World Bank ESMAP Webinar

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POWERING THE FUTURE - INTEGRATING CLEAN HYDROGEN INTO THE POWER SYSTEM

ANTONIO ILICETO

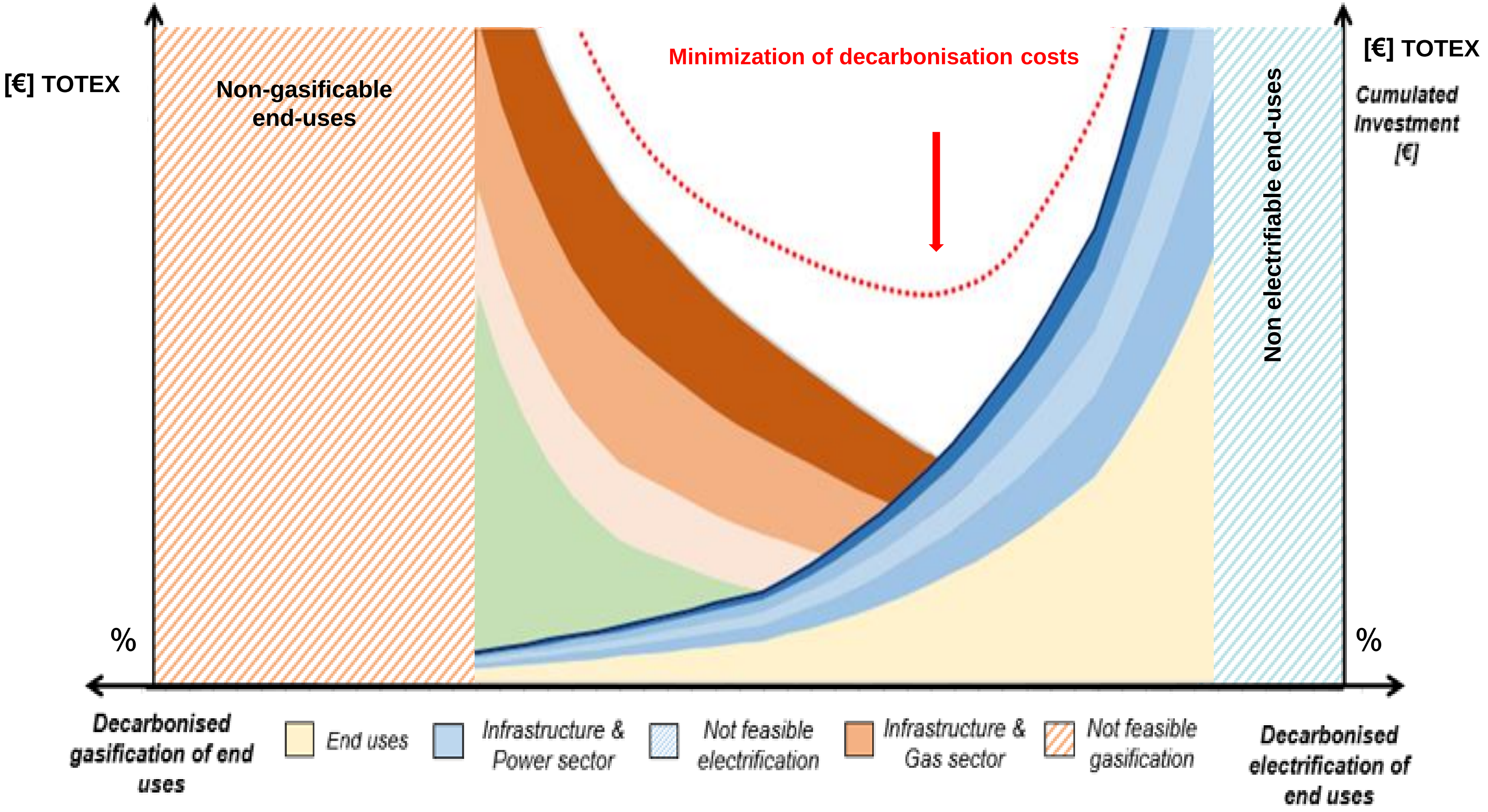
Dii – Desert Energy Advisory Board member

CIGRE Chair of Committee Power System Development & Economics

Contents

- Complementarity of electrons & molecules for decarbonization
- Hydrogen sector impact on power system
- Electricity for hydrogen & hydrogen for electricity
- Hydrogen as energy vector from MENA Region

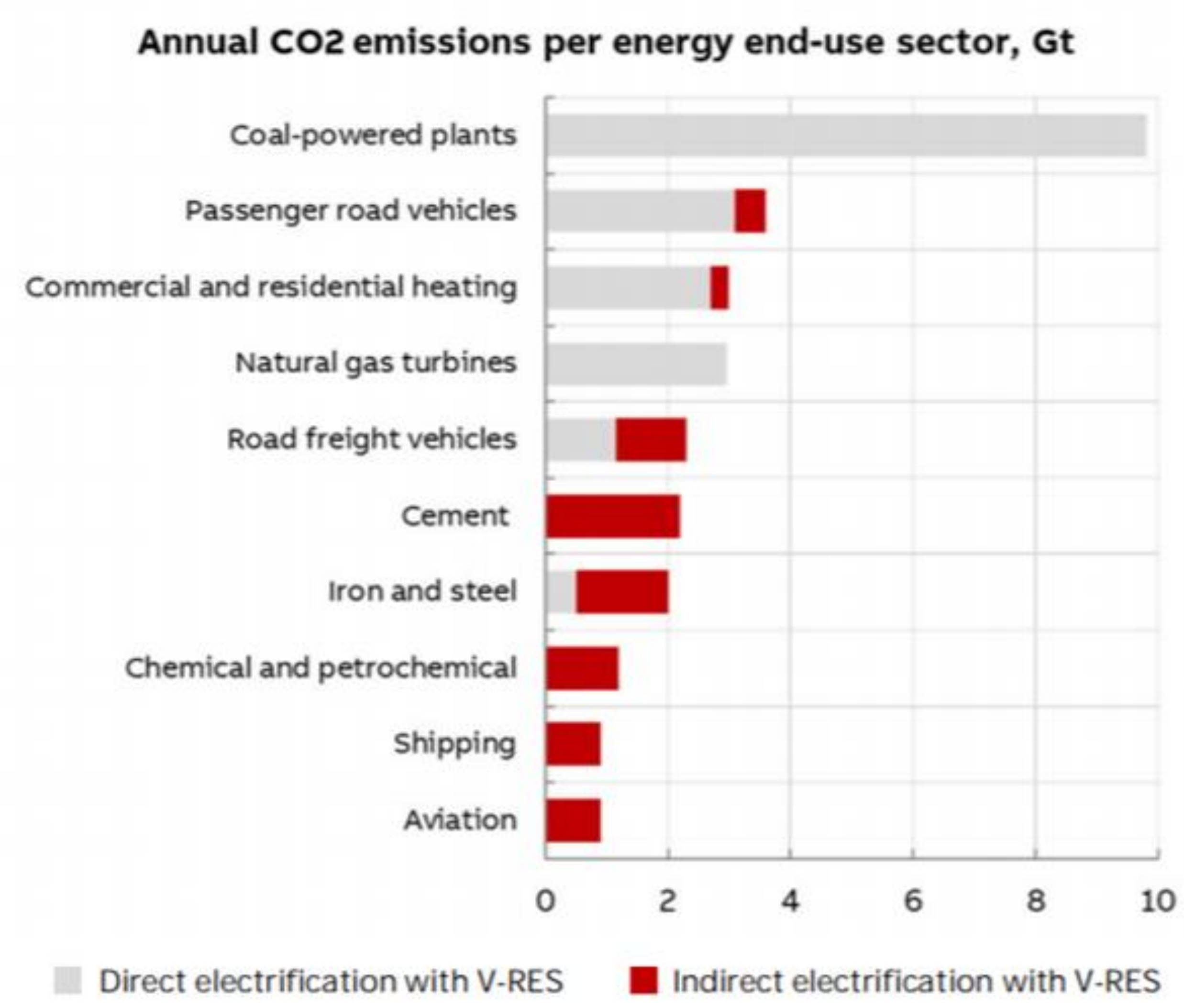
Energy molecules and electrons are both necessary to decarbonise at minimal cost



Source: Terna
Qualitative graph.

The optimal mix Electrons / Molecules will depend on several drivers, also country-specific

Reducing CO2 emissions via direct and indirect electrification



Source: CIGRE, HITACHI Energy

Choice between electrons and molecules depends primarily on energy & decarbonisation efficiency

Is it convenient to decarbonize through conversion of **electricity into synthetic gas or liquid**?

⇩

Yes, but only for those sectors that cannot be electrified or struggles to be electrified.

