Flexibility from Power-to-Hydrogen (P2H2) Webinar

A public stakeholders webinar

Online, 01 February 2023, from 14:30-16:30h

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Reliable Sustainable Connected

Flexibility from Power-to-Hydrogen (P2H2) Webinar

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Moderators

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Integrated Systems Manager, ENTSO-E

Siddhesh Gandhi
Innovation Specialist, ENTSO-E

Webinar Agenda

Moderator: Siddhesh Gandhi & Ioannis Theologitis, ENTSO-E

#	Subject	Presenter	Time
1.	Welcome & introduction to flexibility from Power-to-Hydrogen (P2H2)	Presentation of agenda and opening poll by Moderator	14:30 - 14:40 (10min)
		Opening remarks – *Håkon Borgen, RDIC Chair, ENTSO-E*	14:40 - 14:45 (5min)
2.	Session 1: Trends and projects for electrolysers deployment	Hydrogen market deployment and needed infrastructure – *Grzegorz Pawelec, Hydrogen Europe*	14:45 - 14:55 (10min)
		Scaling up green Hydrogen production projects to enhance power system flexibility - *Alexandre Oudalov, T&D Europe*	14:55 - 15:05 (10min)
	Slido Q&A	Moderator	10 min
3.	Session 2: Assessment of technical capabilities of electrolysers to provide grid system services	Technical characteristics of electrolyser technology & capabilities of providing system services - *Christos Dikaiakos, ENTSO-E*	15:05 - 15:15 (10min)
	Hydrogen for long term flexibility (Power System View)	P2H2 & VRES Curtailment; potential role of hydrogen in the broader energy systems - *Antonio Iliceto, ENTSO-E*	15:15 - 15:25 (10min)
	Hydrogen for long term flexibility (Hydrogen Business View)	Role of H2 supply chain in energy system flexibility – *Alexandre Oudalov, T&D Europe*	15:25 - 15:35 (10min)
		Hydrogen as a key enabler of system flexibility and *adequacy – Joerg Kerlen, Hydrogen Europe*	15:35 - 15:45 (10min)
	Slido Q&A	Moderator	10 min
4.	Session 3: Electrolyser business models, barriers, assumptions, and recommendations	Panel discussion with 5 speakers + moderation by ENTSO-E	15:55 - 16:25 (30min)
5.	Closing remarks	Norela Constantinescu, *Head of Innovation Section, ENTSO-E*	16:25 - 16:30 (5min)

Housekeeping rules

1. Audio

- Participants are muted by default
- Speakers will be asked to switch Audio OFF when not talking

2. Participants' Questions

Participants are invited on Slido to

✓ Directly post their question, comments on Slido tool

✓ Answer poll throughout webinar

⊗ No questions in Teams Chat

No hand raised

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3. Recording

- This webinar is recorded. The video and presentation will be made available after the webinar on event's dedicated site as well as ENTSO-E YouTube channel

Multiple-choice poll

I represent:
(1/2)

157

Transmission System Operator
29 %

Distribution System Operator
3 %

Policy maker
6 %

RD&I Institution, University
22 %

Hydrogen Business Operator
11 %

Generator
13 %

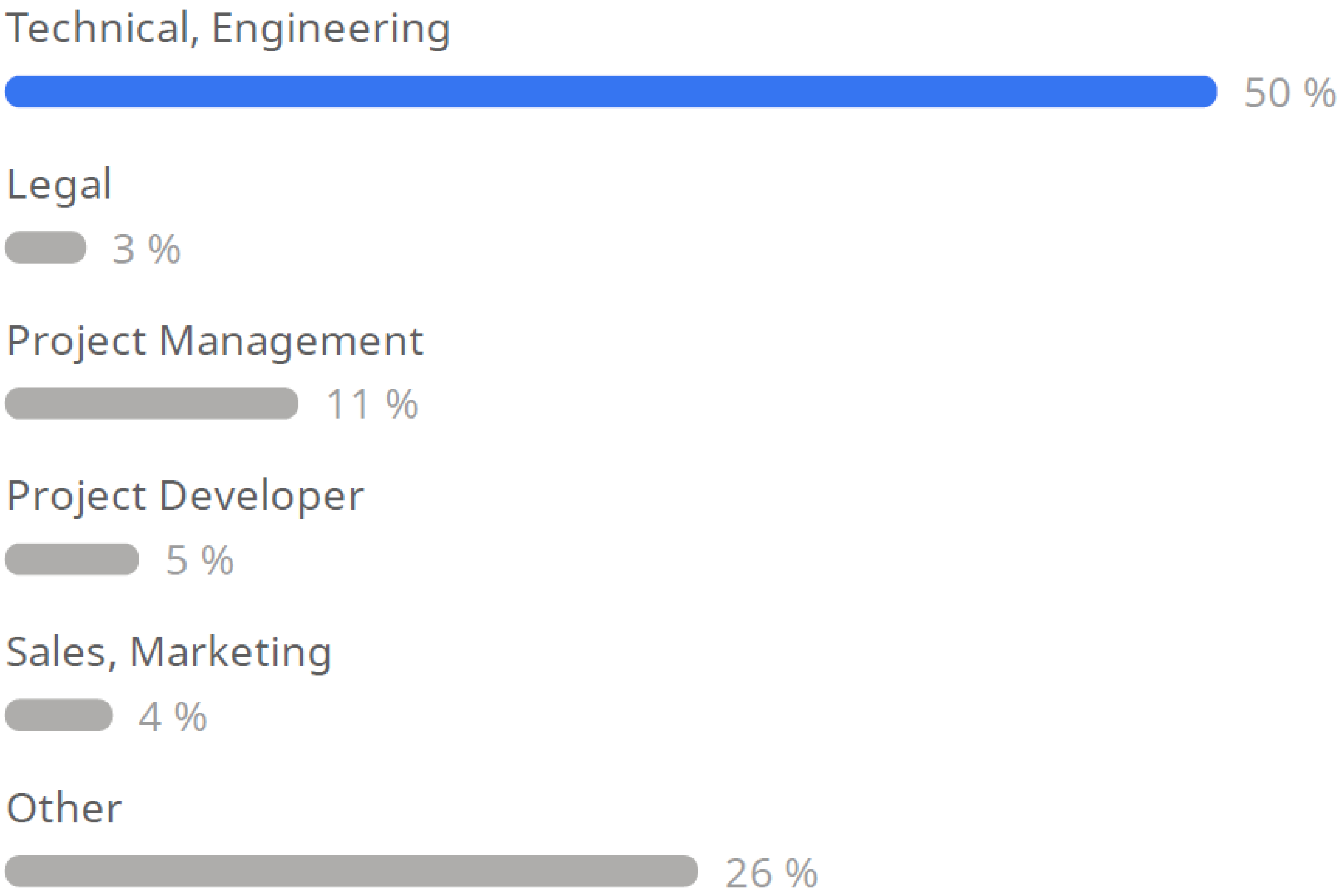
Manufacturer, technology provider/vendor
11 %

Consumer
4 %

Multiple-choice poll

My role is:

171



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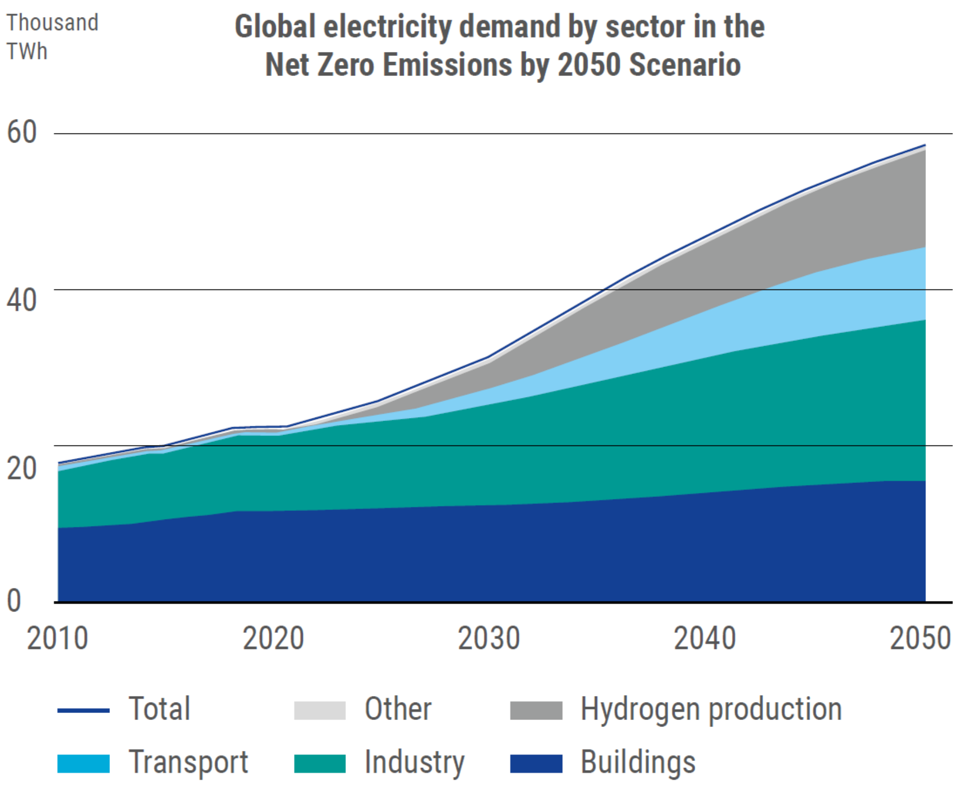
Welcome & introduction to flexibility from Power-to-Hydrogen (P2H2)

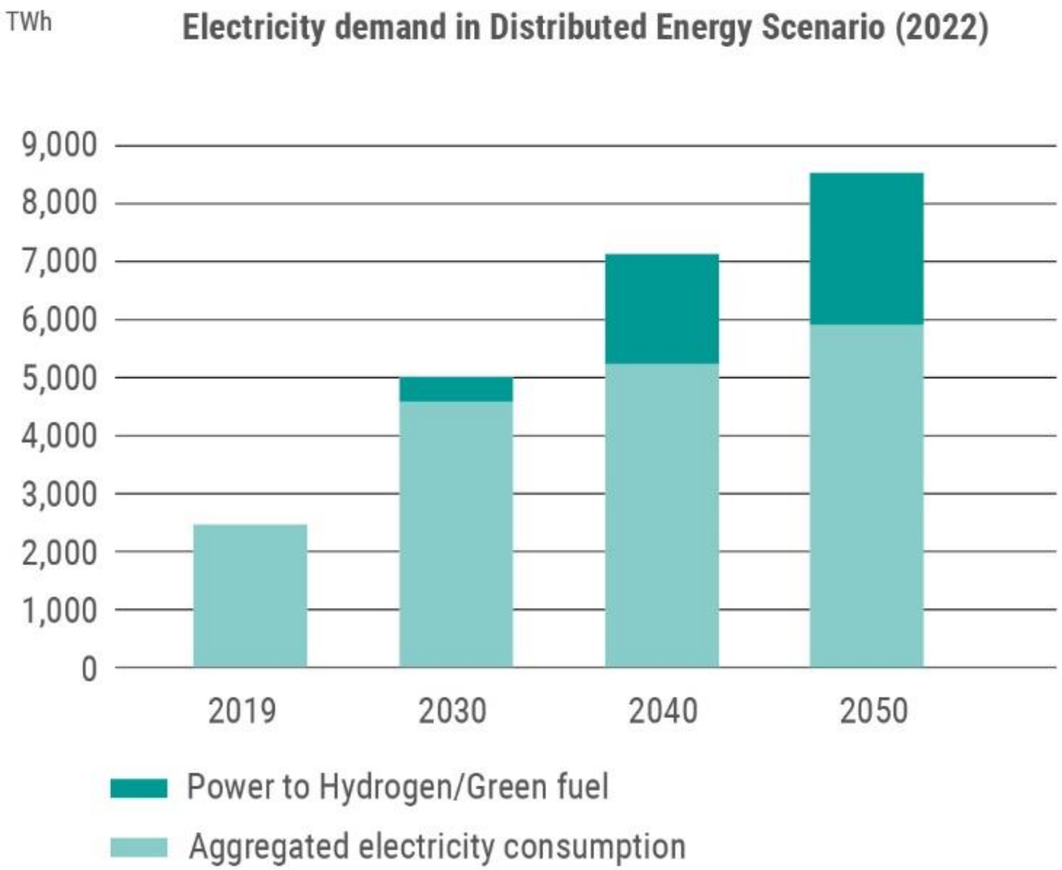
Opening remarks, *Håkon Borgen, ENTSO-E RDIC Chair*

TIME: 5 mins

A carbon neutral Europe needs a much more electrified economy

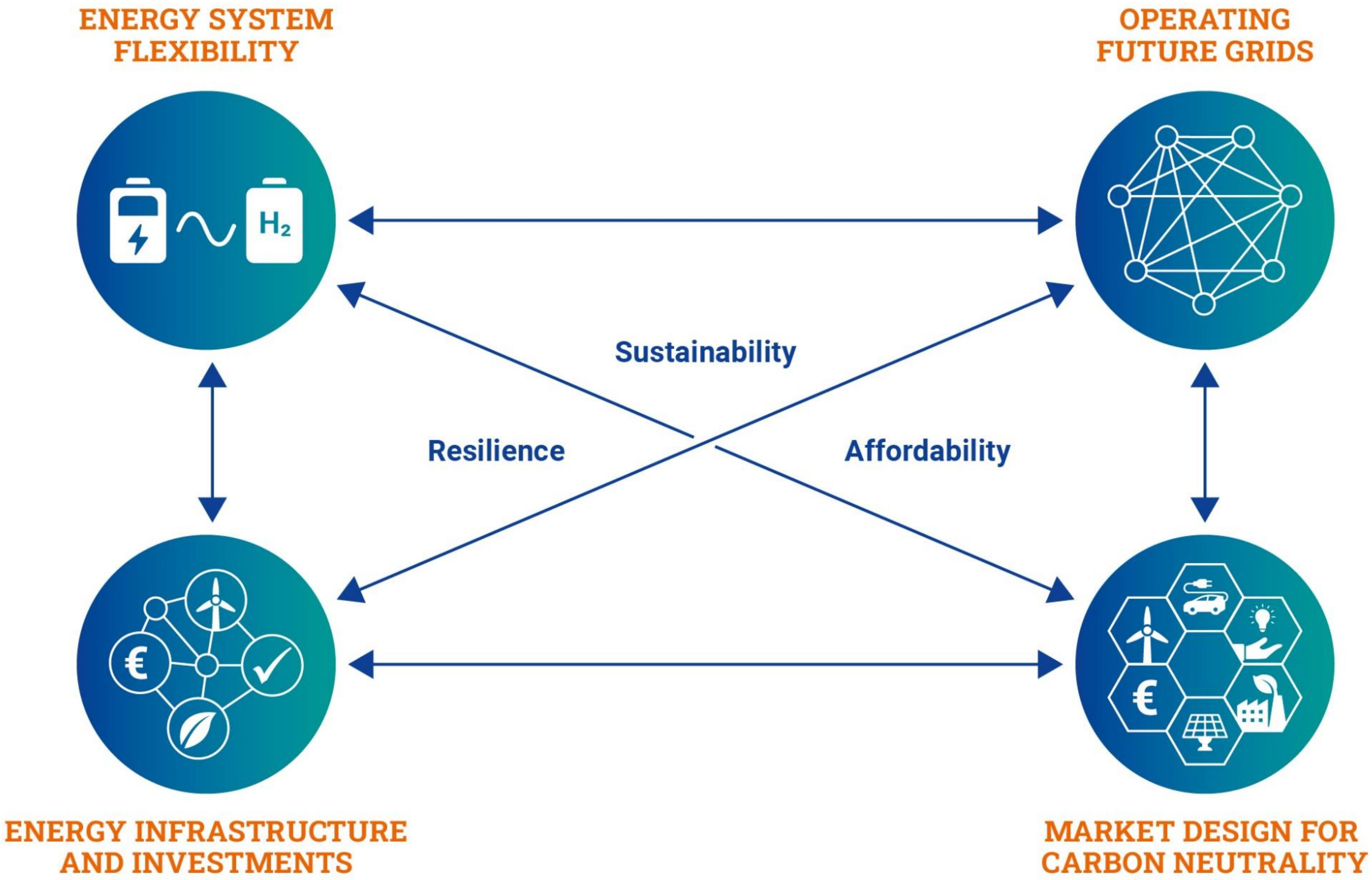


International Energy Agency model for Net Zero.

