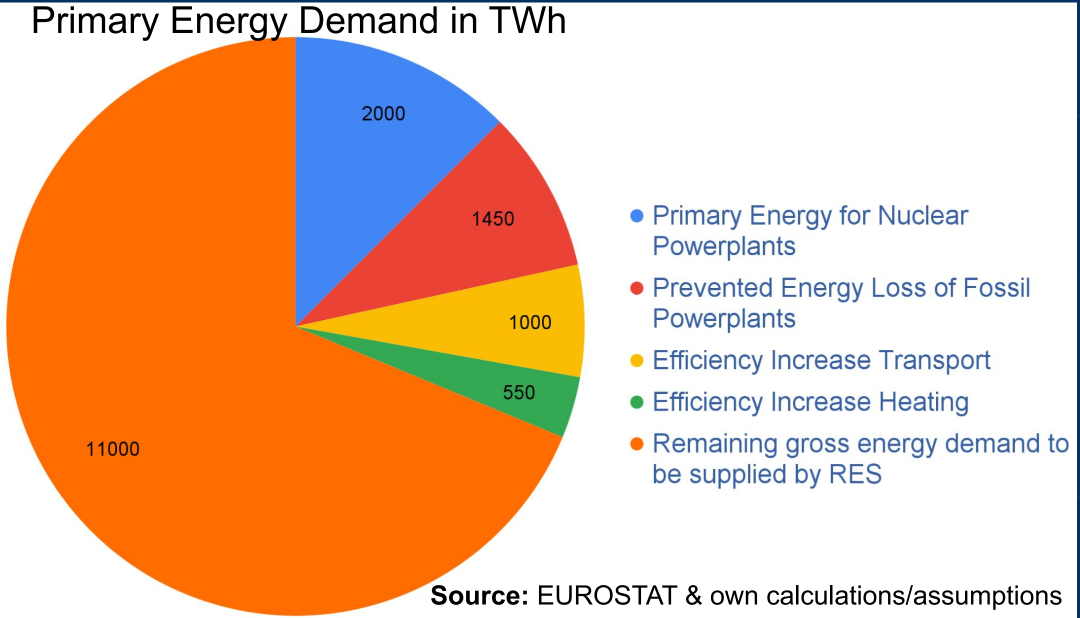
- In 2019, EU27 harvested ca. 1,000 TWh from RES → **11-fold increase required**
- **However, studies show that in principle this is possible from a pure-technical view**
  - [1]: EU27 can harvest 15,000 TWh/year from wind and PV
    - Rooftop PV on all suitable roofs, open-field PV on bare land and open vegetation
    - No PV on farmland, no wind and no PV in environmentally protected zones
    - Onshore wind on farmland, forest, open vegetation and bare land
    - Only 1 out of 10 suitable locations are used.
  - [2]: Even in the case with maximum restrictions, rooftop & free-field PV as well as on- & offshore wind in EU28 can deliver 11,900 TWh/year (3% available area for PV, high restrictions for onshore wind)
- **Yes, it appears we can harvest the energy in principle, but at what cost and in what timeline, and under which environmental & social aspects?**

[1] T. Troendle et al., Home-made or imported: On the possibility for renewable electricity autarky on all scales in Europe, Energy Strategy Reviews (26), 2019, DOI: 10.1016/j.esr.2019.100388

[2] C. Ruiz et al., ENSPRESO - an open, EU-28 wide, transparent and coherent database of wind, solar and biomass energy potentials, Energy Strategy Reviews (26), 2019, DOI: 10.1016/j.esr.2019.100379

How much low carbon energy do we need to replace all fossil primary energy use in Europe?