From an energetic point of view:
- ✗ **Not currently efficient / possible**
- ✓ (yellow) **Has to be evaluated**
- ✓ (green) **Most efficient**

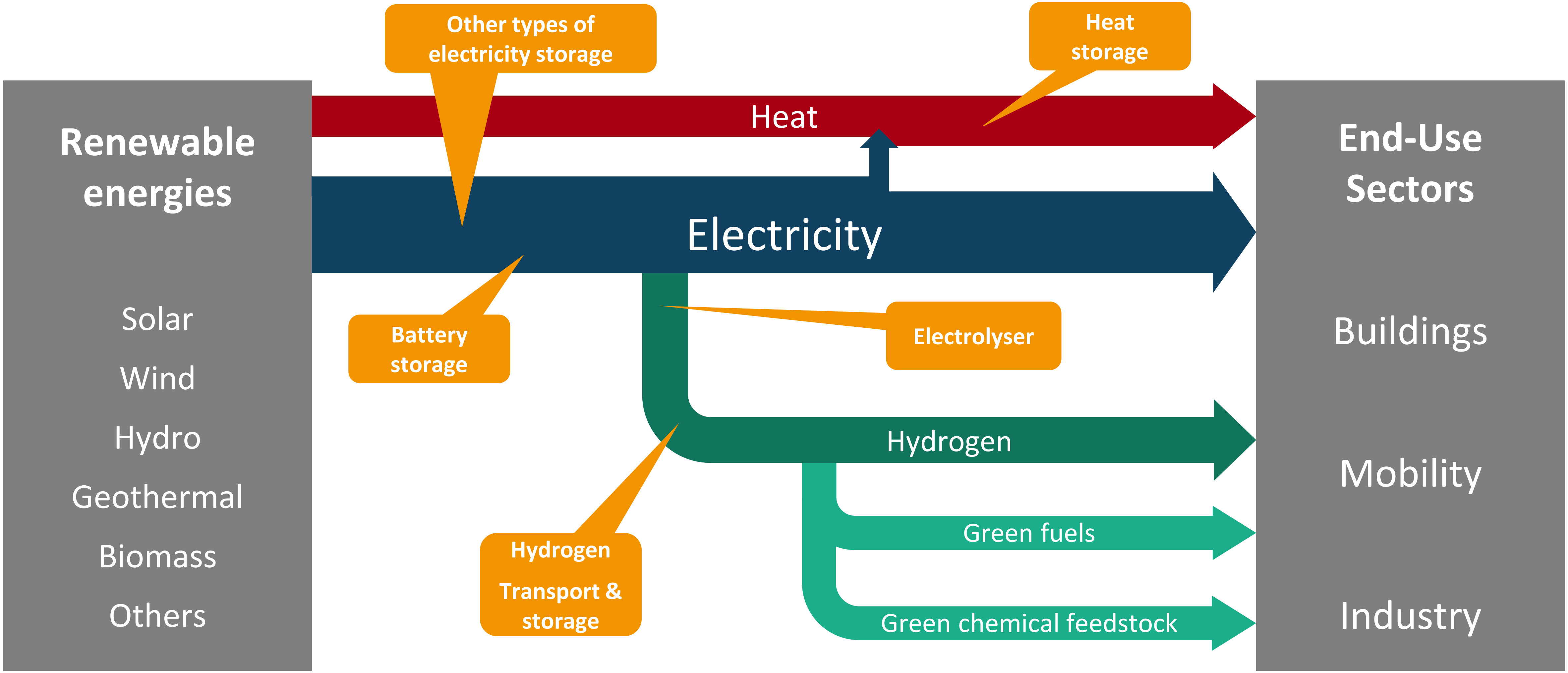
		Electricity	Synthetic molecules
Transport	Passenger, light-duty	η ~ 70%* ✓ (green)	η ~ 15%-25%* ✗
	Heavy-duty	✓ (yellow)	✓ (yellow)
	Maritime, Aviation	✓ (yellow) / ✗	✓ (green)
Domestic / Commercial	Heating	η ~ 100 - 350%** ✓ (green)	η ~ 25%-45% ✓ (yellow)
Industry	Feedstocks	#N/A	✓ (green)
	Heat processes	High-T ✓ (yellow) Low-T ✓ (green)	High-T ✓ (green) Low-T ✗

Source: Terna

*** COP*

✓ **Benchmark will evolve depending both on supply technologies/costs and on final uses technologies/ processes**

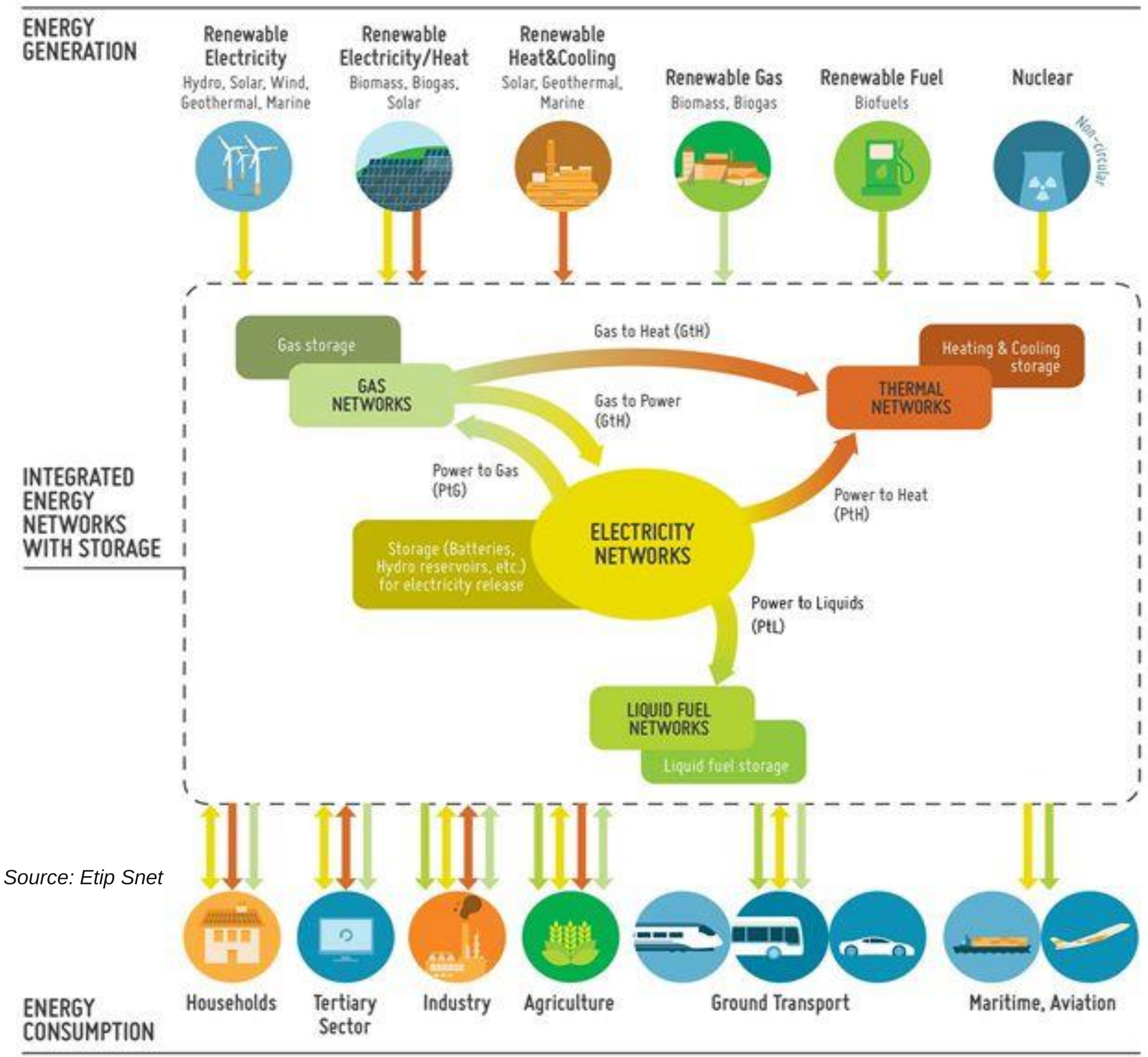
Future Energy System: dominant role of green electricity



Source: Fraunhofer Institute.