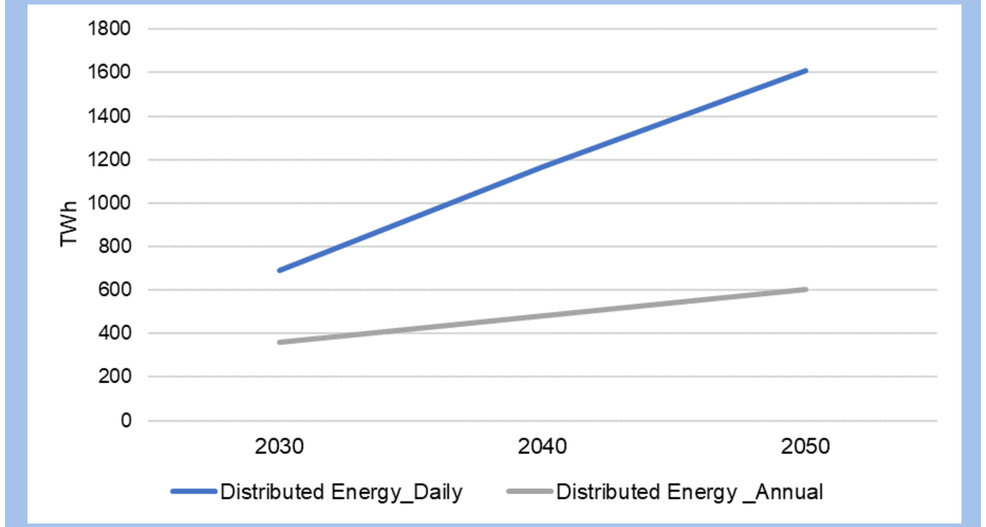


Electricity demand in ENTSO-E countries

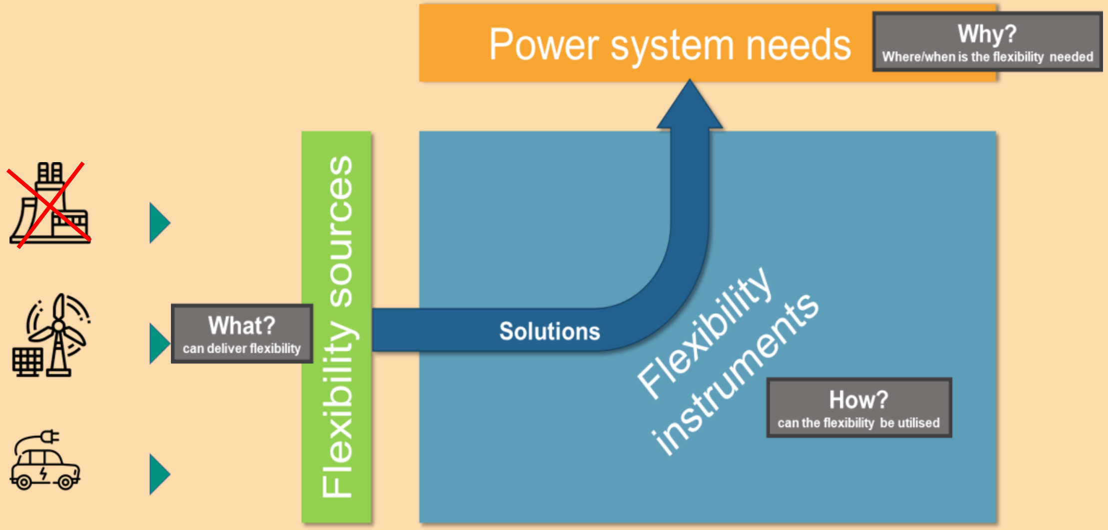
A Vision for Carbon neutral Europe based on 4 Key "Building Blocks"



A fully carbon neutral energy system requires a significant amount of flexibility



In a fully carbon neutral system, large scale flexibility will be essential to complement weather-dependent generation and to manage increased complexity and electrification



- **Short duration flexibility,** to cope with the natural variability of renewables and forecast errors, from milliseconds to several hours.
- **Long duration flexibility,** to deal with low wind and solar energy availability lasting several days to several weeks.

Accelerated innovation is key on priority actions

In spotlight: Optimal cross-sector planning

Data driven services

FOCUS TOPICS
for
ACCELERATION

1. Faster electrification of transport
2. Optimal cross-sector planning (incl. storage & H_2)
3. Need for flexibility & its value at all timeframes
4. Improved modelling & management of extended datasets
5. Multi-vendor, multi-terminal offshore solutions
6. New system stability management approach
7. Fully automated decision support system

Flexibility from P2H2

Electrolysers can provide a wide range of services and long-term storage potential

ENTSO-E RDI Implementation Report2021 – 2025: link
Study on Flexibility from Power-to-Hydrogen: link

Session 1: Trends and projects for electrolysers deployment

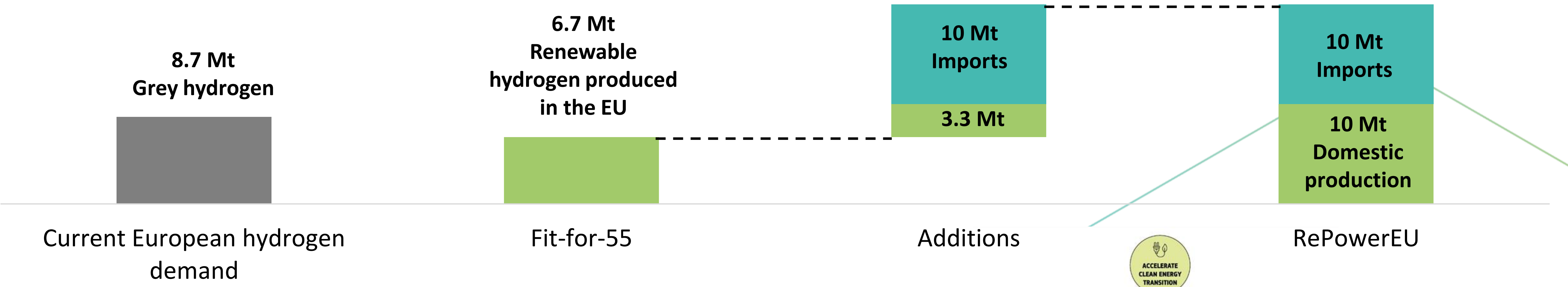
Hydrogen market deployment and needed infrastructure –
Grzegorz Pawelec, Director Intelligence, Hydrogen Europe

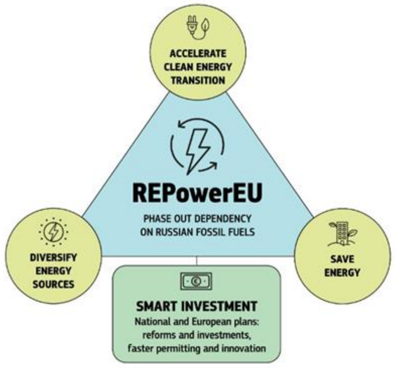
TIME: 10 mins

High renewable hydrogen ambitions

EU Commission has put forward ambitious goals for renewable hydrogen production in the EU

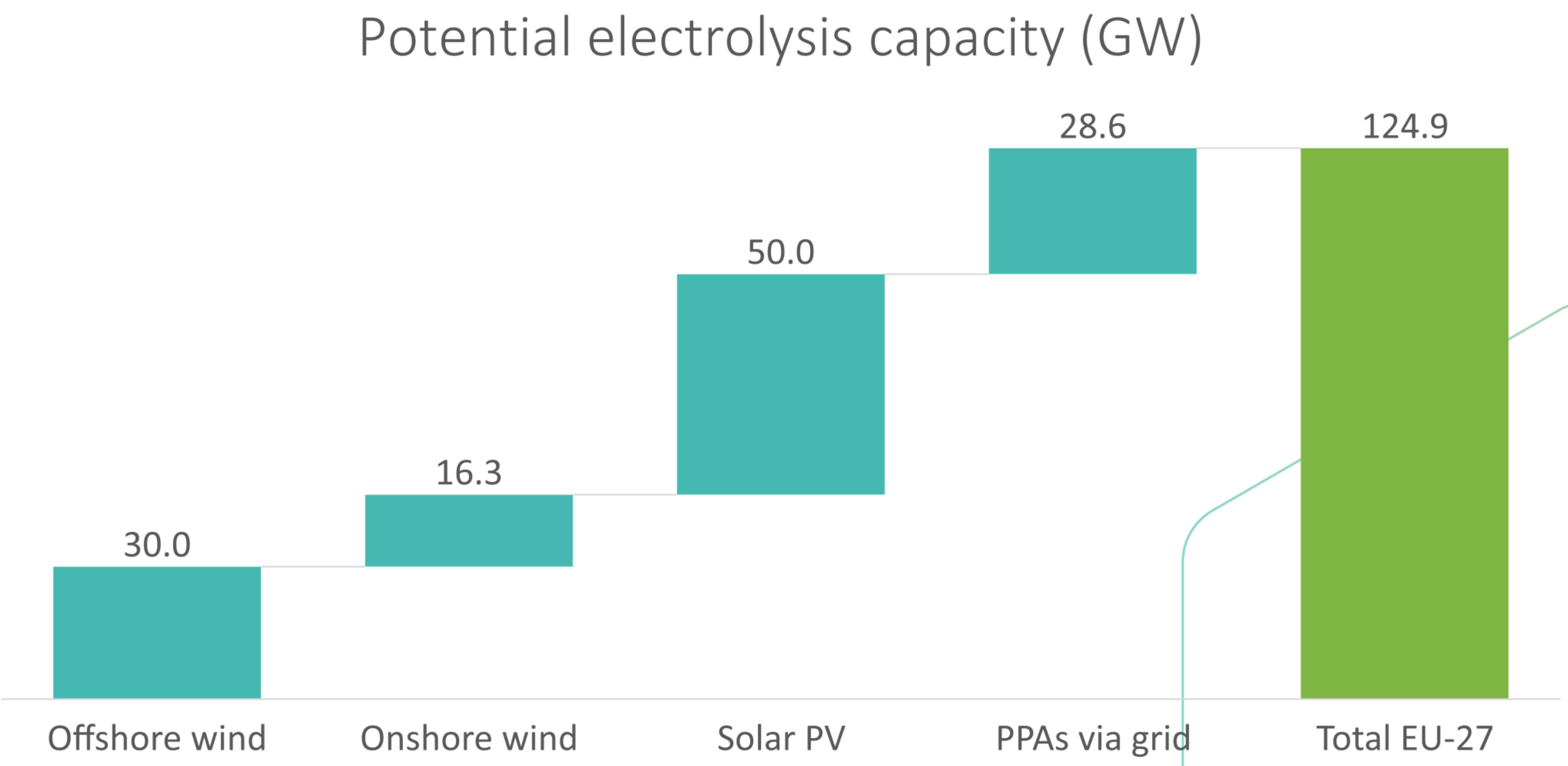
- Up to 10 Million tonnes of renewable hydrogen targeted by the European Commission in REPowerEU in order to reduce energy dependence on Russia





REPowerEU – production scenario

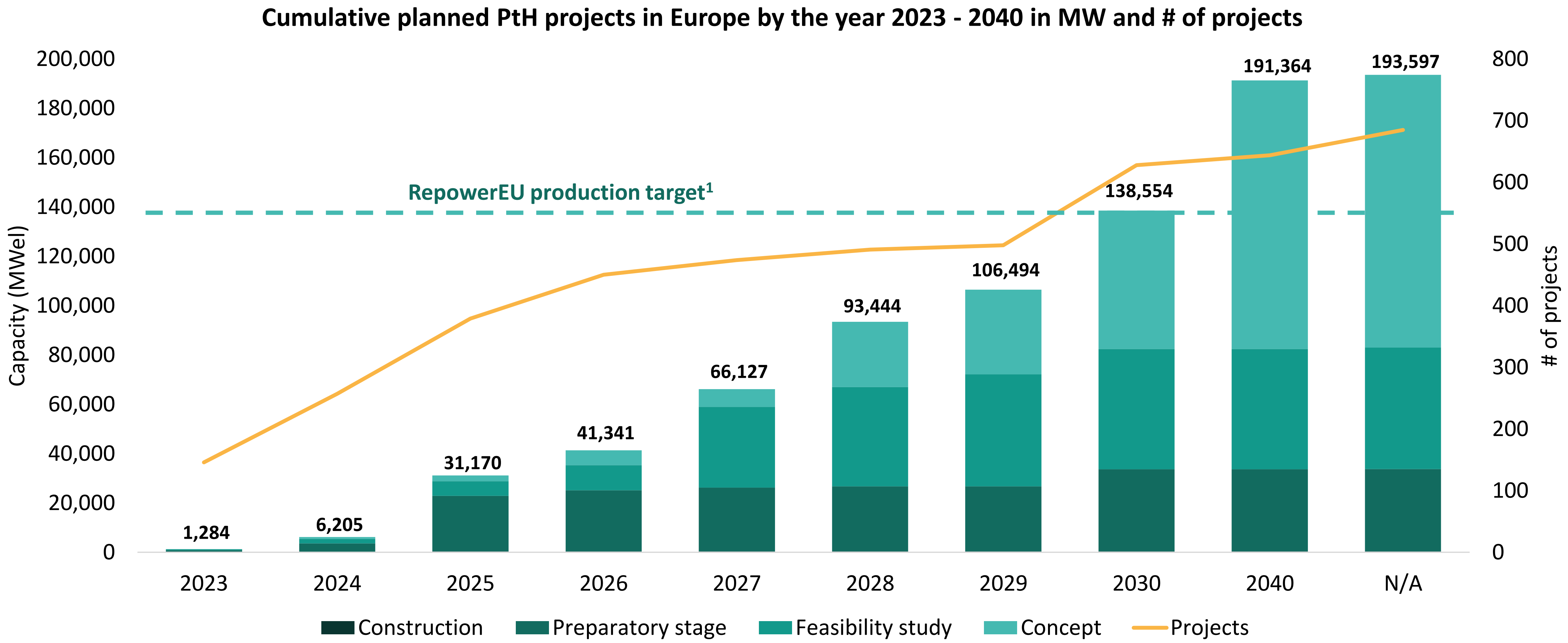
Depending on renewable power mix, reaching REPowerEU goals might require even up to 120-130 GW