- In 2019, EU27 had **16,000 TWh** of **Primary Energy Demand**
- **Do we need to replace all that?**
    - From a decarbonization stand point Nuclear power does not need to be replaced
    - Energy Transition brings significant energy savings that reduces primary energy demand
    - Vectors for storage and transport will increase the demand but not compensate the saving



Source: EUROSTAT & own calculations/assumptions

- Taking this into account, RES need to deliver **11,000 TWh of energy**

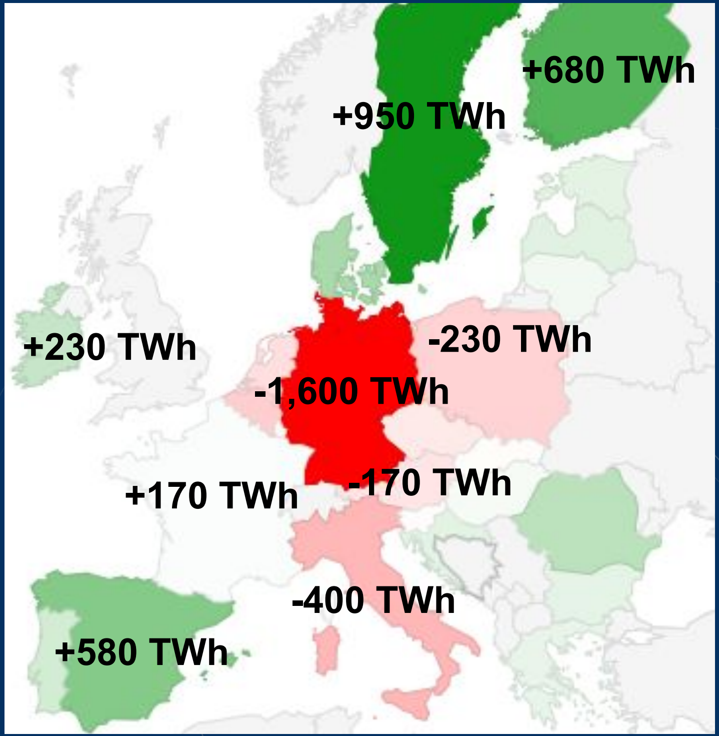
While in total, EU27 has sufficient RES potential, significant local surpluses and deficits will arise

→ **Study [1] also includes spatial resolution, that reveals very significant need of inter-european energy transit**

For comparison:

- **Electricity:** Germany plans additional lines of 8 GW to transport wind energy from north to South → Annual capacity: 70 TWh / year
- **Natural gas (Pipeline):** North Stream 2 has a capacity of 55 bn. m³ per year → 550 TWh / year
- **Hydrogen:** Energy deficit of Germany corresponds to 48 Mio. t of Hydrogen (1,600 TWh)

[1] T. Troendle et al., Home-made or imported: On the possibility for renewable electricity autarky on all scales in Europe, Energy Strategy Reviews (26), 2019, DOI: 10.1016/j.esr.2019.100388



Example: Transport 1,000 Tonnes of Hydrogen

	Unit	gH2 500 bar	LH2	NH3	LOHC
Space vector	m^3	30,000 r 30 kg/m^3	14,000 r 71 kg/m^3	8,300	17,500
Mass vector	t	18,000*	5,000**	6,500	18,200
Energy demand conversion	kWh / MWh	50 - 70 (el.)***	240 - 300 (el.)	220 (el.)	90 (el.)
Energy demand release	kWh / MWh	0	15 (th.)	40 (th.) 250 (th.)	250 - 300 (th.)

*A 500 bar trailer stores 1,100 kg of Hydrogen, assumed weight 20 t

** A LH2 trailer stores 4,000 kg of Hydrogen, assumed weight 20 t

*** Compression from 30 to 500 bar

Timeline - Can we just wait for RES expansion?

- **RES extension is extremely large and capital intensive.**
- To **slow down climate change** as quickly as possible, **additional faster and cheaper solutions** are required.
- **Carbon-Capture & Storage (CCS)** is a **well-established and cost effective process** to decarbonize fossil Hydrogen processes and processes with unavoidable CO2-emissions, such as cement production.

Situation in Germany