Power system and grids as backbone of energy transition (European Vision 2050)

- A very extensive electrification of most sectors of the energy system
- Deep energy efficiency improvements in all sectors
- Extensive use of carbon neutral fuels
- Widespread digitalisation
- Targeting also technological leadership in renewables and decarbonisation
- Adoption of a widely circular approach
- Sustainable buildings
- Progressive societal changes



Source: Etip Snet

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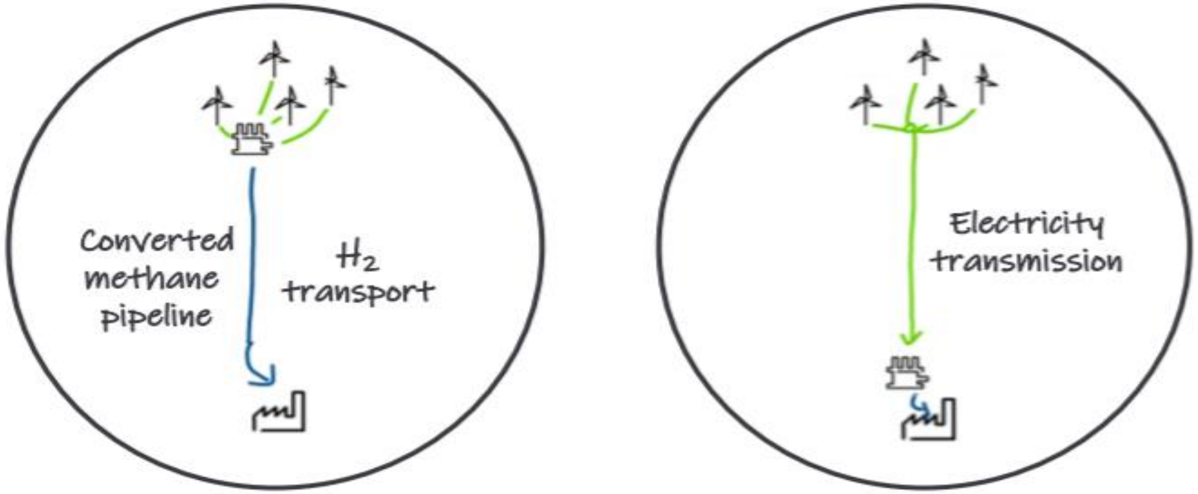
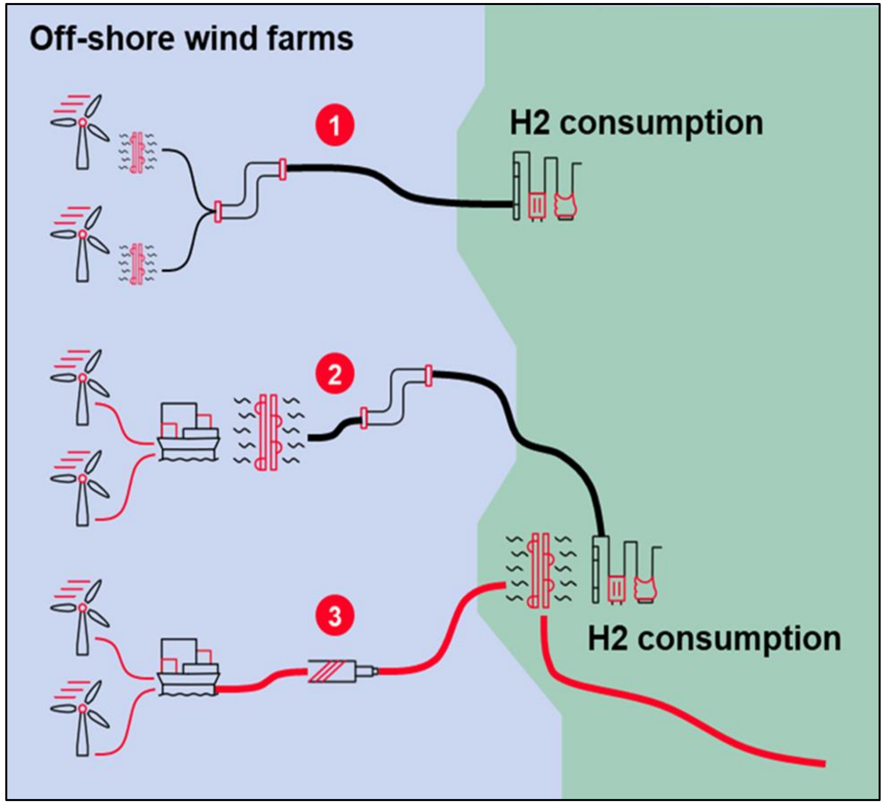
Grid planning : for mediumd length distances, localization of large electrolysers is an energy system planning decision

Placement of electrolysers determines energy transport technology and infrastructure costs



Planning of electrolysers and H_2 network in TYNDPs (EC hydrogen strategy)



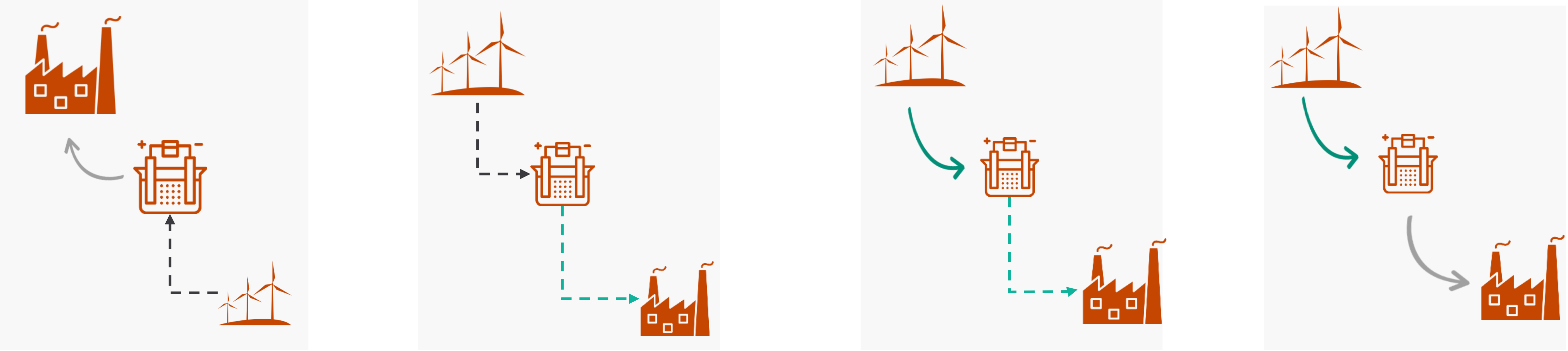
Very short distances → Hydrogen Valleys
Very long distances → power lines not feasible

Localisation of electrolysers is an energy strategy decision, which should optimise the overall energy system (Capex, Opex, energy efficiency, infrastructure utilisation, etc.)

Electrolysers and H2 fuelled generation shall become new components of the integrated energy system

Electrolysers configuration vs the grid, connection type and siting impact both power grid planning and its operation

“on-grid” electrolyser | **“off-grid”** electrolyser | **“Hydrogen valleys”**



Connection to H2 demand | **Standalone electrolyser** | **Connection to power supply** | **Self-standing system**

Direct connection to H2 demand | **H2 network** | **Direct connection to power supply** | **Electricity network**

H2-fuelled power plants (H2P):

- In near term H2P will play a limited (if any) role; but in long term, installed capacity and reserve function shall become quite relevant
- German case – tender 4,4 GW launched for H2 hybrid plants & up to 15 GW of natural gas plants converted to H2 by 2035