Planned power-to-hydrogen project pipeline

Industry plans match EU ambition

Last update: 31/08/2022



Notes: Individual phases with separate FIDs are counted as separate projects

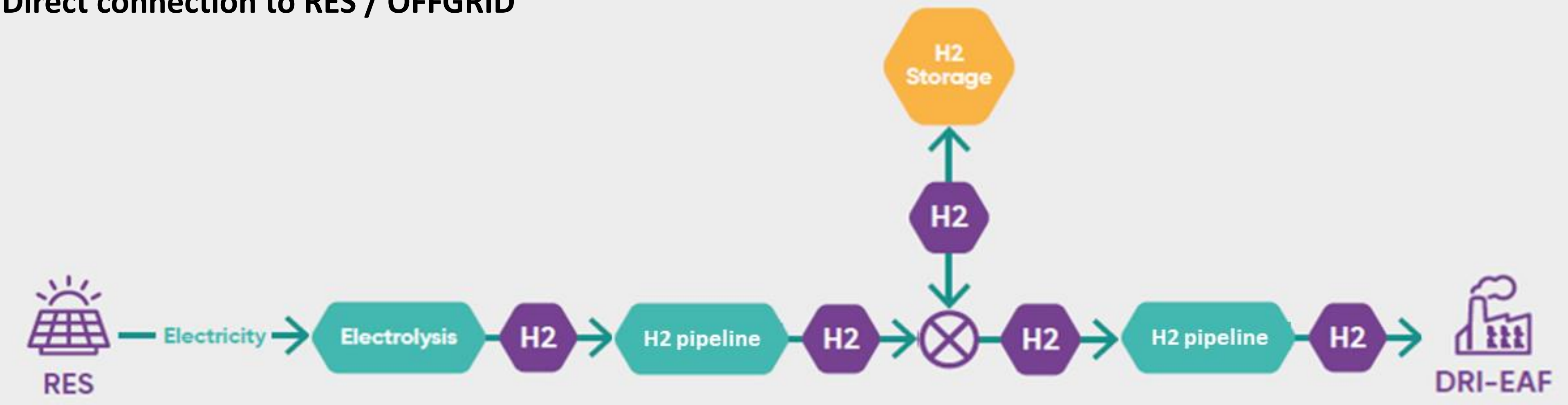
1. Translating 10 Mt of European renewable hydrogen production into installed electrolysis capacity depends on utilization and efficiency assumptions. For PtH projects connected to the electricity grid, an electrolyser capacity factor of 68% was assumed. Country-specific utilisation factors for different electricity sources have been used to calculate expected production for directly connected projects. The values can be underestimated as they do not consider increasing electrolysis efficiency up to 2030, increasing renewable generation utilisation up to 2030, and oversizing renewables directly connected to electrolysers, which are expected to constitute almost 62% of the current planned capacity by 2030.

Source: Hydrogen Europe

Electrolysers directly connected to RES

Not all electrolysers will be equally suitable to provide flexibility to the power system

Direct connection to RES / OFFGRID



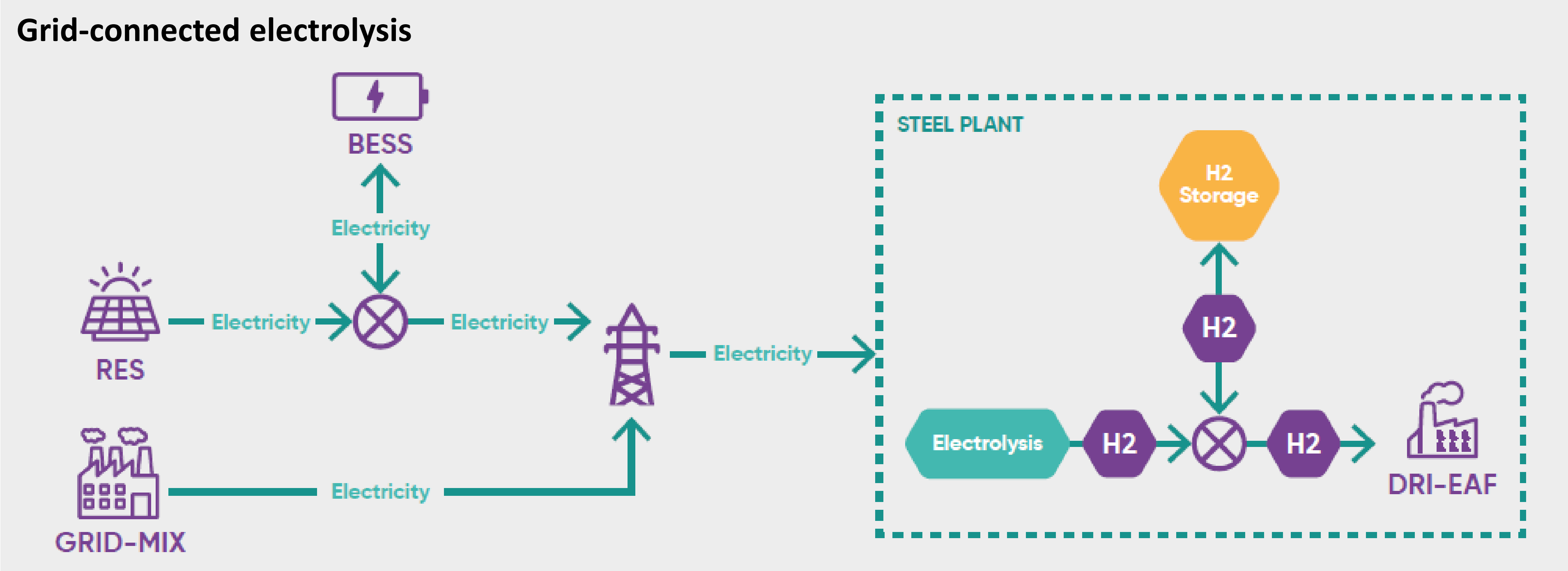
INTERACTIONS WITH THE POWER GRID

- Potentially entirely off-grid electrolysis
- Incentives needed to facilitate for grid connection
- Large scale H2 storage capacity needed to balance variable renewable hydrogen supply with constant industrial demand – up to 120 TWh* available for seasonal energy storage

* Source: Deloitte Finance – IFPEN – Carbon Limits – SINTEF, Hydrogen4EU, Renewable Push scenario, 2022

Electrolysers near demand site

Not all electrolysers will be equally suitable to provide flexiblity to the power system



INTERACTIONS WITH THE POWER GRID

- Potentially limited storage capacity
- Electrolyser connected to the grid – potentially available to provide anciliary services
- Decisive impact of temporal correlation requirements

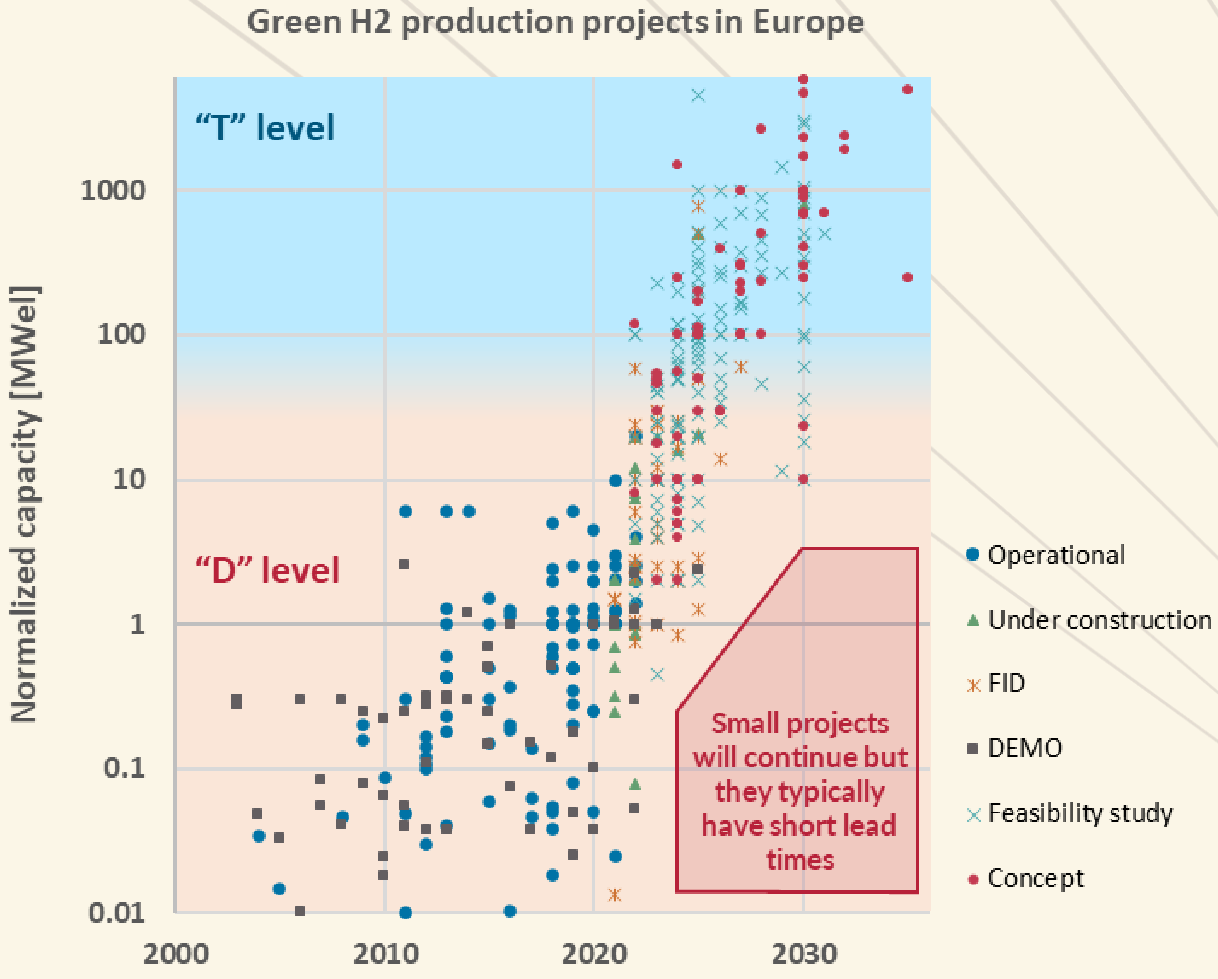
Session 1: Trends and projects for electrolysers deployment

Scaling up green hydrogen production projects to enhance power system flexibility – ***Alexandre Oudalov, Member, T&D Europe***

TIME: 10 mins

ROLE OF HYDROGEN IN A NET-ZERO FUTURE

- Direct electrification is a priority path for the most energy efficient solution
- More than 680 large-scale hydrogen projects have been announced globally as of May 2022
- Projects with the lower risk of stranded costs should be prioritized
- Boosting green hydrogen use should be embedded within Smart Sector Integration
- Flexible operation of electrolyzers in power systems with high share of variable RES may bring additional value



Source: Hydrogen Council Decarbonization Pathways; IEA

FLEXIBLE ELECTROLYZER OPERATION IS EXPLORED IN MULTIPLE DEMONSTRATION PROJECTS

PROJECTS TO PROVIDE GRID SERVICES

1 HyBalance

- 1.2 MW PEM electrolyzer serves clean transport and industry markets.
- Reactivity: Ramp-up rates from 10% to 100% of 1 sec and ramp-down rates of a few seconds
- Flexibility: Down ramping to 10%, not optimized for 5% or even 0%
- Certified by the Danish energy authorities as bidder in all electricity markets

3 H2FUTURE

Green Hydrogen

- 6 MW PEM electrolyzer serves steel production
- Ramping up/down of 1MW reached in 8 sec, half-load from zero reached in 75 sec.
- Minimum load requirement limits the regulation range
- Certified by the Austrian energy authorities as bidder in all electricity markets

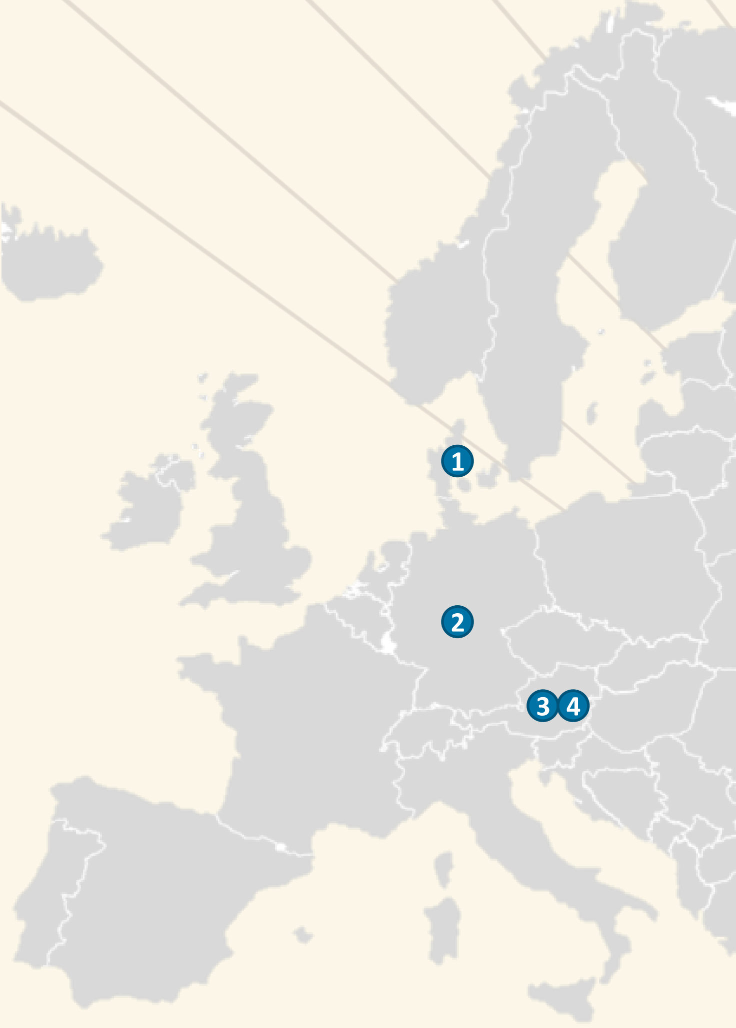
2 REFHYNE

CLEAN REFINERY HYDROGEN FOR EUROPE

- 10 MW PEM electrolyzer serves refinery
- Grid and load balancing via flexible and rapid response
- SCR found to be more lucrative compared to PCR (2018)