Grid operation: beyond present concept of residual load profile

- **Evolution of electric system operating philosophy:**

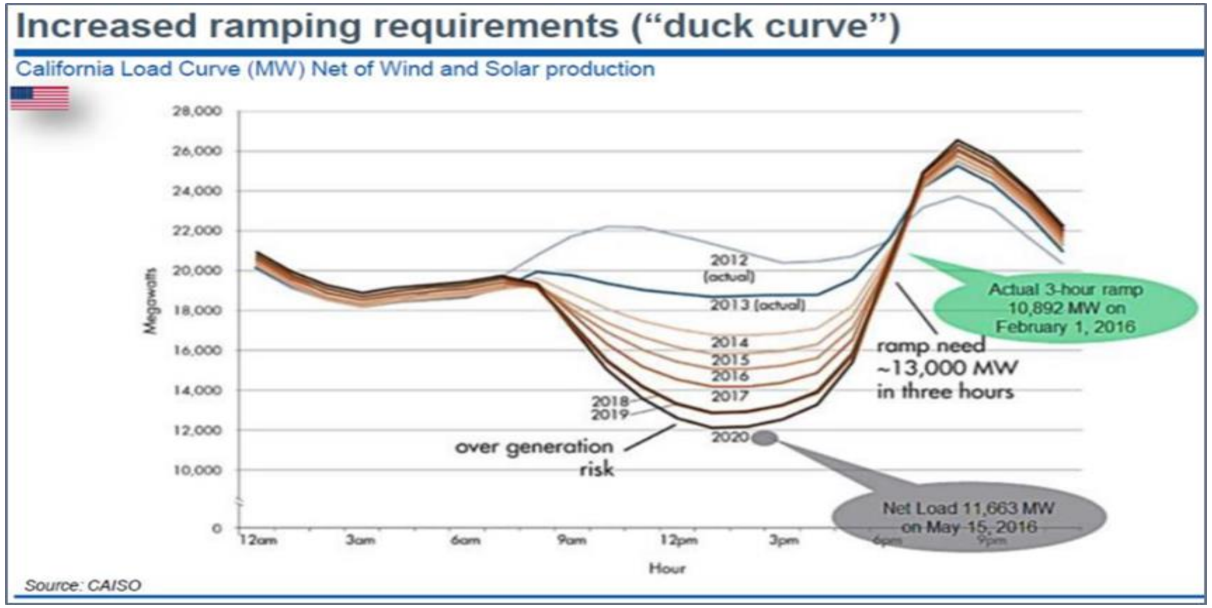
Generation follows Load

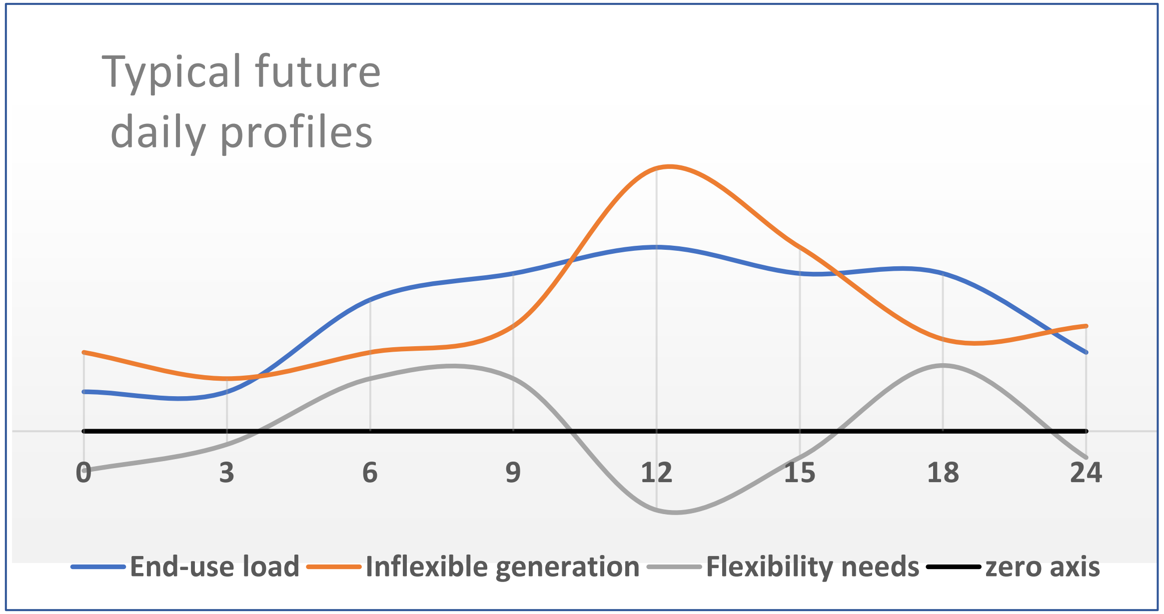
THE PAST → Load profile given as independent variable (inflexible load), generation has to follow the load

THE PRESENT → Residual load profile (total load minus variable RES generation) covered by traditional flexible generation + initial flexibility means

THE FUTURE → Generation profile given as independent variable (inflexible generation), so grid and load have to become flexible through a wide portfolio of flexibility means

Load follows Generation



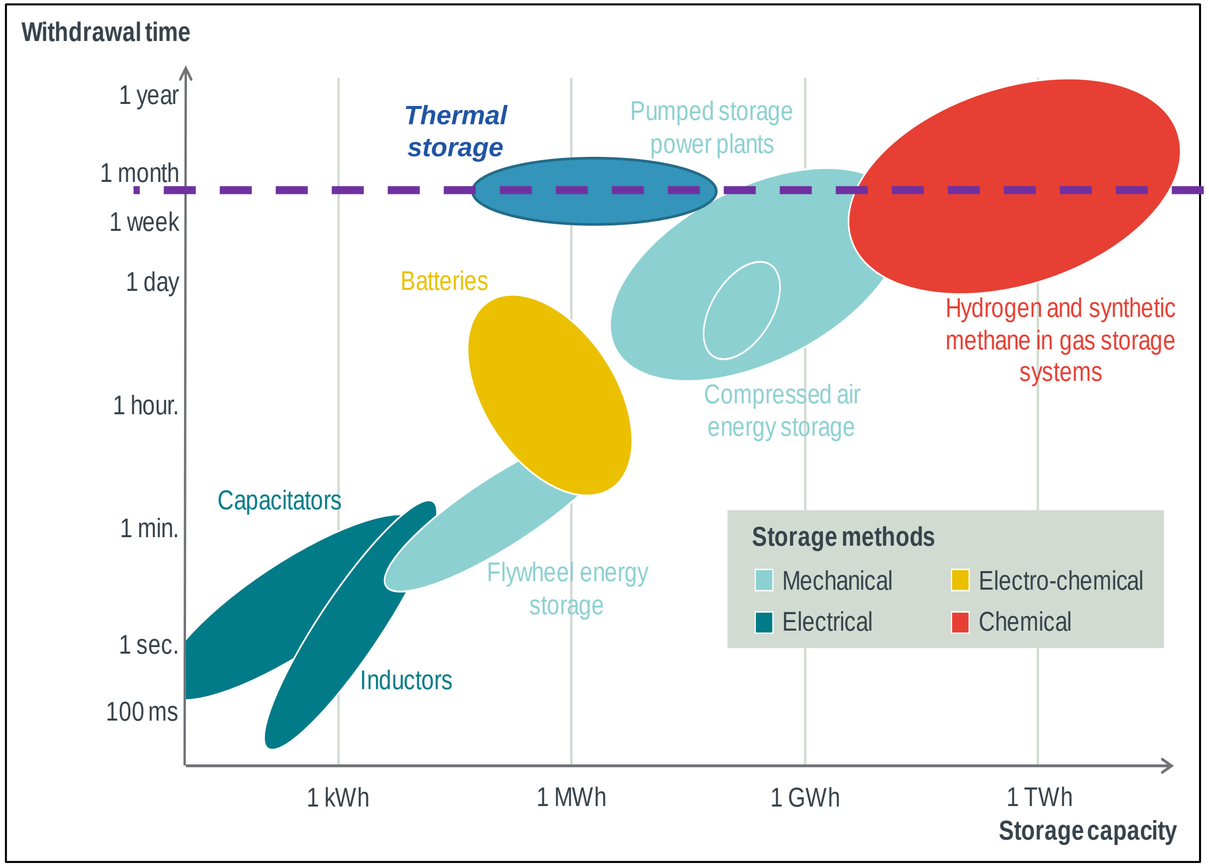


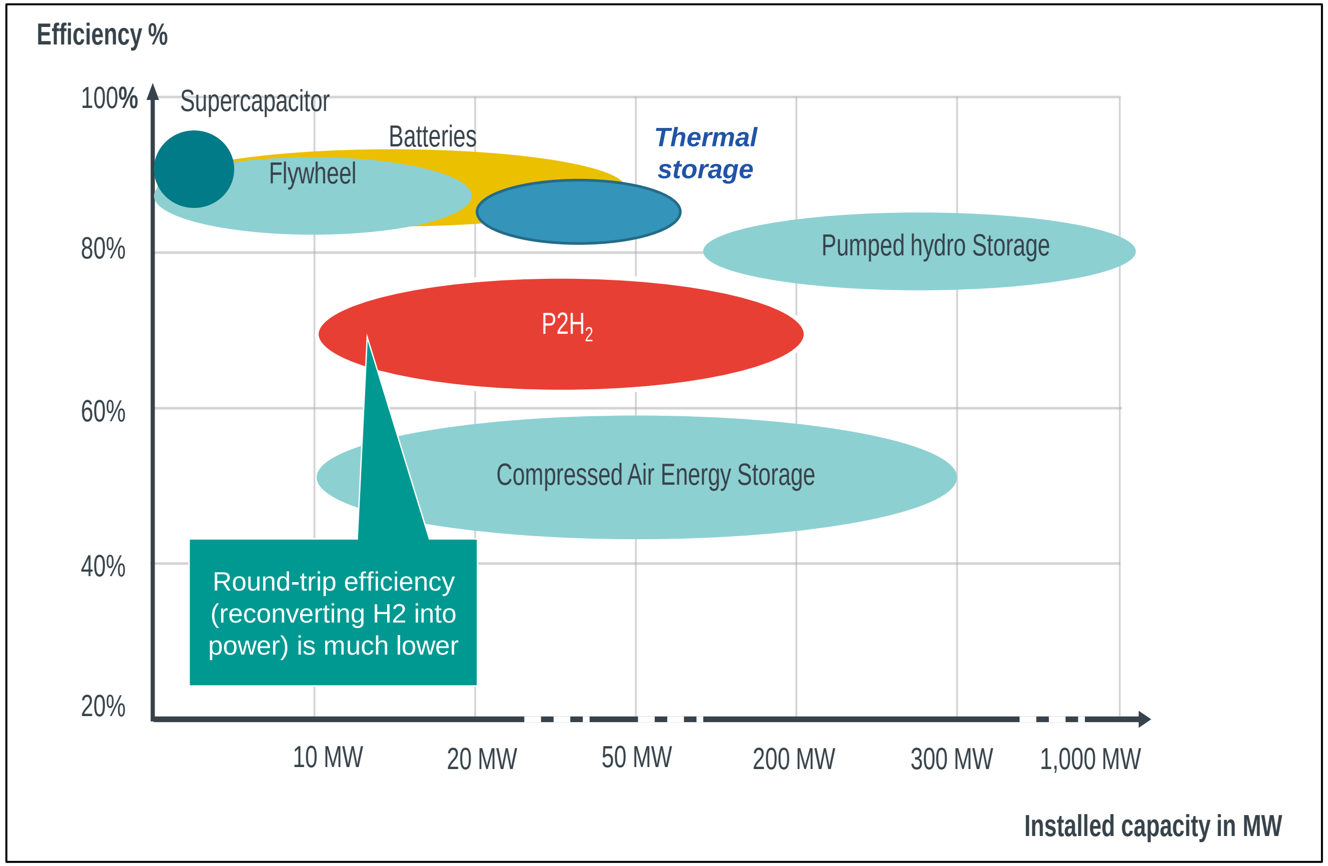
Short duration flexibility: electrolysers' capabilities of providing grid services

	Alkaline		PEM		SOEC	
	Today	2030	Today	2030	Today	2030
FCR	Yes with limits	Yes with limits	Yes with limits	Yes with limits	No	Uncertainty about flexibility
aFRR	Yes with limits	Yes with limits	Yes	Yes	No	Uncertainty about flexibility
mFRR	Yes	Yes	Yes	Yes	No	Uncertainty about flexibility
RR	Yes	Yes	Yes	Yes	No	Uncertainty about flexibility
Voltage control	Electrolysers can provide reactive power if they are equipped with self-commuted rectifiers					
Congestion management	Yes	Yes	Yes	Yes	No	Uncertainty about flexibility

If properly designed, realized and operated, electrolysers could provide many grid services

Long duration flexibility: few means are promising





Pumped hydro sites in EU are already utilised; thermal storage and compressed air are in development stage → molecules are a promising candidate

N.B. The analysis focuses on energy exchanges with power grid (absorbing/storing/release)

Flexibility from hydrogen sector - summary

Short duration → demande response and daily storage for grid operation

- Electrolysers will be new and important loads for the grids
- Technically their rate of operation can be modulated to a certain extent → flexibility as demand response
- It depends mostly on the connection configuration, operational mode, as well as storage capacities in the hydrogen system to de-couple electricity input from hydrogen output to final use

Long duration → seasonal storage for system adequacy

- Hydrogen (both blue and green) can be stored seasonally, providing flexibility to the wider energy system
- Very valuable service in a vRES-dominated future generation mix, few alternative exist (compressed air, thermal storage)
- Uneven location of storage facilities

General considerations

- Amount of RES necessary to feed all electrolysers → risk of mismatch in the (long) transition period
- Making hydrogen a flexibility provider to the electrical system will require structural investments beyond the electrolysers: hydrogen/synfuels pipelines/grids, storages, logistics

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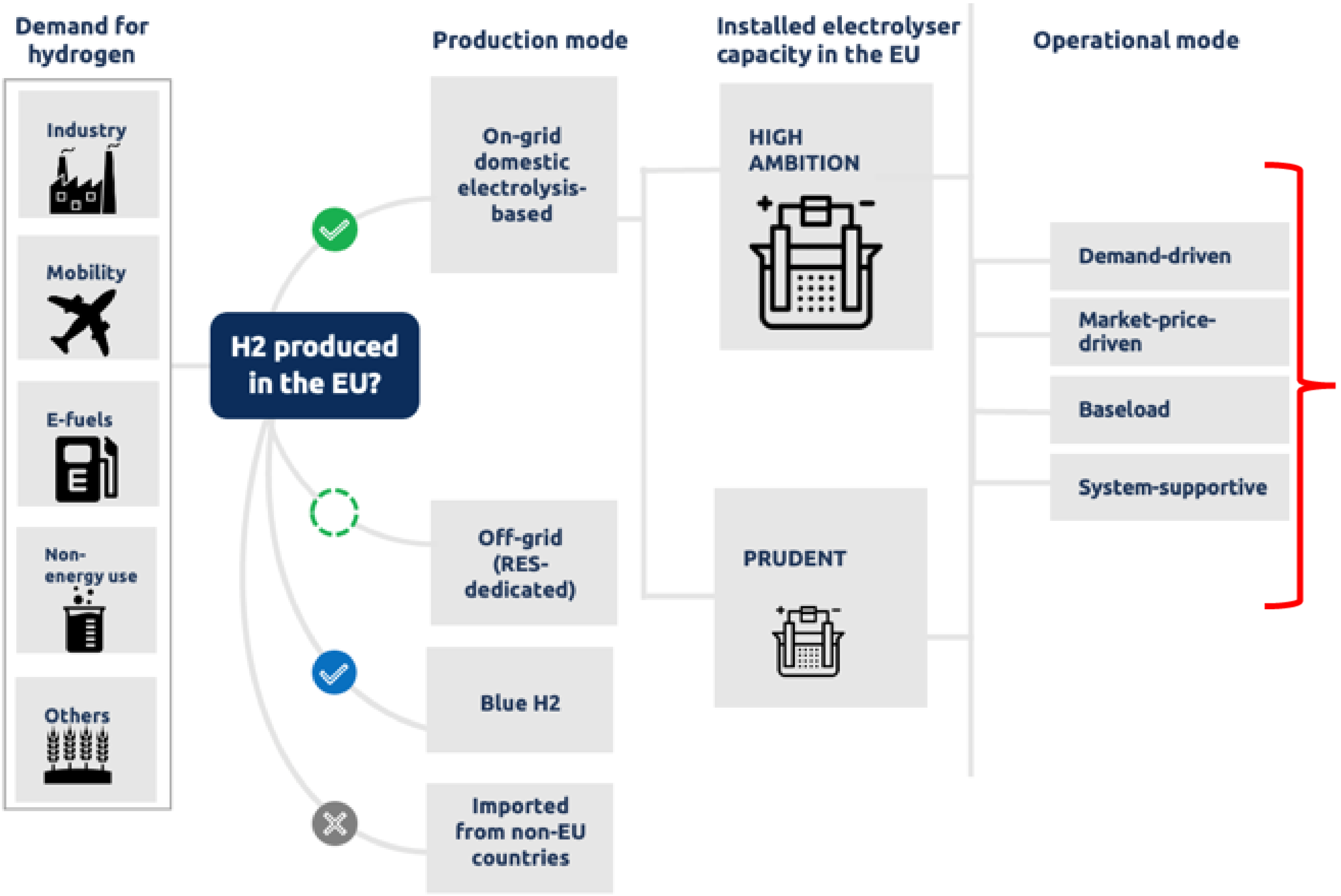
Operational modes and flexibility potential also depends crucially on the presence and utilisation options of hydrogen infrastructures



Modes identified as **extreme cases of load profile** from the grid (in reality combinations can be applied):

- **demand driven**: follows H2 contracted off-take (only chance if there is no logistic system behind)

- **market price driven**: follows lowest electricity prices to minimise OPEX cost in LCOH

- **baseload**: maximise capacity factor to minimise CAPEX cost in LCOH

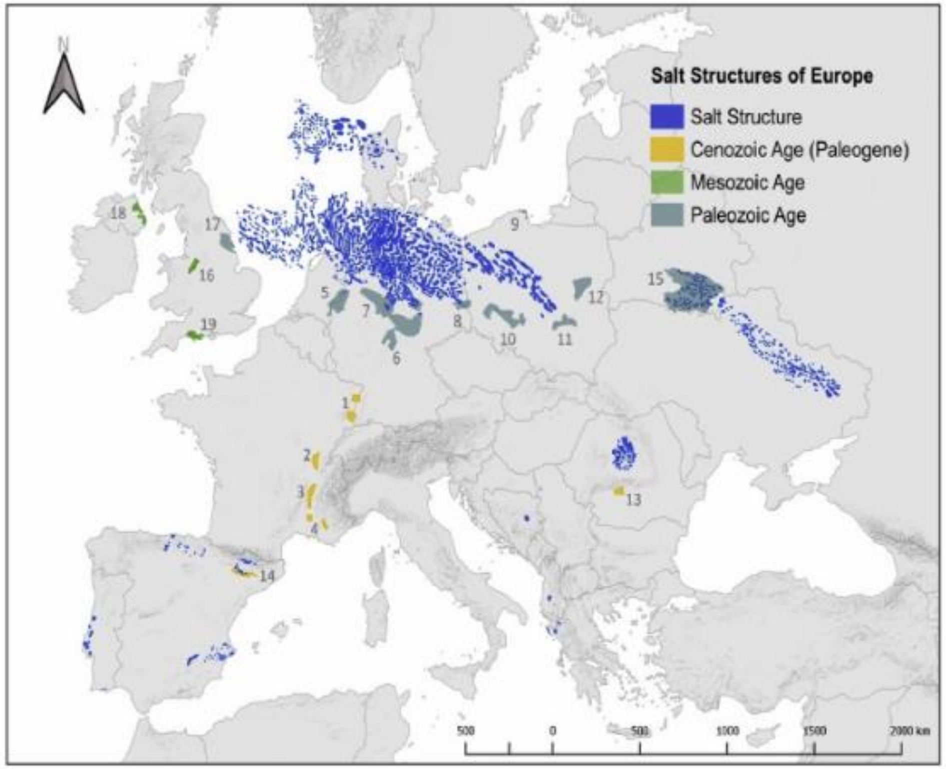
- **system supportive**: consider in their business plan also selling system services