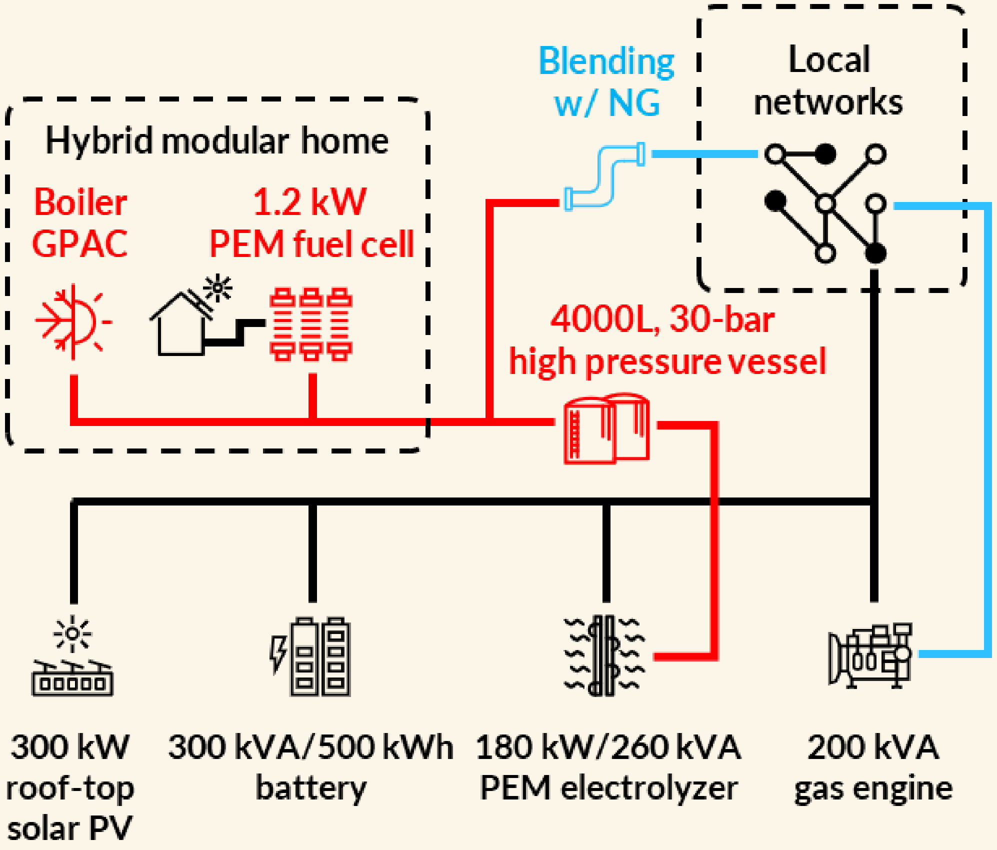
4 DEMO 4GRID

- 3.2 MW pressurized alkaline electrolyzer serves retail food site including delivery trucks
- Technical results from grid services operation yet need to be validated at real-scale



ATCO'S CLEAN ENERGY INNOVATION HUB

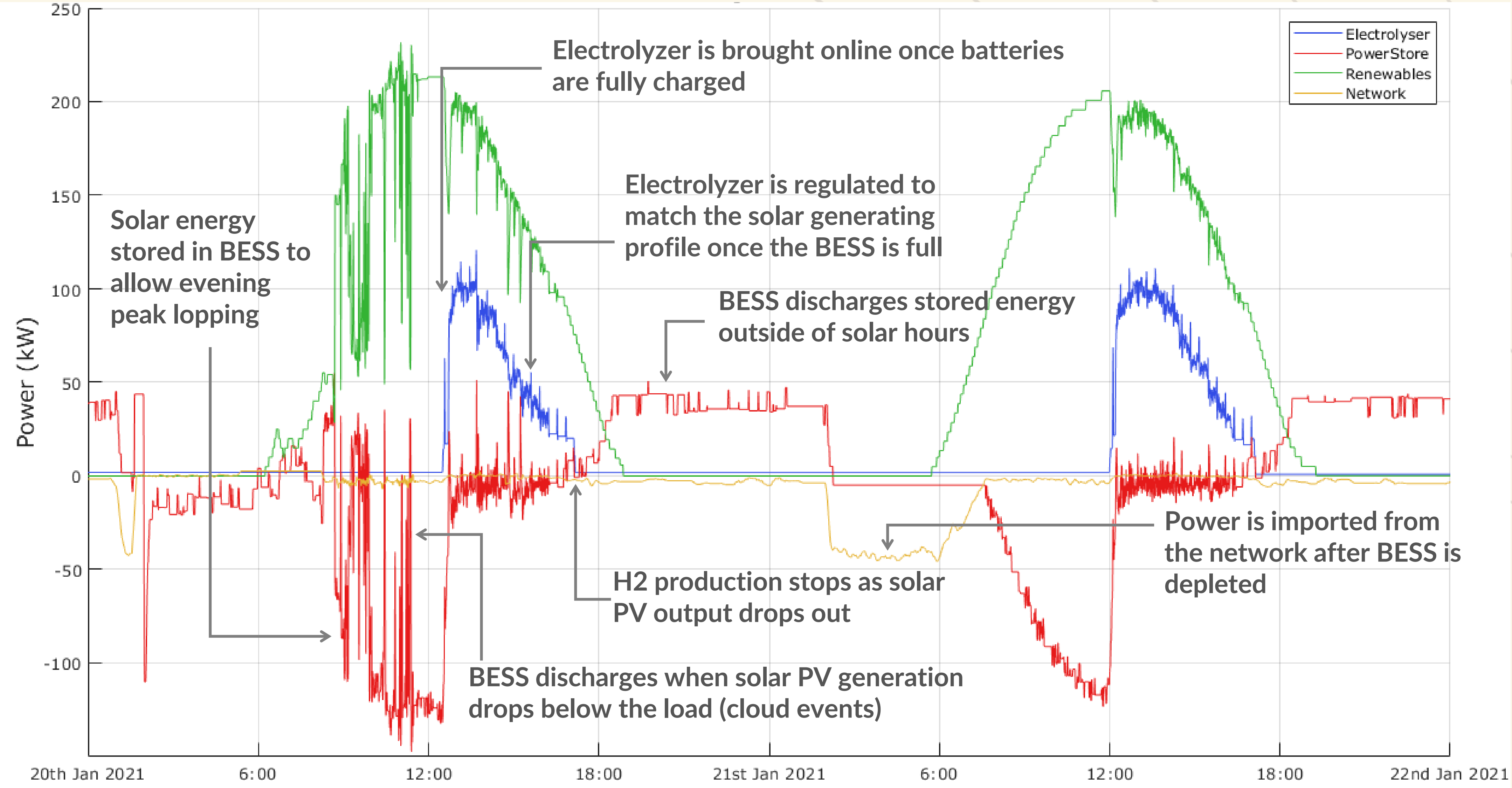
Main goal: operate a hybrid microgrid to maximize RES hosting capacity, enhance reliability and run 100% green hydrogen production



180 kW/260 kVA PEM electrolyzer (left) and 4000L 30-bar high-pressure hydrogen storage vessel (right)

Source: ATCO

ATCO’S CLEAN ENERGY INNOVATION HUB



ELECTROLYZERS FOR EVERY SCALE

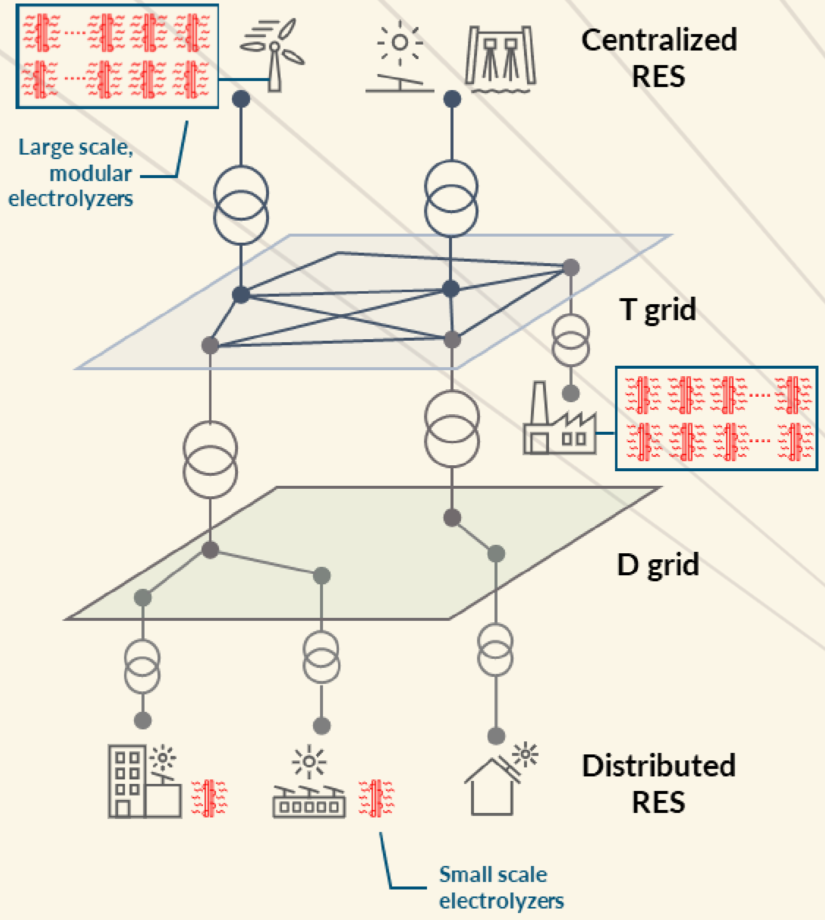
SMALL VS LARGE SIZE

SMALL SCALE ELECROLYZERS 1-10 MW

- Connected to the distribution grid
- Higher cost for a direct market participation
- Fixed electricity tariffs/PPAs
- Potential services provided:
  - Peak Load Management*
  - Local Voltage Support
  - Congestion Management*
  - Frequency Control (stand alone or via an aggregator)

LARGE SCALE ELECROLYZERS 100-1000 MW

- Connected to the transmission grid
- Lower cost for a direct market participation
- PPAs
- Potential services provided:
  - Frequency Control
  - Voltage Control
  - Congestion Management*



***) Can be limited by a mandatory requirement to follow variable renewable generation**

What are the major gaps on delivering large-scale P2H2 projects that needs to be prioritized and accelerated?

1 0 2

regulation
The cost of electrolyzers
System Control/Protection
storage
Additionality
grid capcity
CO2BATTERY
tariffs
profitability
viability
opex
Infrastructure
LDES
regulatory stability
price
Grid capacity
interconnection
permitting
Regulatory framework
Incentives
CO2 battery
Economics
sufficient RES production
Price transparency
Rawmaterial

Session 2: Assessment of technical capabilities of electrolysers to provide grid system services

Technical characteristics of electrolyser technology & capabilities of providing system services – Christos Dikaiakos, *Expert, ENTSO-E*

TIME: 10 mins

Electrolysers capabilities of providing system services

Technical characteristics of electrolysers technology

We analysed three different P2H2 technologies – not all are at the same level of technological maturity

	Alkaline	PEM	SOEC
Cost, lifetime and efficiency*	▪ Typical capex is in the range of 700 €/kWe today and is expected to decrease slightly. ▪ Efficiency ranges from 63-70% and is expected to increase slightly over the next decade.	▪ Typical capex is c. 1,200 €/kWe today but is anticipated to fall and be broadly similar to AEL costs by 2030. ▪ Efficiency is in the range of 61-70% and is expected to increase slightly over the next decade.	▪ Typical capex is c. 3,000 €/kWe and is expected to fall by more than 40%. ▪ Efficiency is in the range of 74-91% and is anticipated to increase further over the next decade.
Plant size	▪ Currently, Toshiba operates the largest alkaline electrolyser of **10 MW.** Future plant capacity is expected to increase up to **200 MW**.	▪ Air Liquide recently inaugurated a **20 MW** PEM electrolyser**.** Future plant capacity is expected to increase up to **200 MW**.	▪ Currently, the largest SOEC electrolyser has a capacity of **225 kW**. Future plants are anticipated to reach a capacity of **100 MW.**
Flexibility	▪ The start-up time is in the range **of 1 to 10 minutes.** ▪ Ramp-up / down response is **0.2 – 20 % / second**	▪ The start-up time is in the range of **1 second to 5 minutes.** ▪ Ramp-up / down response is **100% / second.**	▪ There is very limited information on SOEC electrolysers' characteristics with respect to flexibility.

Size and flexibility are the main characteristics that influence electrolysers' capability to provide system services

*Efficiency is defined as the energy output in H2 as a percentage of energy input in electricity

Electrolysers capabilities of providing system services

Identification of system services and their technical requirements

We have identified a set of system services. Then, for these services, we have listed some of the key technical features.

	Full Activation Time	Minimum Bid Size	Symmetry
Frequency Containment Reserves (FCR)	▪ 30 seconds	▪ 1 MW	▪ Yes
Automatic Frequency Restoration Reserves (aFRR)	▪ 5 minutes	▪ 1 MW	▪ No
Manual Frequency Restoration Reserves (mFRR)	▪ 12.5 minutes	▪ 1 MW	▪ No
Reserve Restoration (RR)	▪ 30 minutes	▪ 1 MW	▪ No
Voltage Control	▪ Few seconds to 15 minutes	▪ NA	▪ No
Services for Congestion Management	▪ 15 minutes	▪ 1 to 10 MW	▪ No

Electrolysers capabilities of providing system services

In theory, electrolysers could provide most system 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

Session 2: Electrolysers for long term flexibility (Power System View)

Long term flexibility, P2H2 & VRES curtailment; potential role of hydrogen in the broader energy systems –

Antonio Iliceto, Convenor of WG Future of Energy Systems, ENTSO-E

TIME: 10 mins

Many flexibility means available, inside and outside the electricity system …

Flexible Grid	Flexible generation	Flexible loads	Storage within electric system	Storage in other energy systems

- Extended use of grid components
-Interconnections
- Exchanges with neighbouring areas
	- Traditional plants' modulation
	- Enhanced ancillary services
	- Improved performances (ramps, response speed, capability range, start-stop sequences, duty cycles)
		- Demand response
		- Interruptible customers
		- Balancing services
		- Aggregators
		- Market & trading mechanisms
		- **Smart EV charging**
			- Grid batteries
			- Fly wheels
			- CAES/LAES
			- Supercapacitors / Supermagnetes
			- Pump Hydro
			- **Vehicle-to-Grid**
				-Thermal
				- Thermochemical
				- Desalination
				- Molecules:
				  - **H2 & green Gases**
				  - Liquid fuels
				  - Chemicals

Direct impact on grids / direct interaction with grid operators

Converted energy is managed by other operators

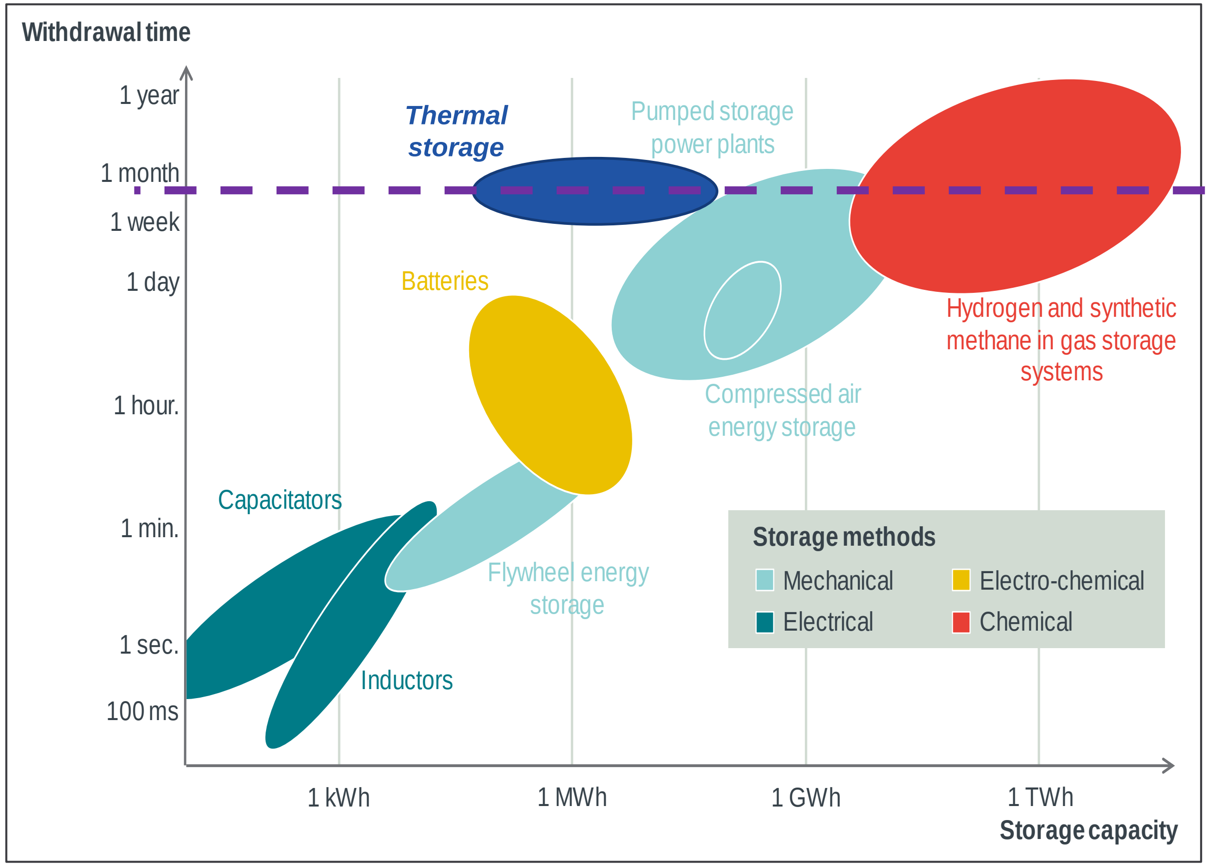
Many flexibility means available, inside and outside the electricity system …

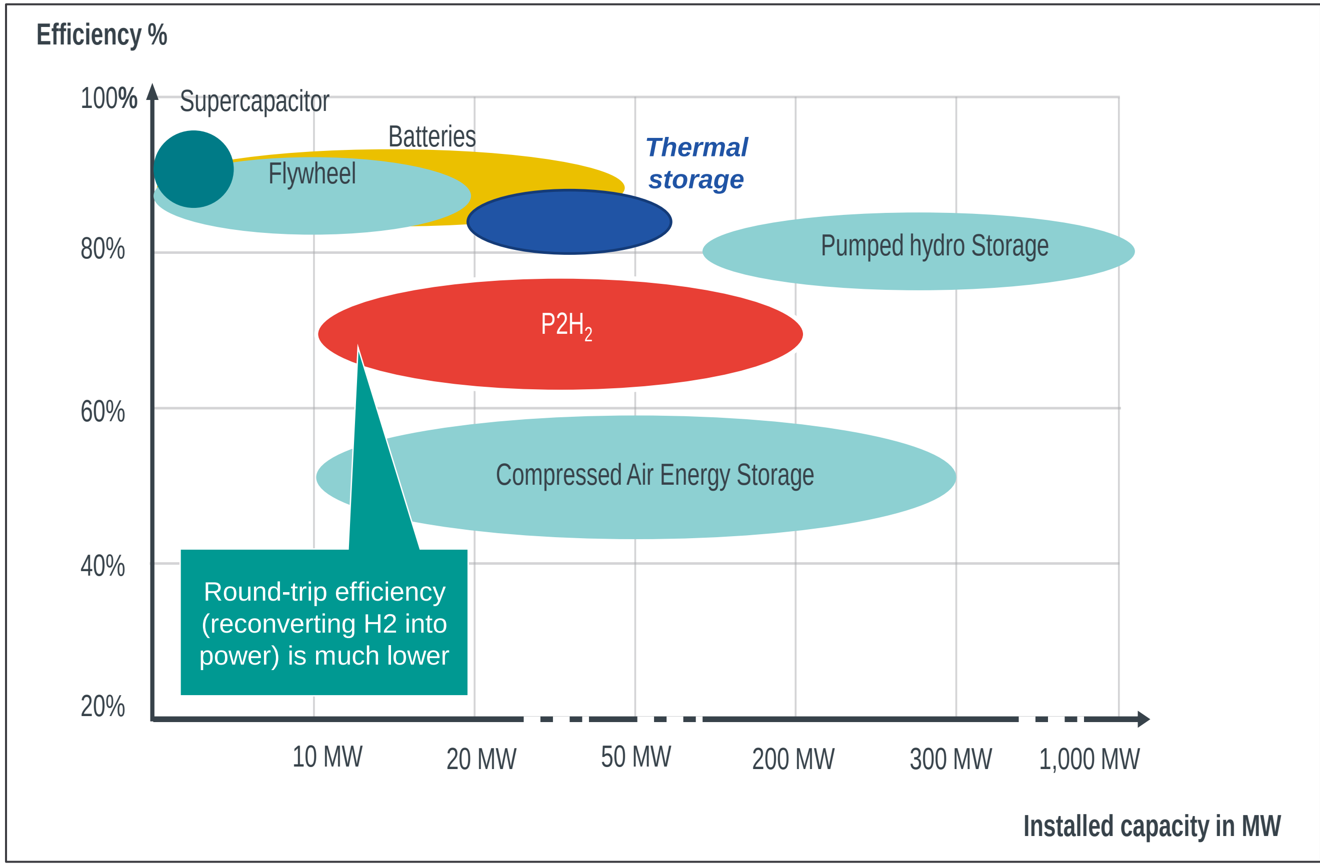
Flexible Grid	Flexible generation	Flexible loads	Storage within electric system	Storage in other energy systems
- Extended use of grid components -Interconnections - Exchanges with neighbouring areas	- Traditional plants' modulation - Enhanced ancillary services - Improved performances (ramps, response speed, capability range, start-stop sequences, duty cycles)	- Demand response - Interruptible customers - Balancing services - Aggregators - Market & trading mechanisms - Smart EV charging	- Grid batteries - Fly wheels - CAES/LAES - Supercapacitors / Supermagnetes - Pump Hydro - Vehicle-to-Grid	-Thermal - Thermochemical - Desalination - Molecules: - **H2 & green Gases** - Liquid fuels - Chemicals

- Main goal of power system management shall become:
  - Operation: how to **best <u>use</u> and <u>combine</u>** the many flexibility means available
  - Planning: efficient development of power grid in coordinated manner with other <u>indipendent actors and sectors</u>: not only generation and load, but also new services and new interfaces → infrastructure optimisation, avoiding stranded assets

Electrolysers for long term flexibility & broader energy system

… but few long duration flexibility means are available





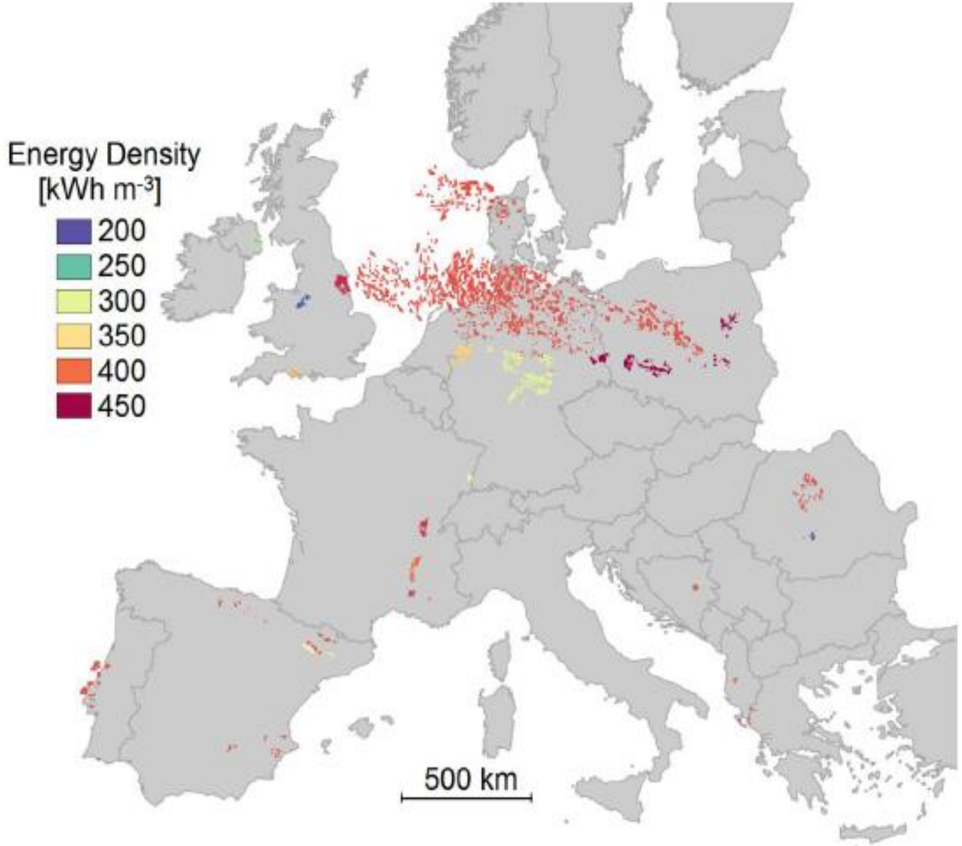
Pumped hydro sites in EU are already utilised; thermal storage is in development stage → molecules are a promising candidate

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

Electrolysers for long term flexibility & broader energy system

Long duration flexibility implies large storage potential, but not only

- **Several options for H2 / green gases storage: steel tanks, underground geological structures, transformation into liquid ammonia; pipelines line-pack is also providing flexible storage in H2 supply chain**
- **Underground include salt caverns, aquifer, depleted oil/gas fields**



- Large amount of technical storage potential in Europe (**~85,000 TWh** with 1,200 TWh currently used for CH4 storage).
- However:
  - **Timelines** for commissioning or reconversion estimated around 7-10 years
  - **Uneven location**, with most potential in Northern Europe and offshore.
- Flexibility requires not only storage but also transport capacity, logistic **infrastructures** and **flexible operational patterns**

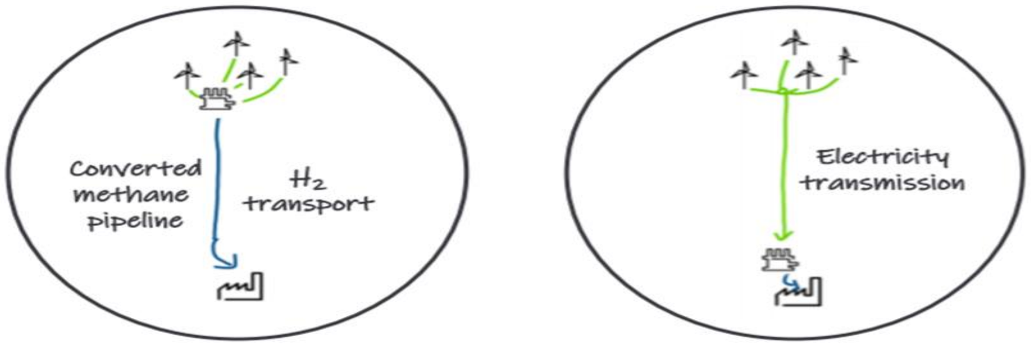
Flexibility depends also on electrolysers' location and operational modes

With electrolysers' CAPEX expected reduction, H2 cost will depend basically on the combination electricity price & capacity factor, i.e. on location and operational mode