H2 infrastructures are crucial for higher integration vs power system: underground storage and pipeline network

H2 infrastructures are **transport** facilities (pipelines, rail/truck, ships off-takes) and **storage** (local tanks, pipeline pack, underground storage, trading hubs)

They make it possible to **decouple**:
- power load profile from H2 production
- H2 production from H2 consumption

So creating possibility to **modulate electrolyser operation, i.e. flexibility**
They also make possible **trading of H2 as a liquid commodity**



Operational modes and flexibility potential also depends crucially on the presence and utilisation options of hydrogen infrastructures

Taxonomy of operational configuration and business cases (system perspective)

Configuration	Operation	Storage	Grid Congestions risk	Flexibility short term	Flexibility long term
Non electrolyser H2			no	no	no
RES-dedicated Electrolysers (Off- Grid)			no	no	no
On-Grid electrolysers	User demand driven	No storage elements	yes	no	no
		Storage elements	no	yes	yes
	Market price driven	No storage elements	No, decongestion effect	no	no
		Storage elements	no	yes	yes
	Baseload	No storage elements	yes	yes	no
		Storage elements	no	yes	no
	System supportive	Storage elements	no	yes	yes

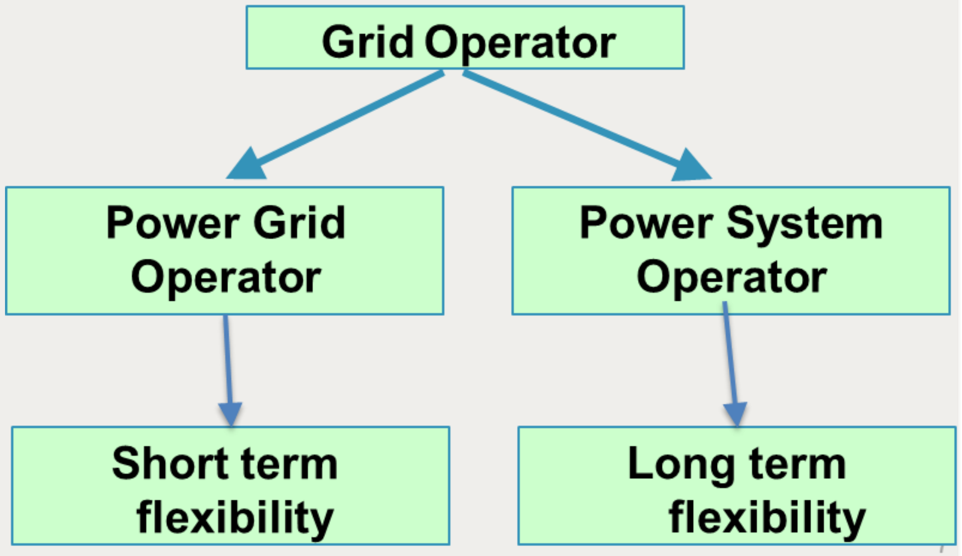
**** Storage element either on electric side or on hydrogen side: tanks, pipelines, caverns, consumer tanks, etc.. Creating a buffer which de-couples electricity input from hydrogen output***

Green labeling of Zero / Low Carbon hydrogen and derivatives - the European approach

- ✓ Need of **a new ad-hoc system** for labelling green hydrogen, valid across jurisdictions (ideally worldwide)
- ✓ **Additionality principle** - electrolysers use "new" renewable electricity (i.e. from new RES) accordingly to a robust methodology for unambiguos assessment (avoiding potential double counting and greenwashing), as well as avoiding cannibalization of other decarbonisation processes (e-mobility, electric heating, industrial processes electrification, etc.)
- ✓ **Geographical correlation** – for ensuring the utilised RES are not impaired by grid congestions, assessed at power market granularity (market / bidding zone)
- ✓ **Time correlation →** for ensuring that utilised RES are not impaired by grid congestions, which occur and are assessed at power market granularity (1h / 15 minutes)

Impact of Hydrogen sector on Power Systems

- Hydrogen as a <u>new system component</u>
  - Complementary and necessary for decarbonisation of hard-to-abate sectors
  - Green labelling substantially determinant of investments and considering grids constraints
- Impact on grid <u>operation</u>
  - Provision of flexibility, adequacy, resilience
    - Short and long term flexibility
  - Decoupling RES infeed and H2 demand profile through buffer storage
- Impact on grid <u>planning, to be coordinated with hydrogen (and natural gas) infrastructures planning</u>
  - H2 sector requires relevant logistic infrastructures, not only electrolysers
  - Use cases incentives linked to end-to-end project assessment



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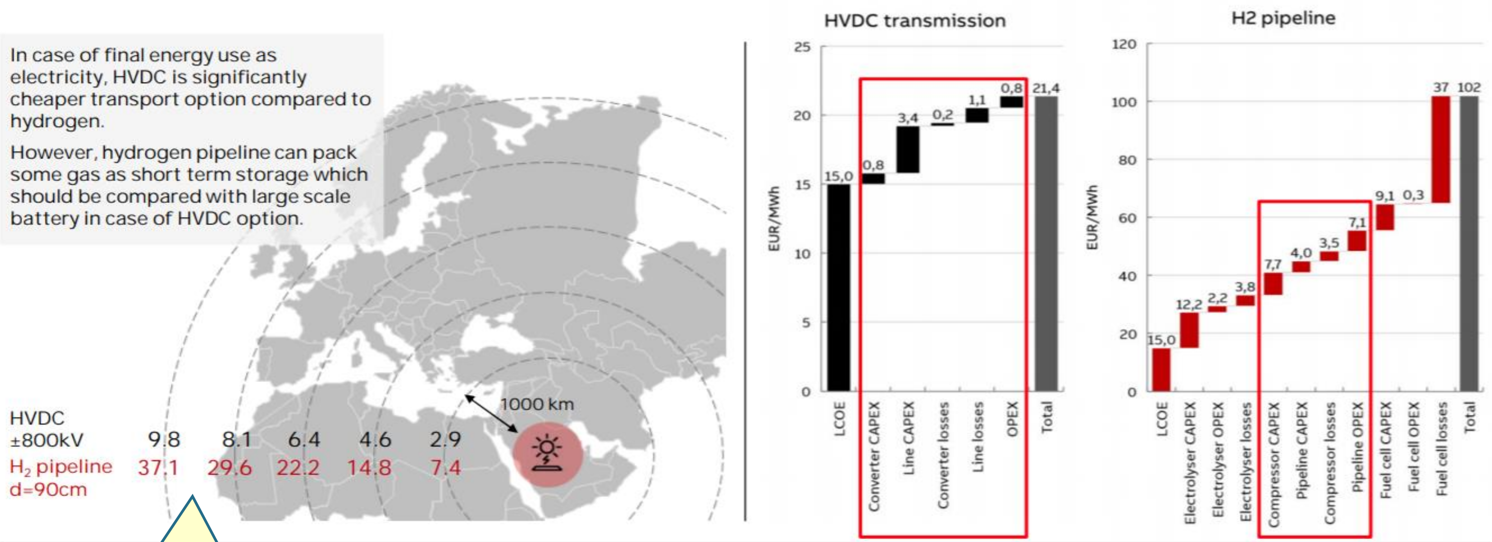
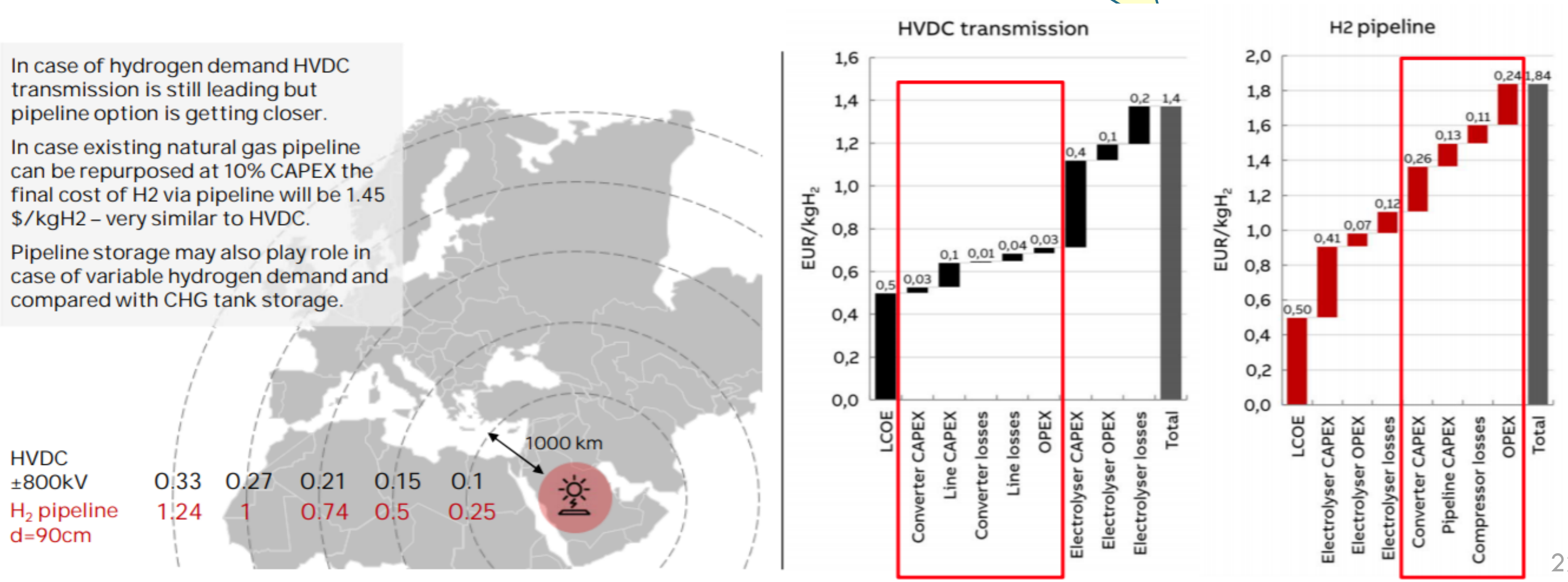
Bulk energy transport: benchmark depends on morphology (land/sea), existing/new infrastructures and type of final use

Figures are exemplary for case studies



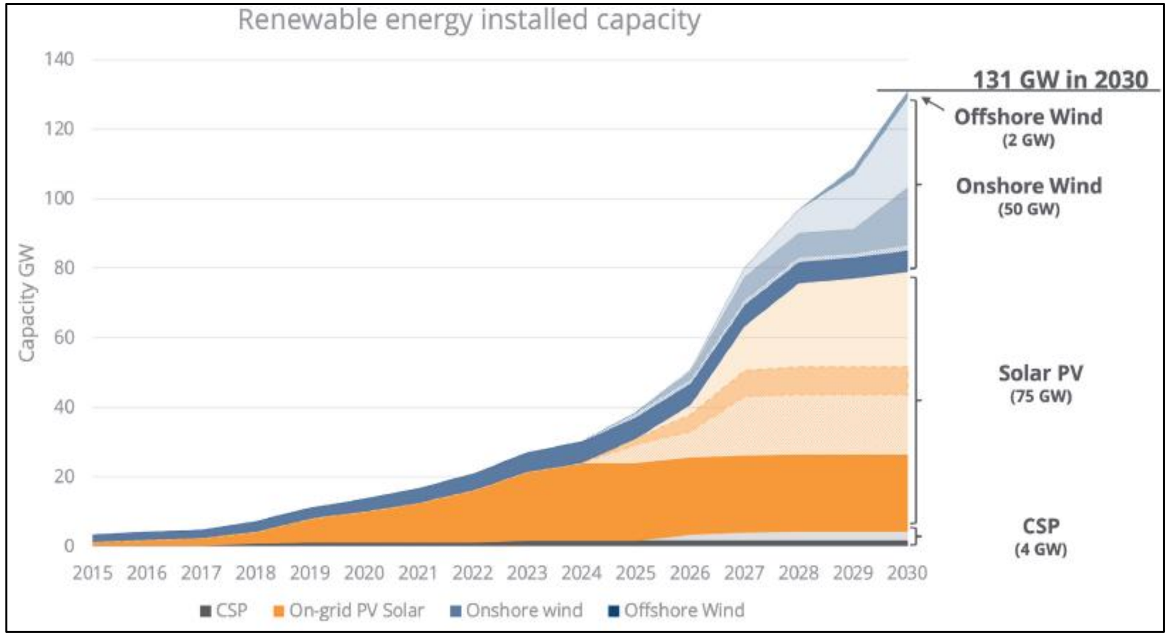
In case final use is hydrogen with converted pipelines, costs are comparable

If final use is electricity, OHL power line is cheaper; in case of underground/submarine cables, it might be opposite



Source: CIGRE, HITACHI Energy

MENA Region (Middle East + North Africa): projected RES & hydrogen capacities



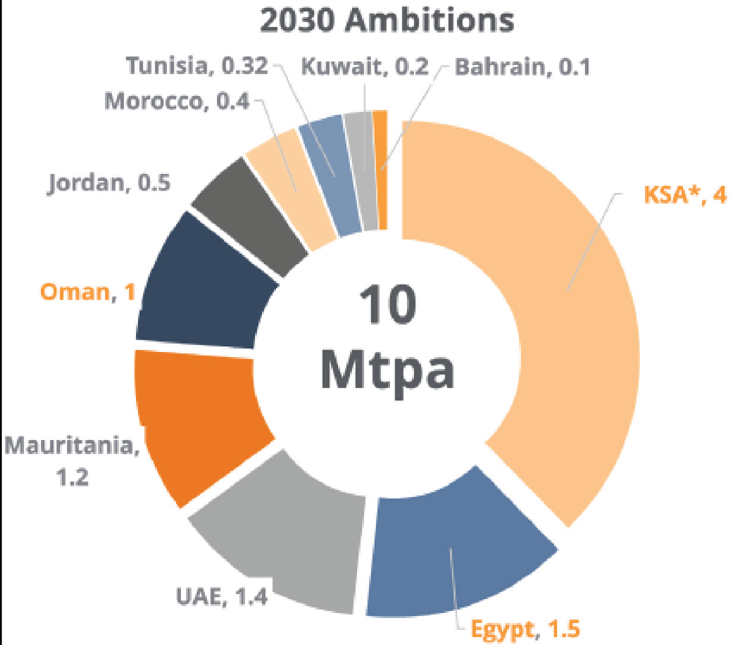
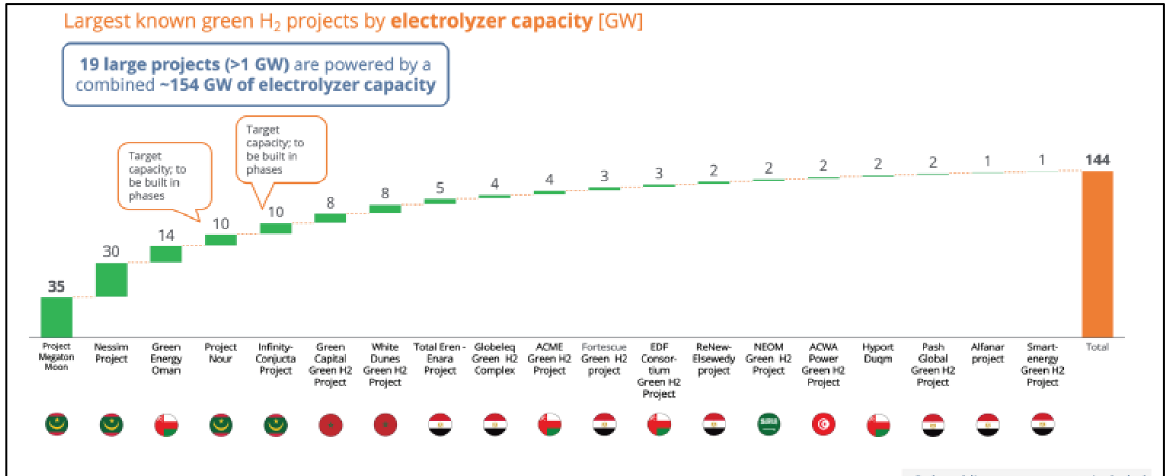


Figure 12: Declared ambitions for hydrogen production in the MENA region by 2030. Data labels for unofficial targets i.e. not part of an official strategy, are reported in orange.