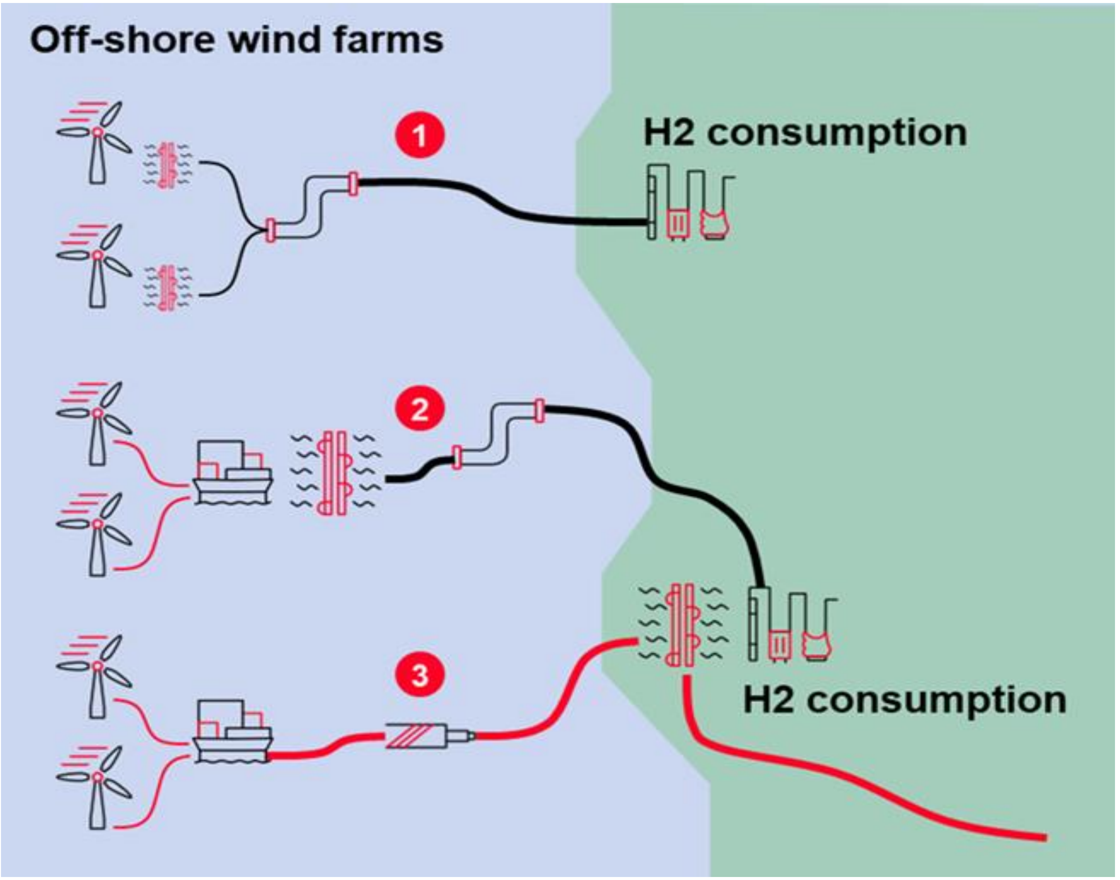
LOCATION OPTIONS

- On grid / Off grid
- Next to RES (transport of H2) / next to off-taker (transport of electricity)
- On site off-take (H2 valley) / remote off-take → requires H2 logistics

Off grid has no direct impact on power grid → no flexibility provision



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



Operational configuration and business cases

Non electrolyser H2

RES-dedicated Electrolysers (Off- Grid)

On-Grid electrolysers

User's demand driven (no storage/buffer elements *)

Market price driven (exploiting low or negative prices/ curtailment)

Baseload (with CO2-free electricity like gethermal or nuclear or PPA)

System supportive

**** 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***

Electrolysers for long term flexibility & broader energy system

Operational configuration and business cases

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

Electrolysers for long term flexibility & broader energy system

System value of electrolysers can be high and should be included in the business case

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)**

Important to assess also how much non-electrolyser Hydrogen and how much imported H2 will be produced → they reduce the impact on power grids

Green labelling conditions are relevant for system planning and flexibility provision:
- **Geographical** correlation: same country/same bidding zone ?
- **Time** correlation: at daily / 1h / 15 minutes granularity, rather than on yearly/monthly average ?

Additionality Principle? Need to **align evolution of additional RES capacity with new electrolysers**, to avoid cannibalisation in decarbonisation targets vs electrification of other end uses

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

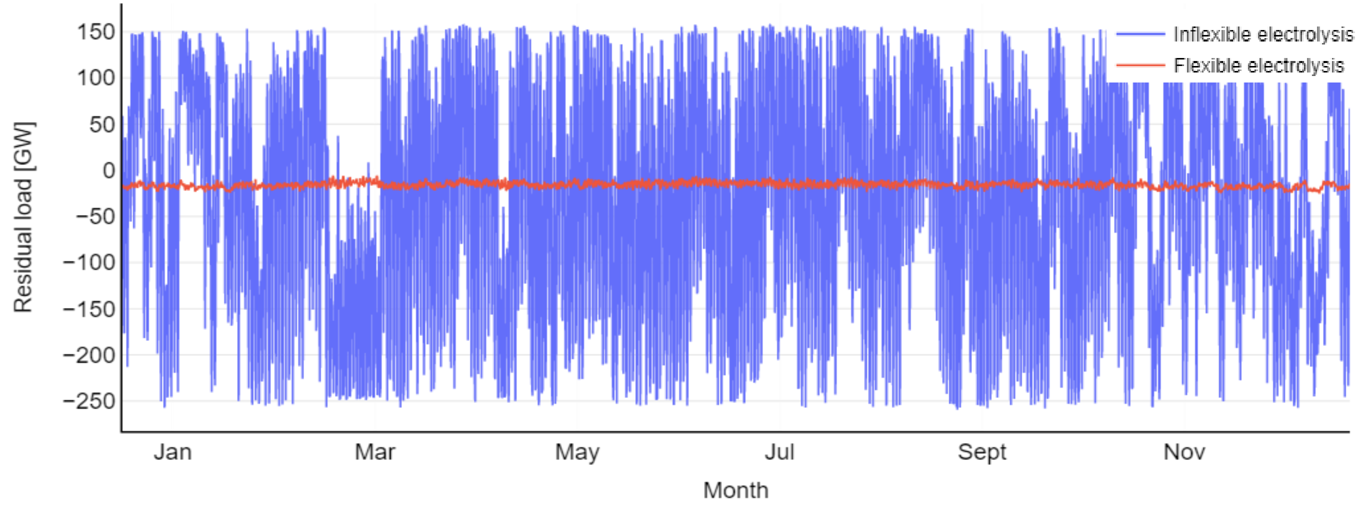
Session 2: Electrolysers for long term flexibility (Business View)

Role of Hydrogen supply chain in energy system flexibility – *Alexandre Oudalov, Member, T&D Europe*

TIME: 10 mins

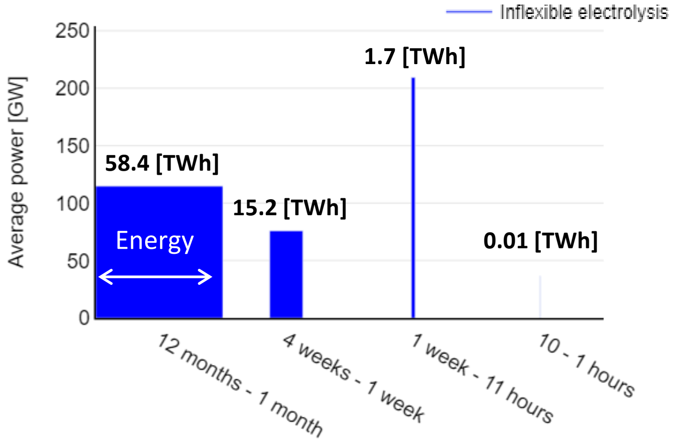
FLEXIBILITY NEEDS IN THE FUTURE ENERGY SYSTEM

- Residual load is the difference between the total demand (incl. electrolysis) and VRES electricity generation.
- There is a need in wide-range of flexibility options to balance supply-demand on time-scales ranging from intra-day to months.
- Flexible operation of electrolyzers decreases needs for other flexible technologies.



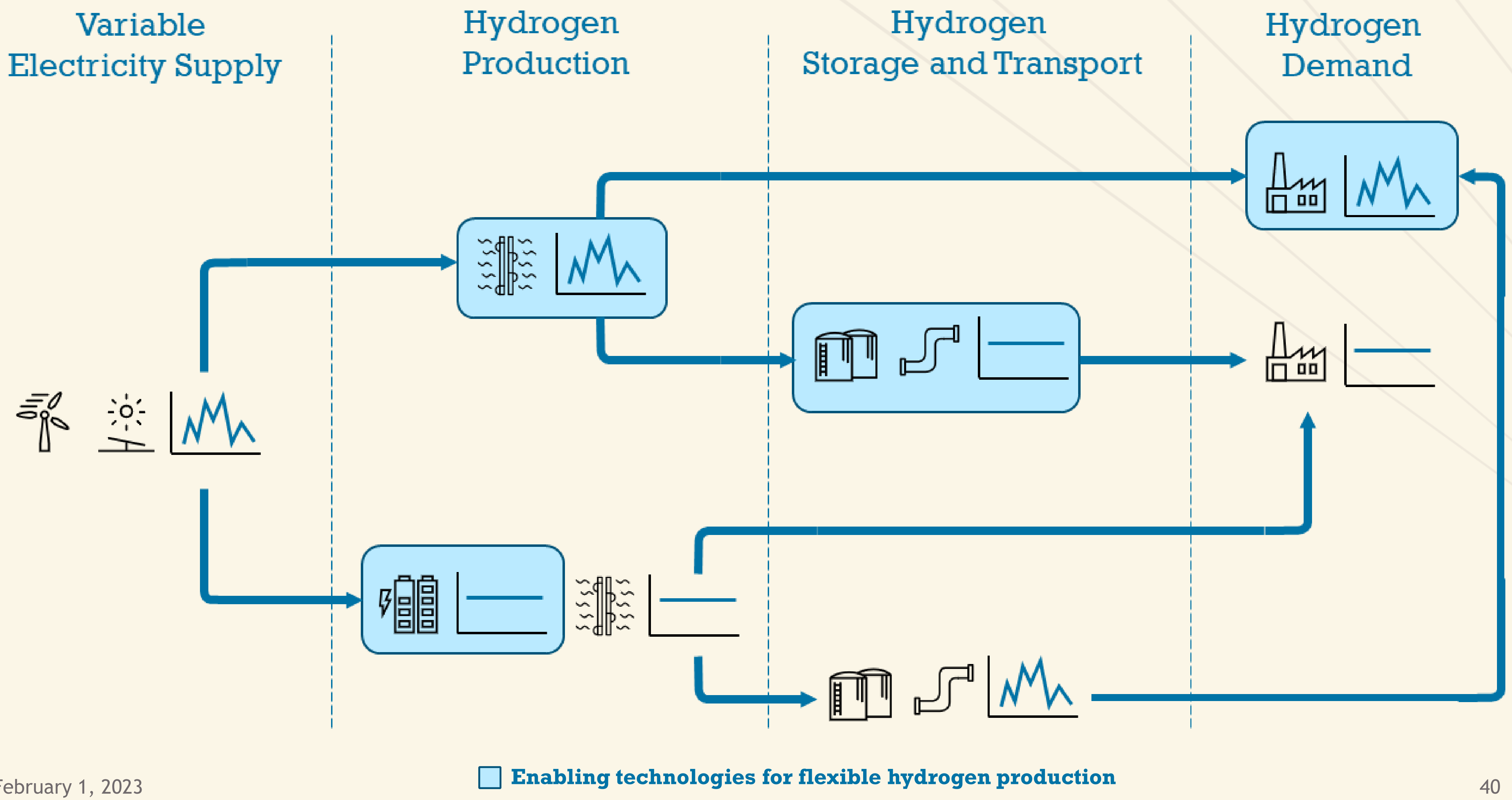
Flexibility needs in Europe by 2040

- In addition to electrolyzers, batteries and pumped hydro storage contribute to flexible operation. Their installed capacities are:
  - Batteries: 47.3 GW / 300 GWh
  - PHS: 56.5 GW / 450 GWh



Sources: PAC Scenarios; Hitachi Energy

HANDLING FLEXIBILITY AT DIFFERENT LEVELS



FLEXIBILITY NEEDS IN THE FUTURE - ELECTRICITY

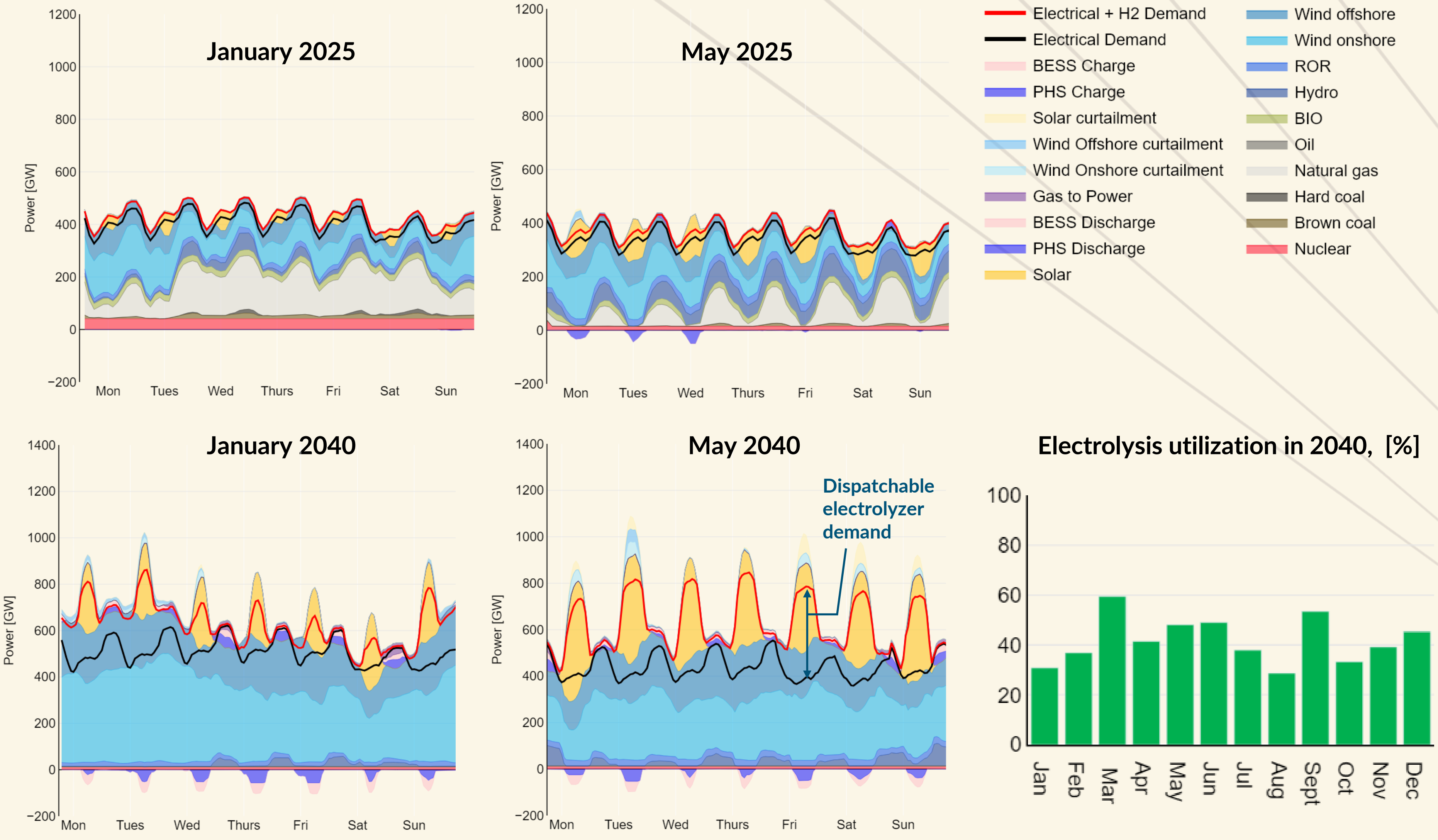
T&D europe

2025

- VRES cover a large portion of demand
- Natural gas, hydro and PHS are the main sources of flexibility