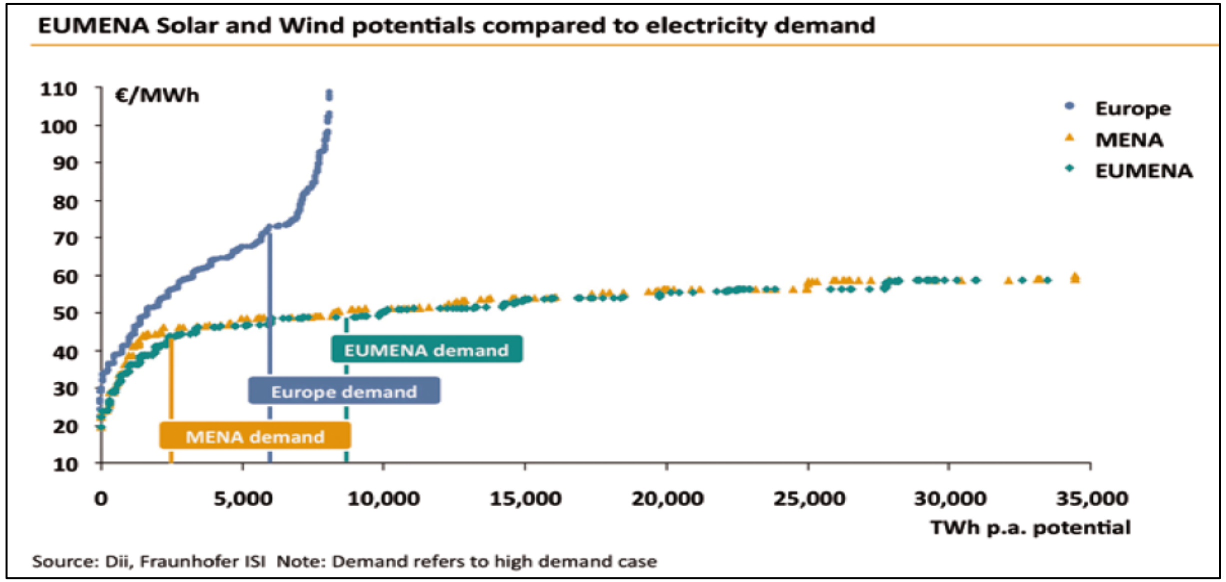
**KSA declares ambitions for all colours of hydrogen, without specifying which portion is green.*



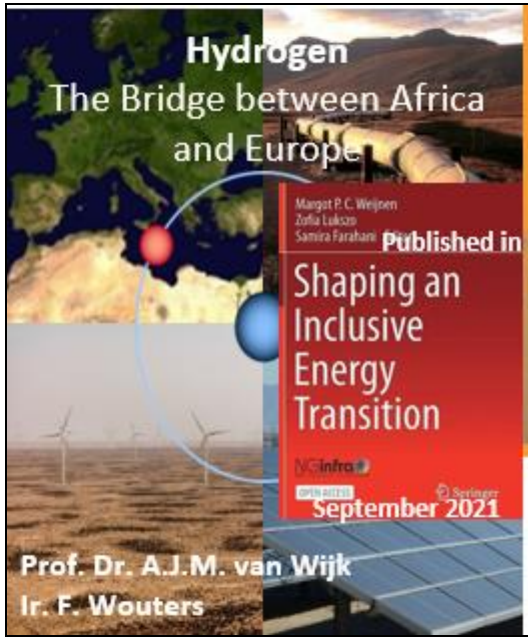
Source: Desk research, Roland Berger

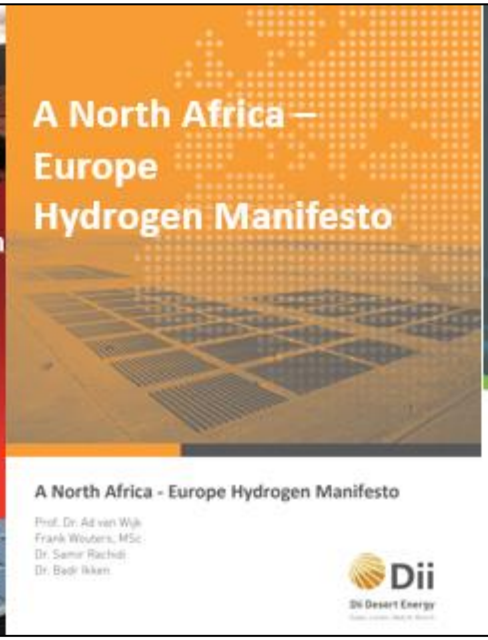
Only public announcements included

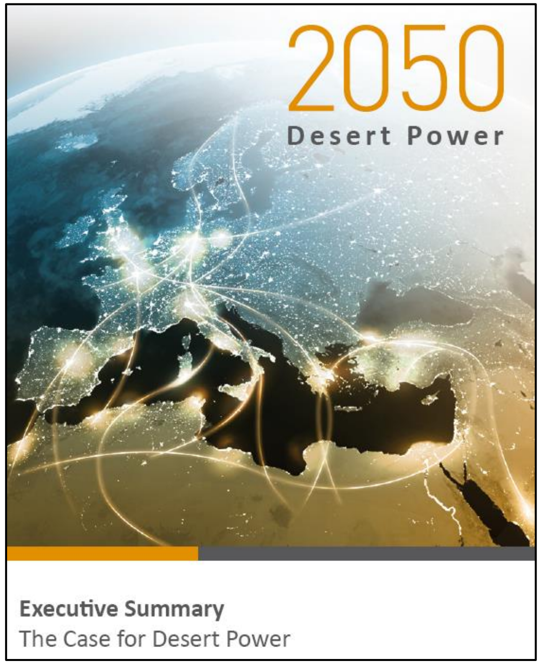
MENA generation economics and transport options

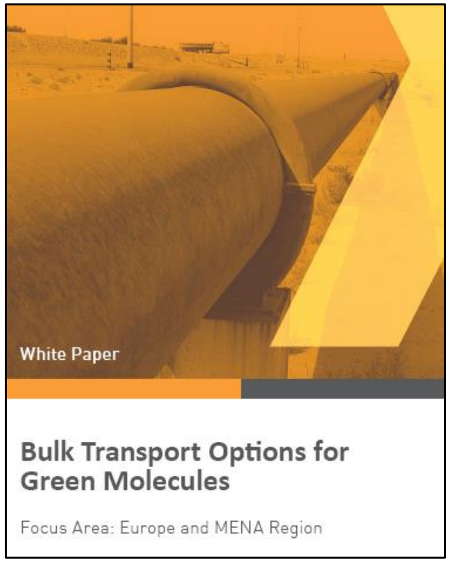


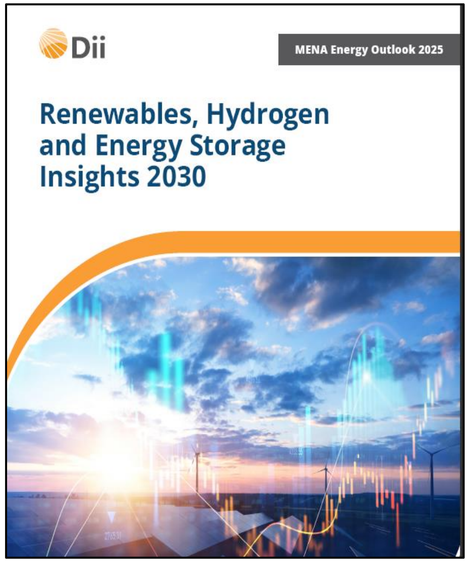
Dii Desert Energy publications in this field

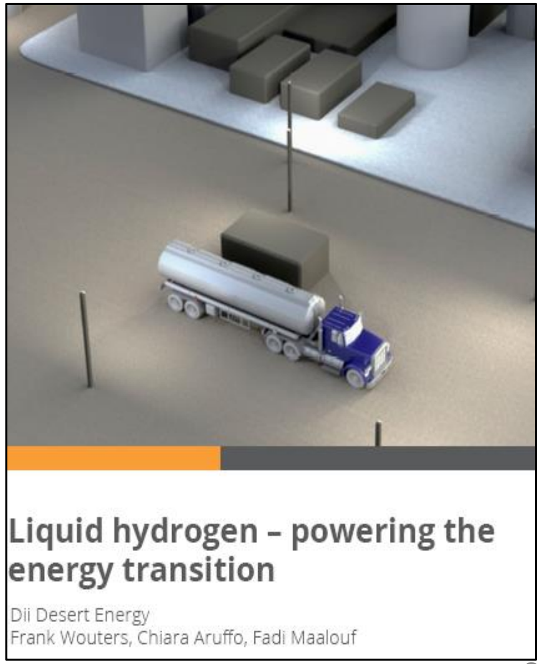












Take-aways

Location, logistic configuration and operational mode of new electrolysers is a strategic **system architecture** question → Appropriate coordination between hydrogen projects and electric/gas grid development is needed to ensure compatibility and optimality at energy system level **(NOT JUST A NEW CONNECTION REQUEST)**

Large electrolysers can become relevant flexibility providers: demand response, ramping as well as storage features for short and long duration, competing with other sources

Green labelling conditions are relevant for system planning and flexibility provision; supply and demand of green H2 should proceed in parallel

Grid planning requires joint scenarios and coordinated planning across sectors (electricity-gas-hydrogen), which should include imports from outside EU → MENA as well as non-electrolysers hydrogen

Win-win solution between electrolysers' business case and the needs of the system