2040

- VRES become a dominant source of electricity
- Electrolyzers, energy storage and hydro are the main sources of flexibility
- ~2.7% of renewable energy is curtailed



 Sources: PAC Scenarios; Hitachi Energy

FLEXIBILITY NEEDS IN THE FUTURE - HYDROGEN

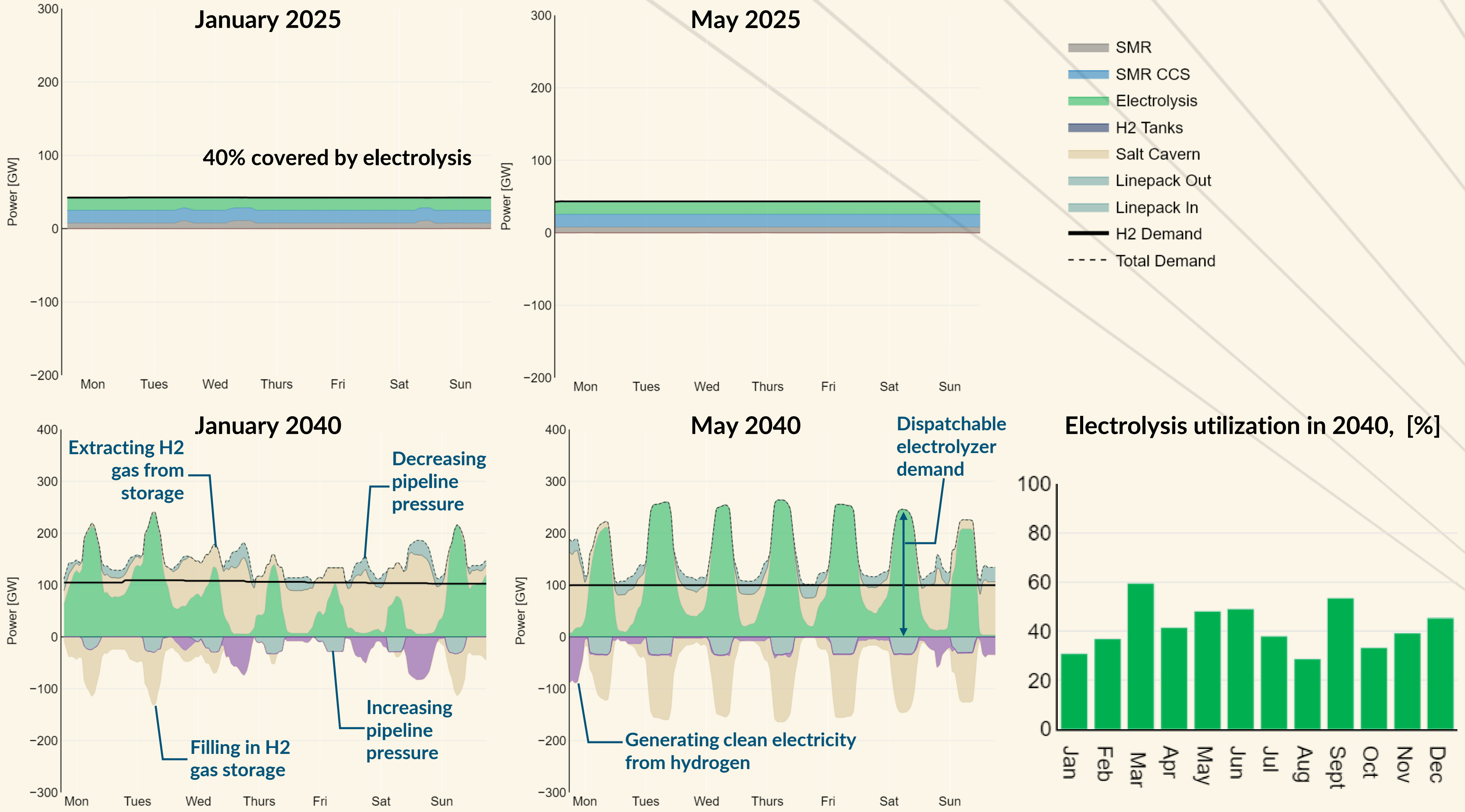
T&D europe

2025

- Electrolysis is the fastest growing source of hydrogen

2040

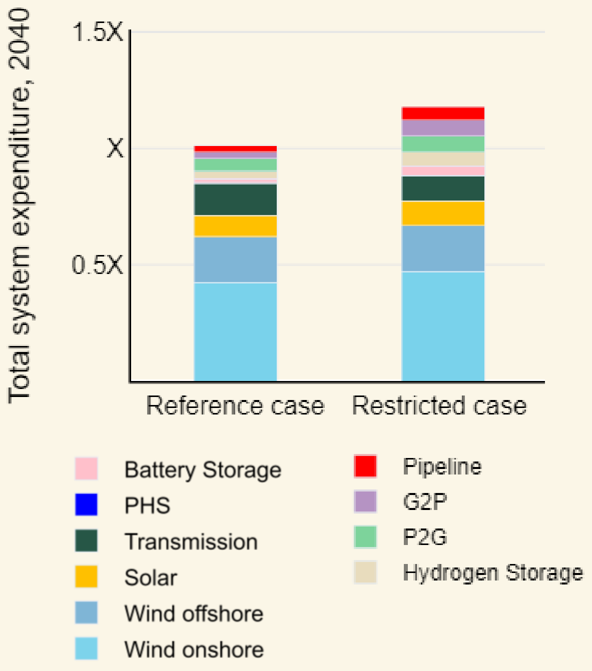
- Significant increase in H2 demand, 100% supplied by electrolysis
- Electrolyzers become important source of flexibility enabled by storage and linepack.
- They contribute to both diurnal and seasonal supply-demand balance

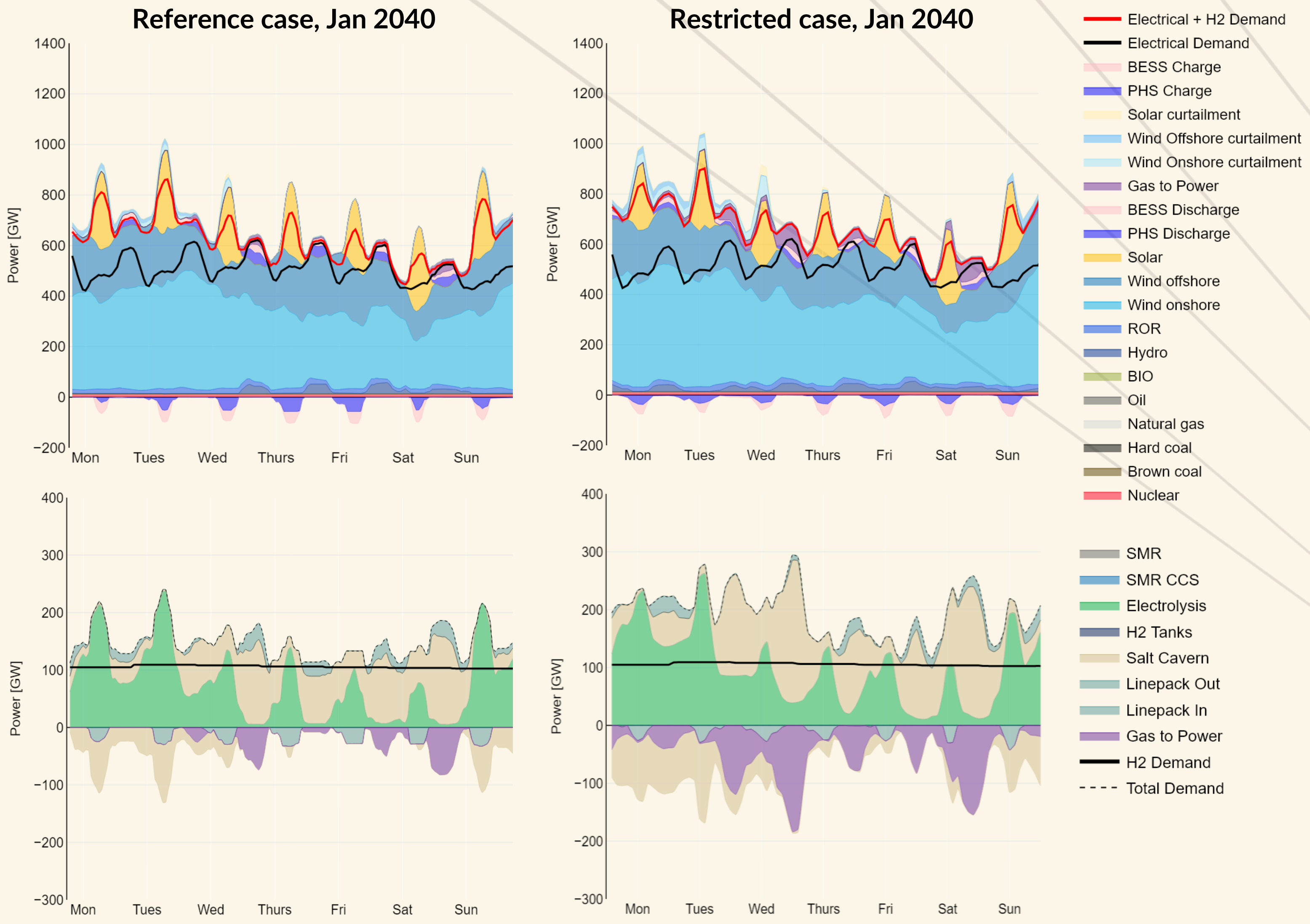


Sources: PAC Scenarios; Hitachi Energy

SENSITIVITY ANALYSIS

Restricted case
- No new investment in cross border interconnection capacity - Battery cost increase by 50% - No new Pumped Hydro Storage





 Sources: PAC Scenarios; Hitachi Energy

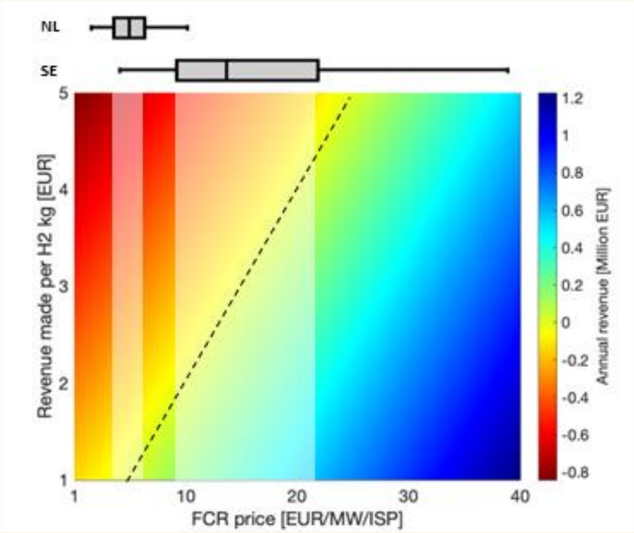
FREQUENCY CONTROL RESERVES EXAMPLE

FREQUENCY CONTAINMENT RESERVE

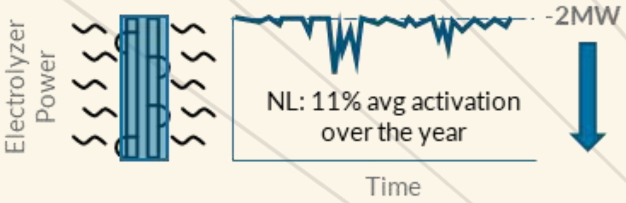
- Stabilizes frequency disturbance in the entire connected grid
- Paid per allocated power capacity
- Electrolyzer provides symmetric regulation of power consumption, thus, operating below rated power

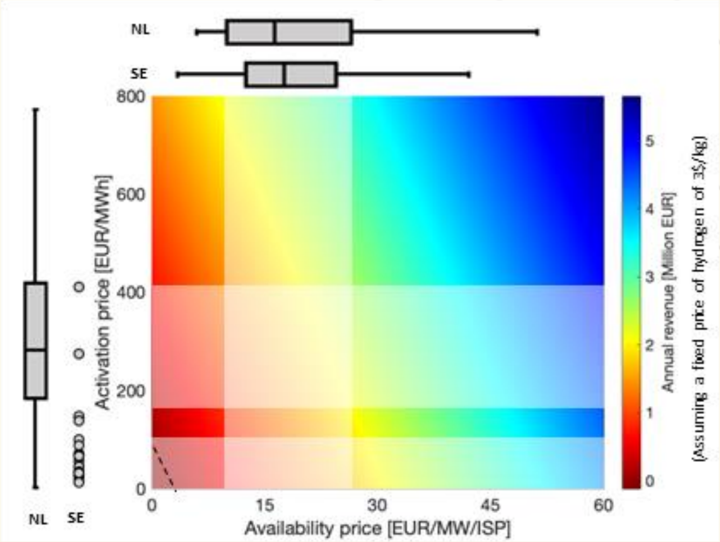
FREQUENCY REGULATION RESERVE

- Maintains the real-time balance in the control area
- Paid per allocated power capacity and activated energy
- Electrolyzer provides a unidirectional downward regulation



- Based on cost assumptions and current market prices provision of balancing reserves can be lucrative
- However, prices of reserves may go down in the future due to higher competition from other electrified loads … and a limited market size compared to projected installed capacity of electrolyzers in Europe by 2030





Assumption: electrolyzer provides a system service only if the expected revenue from the service outweighs the opportunity cost of selling H2

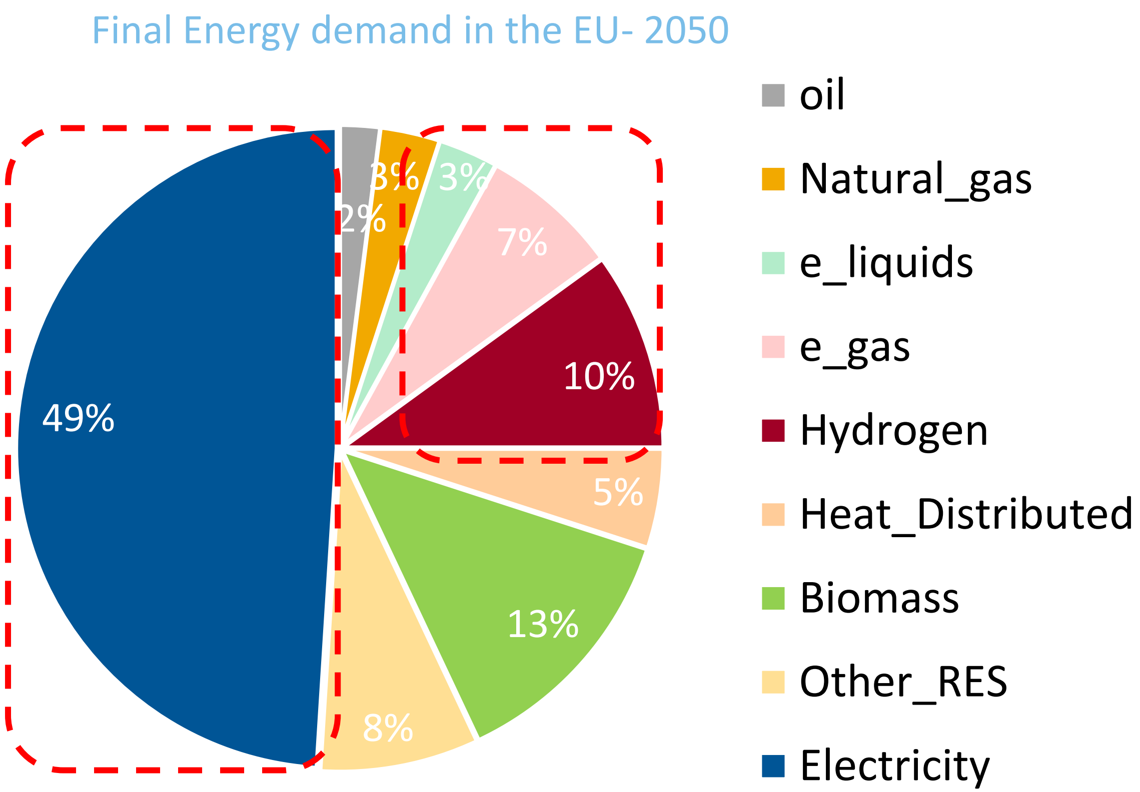
 Sources: ENTSO-E, Nord Pool, Hitachi Energy

Session 2: Electrolysers for long term flexibility (Business View)

Hydrogen as a key enabler of system flexibility and adequacy – Joerg Kerlen, *Member, Hydrogen Europe*

TIME: 10 mins

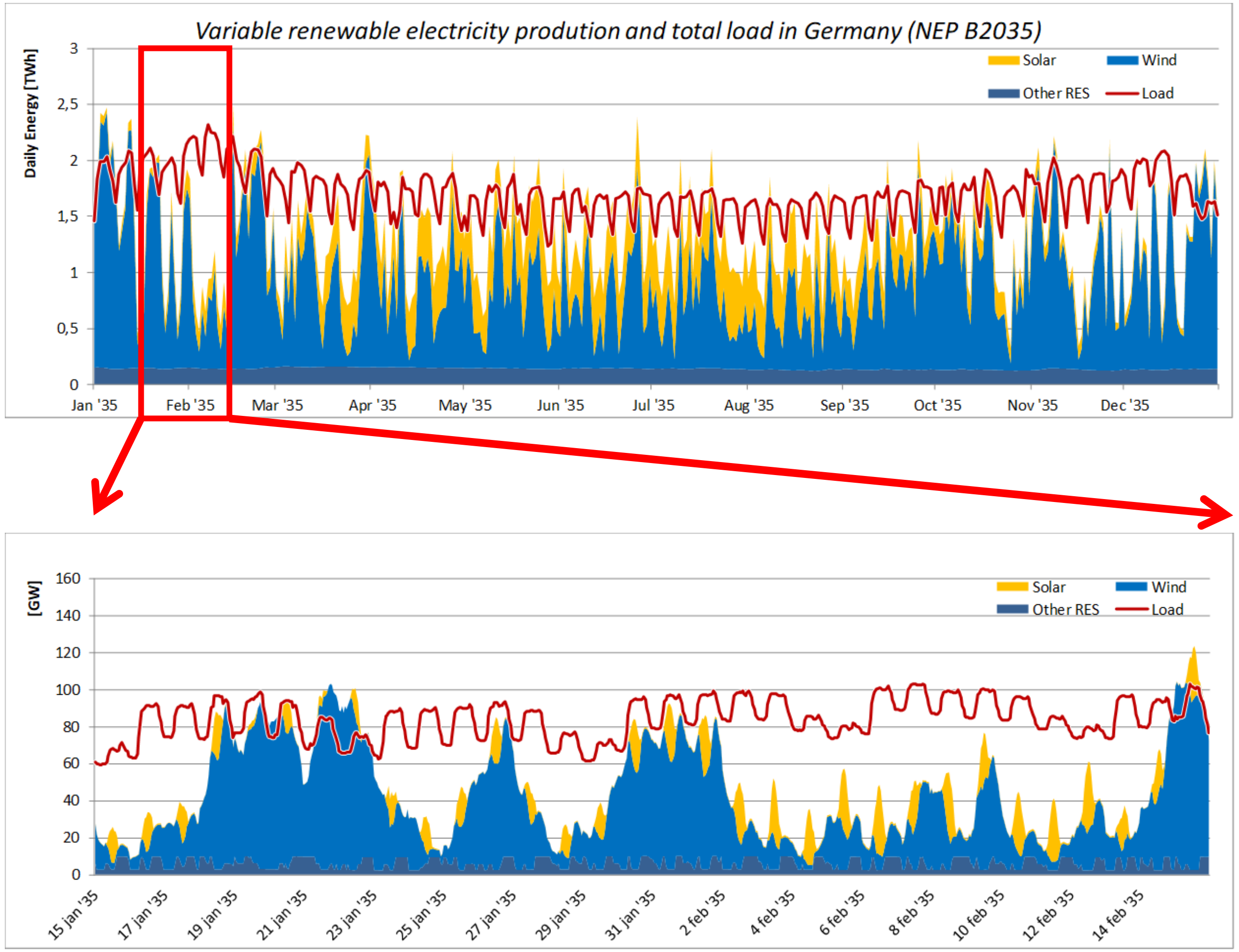
Priority on direct electrification - however, hydrogen needed to provide access to CO2-neutral energy for all consumers



- Direct electricity use covers half of the final energy demand
- Clean hydrogen and its derivatives will make up for more than 20%

Source: Windeurope based on EC's Impact assessment 2030, Mix scenario 2050
Final Energy demand: 615Mtoe equivale to 7,152 TWh

Decarbonizing dispatchable and flexible capacity to manage residual load and long-term storage still indispensable



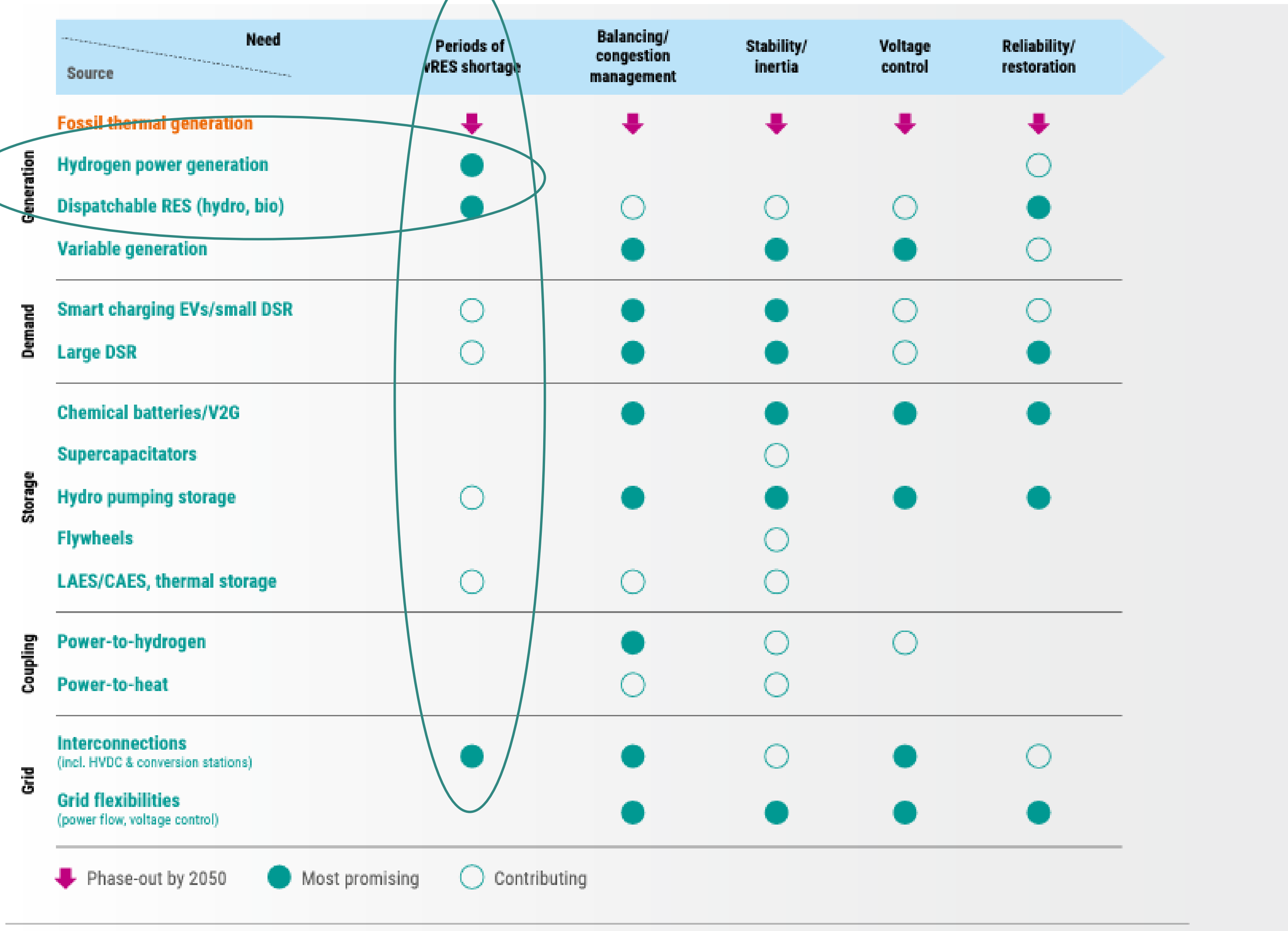
Source: German Grid development plan, Tennet

- By 2035 , the residual load in Germany will vary significantly throughout the year.
- The variation of the residual load will increase significantly daily and seasonal as heat and transport demand becomes more electric.
- Potential of storage, grid expansion and DSM is too limited to cover residual load.

Potential of other options to cover residual load and ensure system flexibility and adequacy is quite limited

Hydrogen Europe

- Not many option to deal with periods of short vRES
- Potential of storage, grid expansion and DSM is too limited to cover residual load.
- In some Member States, nuclear or fossil thermal (+CCS) generation are politically not accepted.



	Need / Source	Periods of vRES shortage	Balancing/ congestion management	Stability/ inertia	Voltage control	Reliability/ restoration
Generation	Fossil thermal generation	Phase-out by 2050	Phase-out by 2050	Phase-out by 2050	Phase-out by 2050	Phase-out by 2050
Generation	Hydrogen power generation	Most promising				Contributing
Generation	Dispatchable RES (hydro, bio)	Most promising	Contributing	Contributing	Contributing	Most promising
Generation	Variable generation		Most promising	Most promising	Most promising	Contributing
Demand	Smart charging EVs/small DSR	Contributing	Most promising	Most promising	Contributing	Contributing
Demand	Large DSR	Contributing	Most promising	Most promising	Contributing	Most promising
Storage	Chemical batteries/V2G		Most promising	Most promising	Most promising	Most promising
Storage	Supercapacitators			Contributing		
Storage	Hydro pumping storage	Contributing	Most promising	Most promising	Most promising	Most promising
Storage	Flywheels			Contributing		
Storage	LAES/CAES, thermal storage	Contributing	Contributing	Contributing		
Coupling	Power-to-hydrogen		Most promising	Contributing	Contributing	
Coupling	Power-to-heat		Contributing	Contributing		
Grid	Interconnections (incl. HVDC & conversion stations)	Most promising	Most promising	Contributing	Most promising	Contributing
Grid	Grid flexibilities (power flow, voltage control)		Most promising	Most promising	Most promising	Most promising

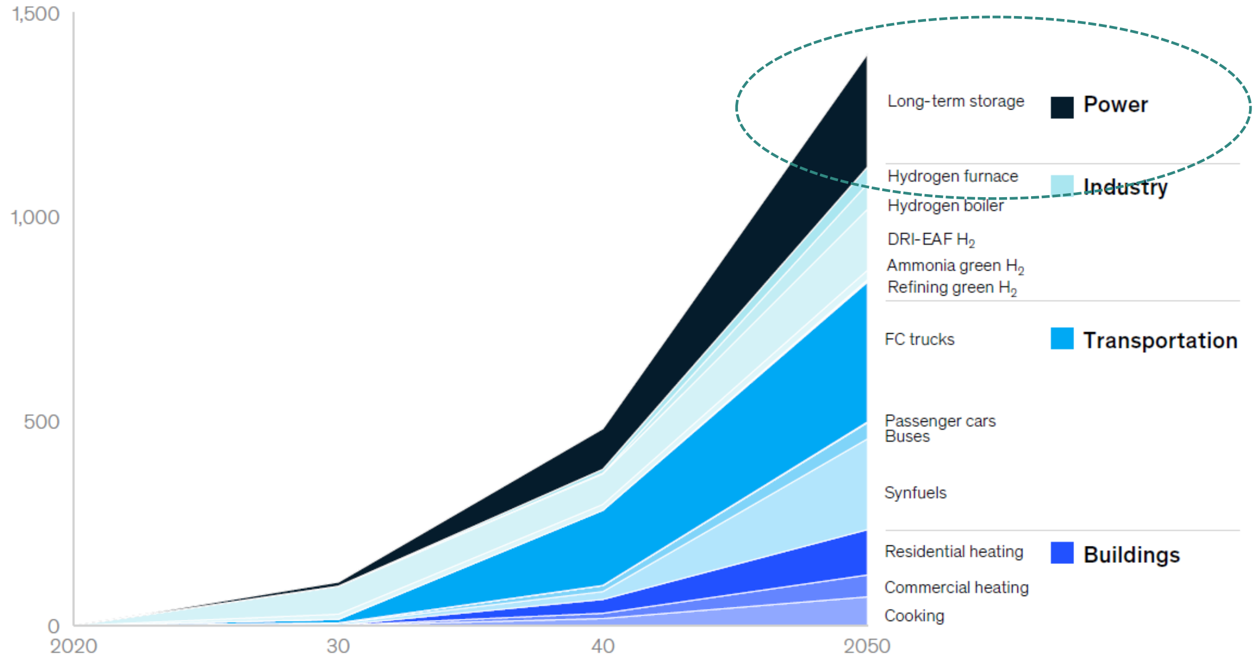
Phase-out by 2050 · Most promising · Contributing

Qualitative analysis of flexibility sources potential with respect to current use

ENTSO-E A Power System for a Carbon Neutral Europe // 7

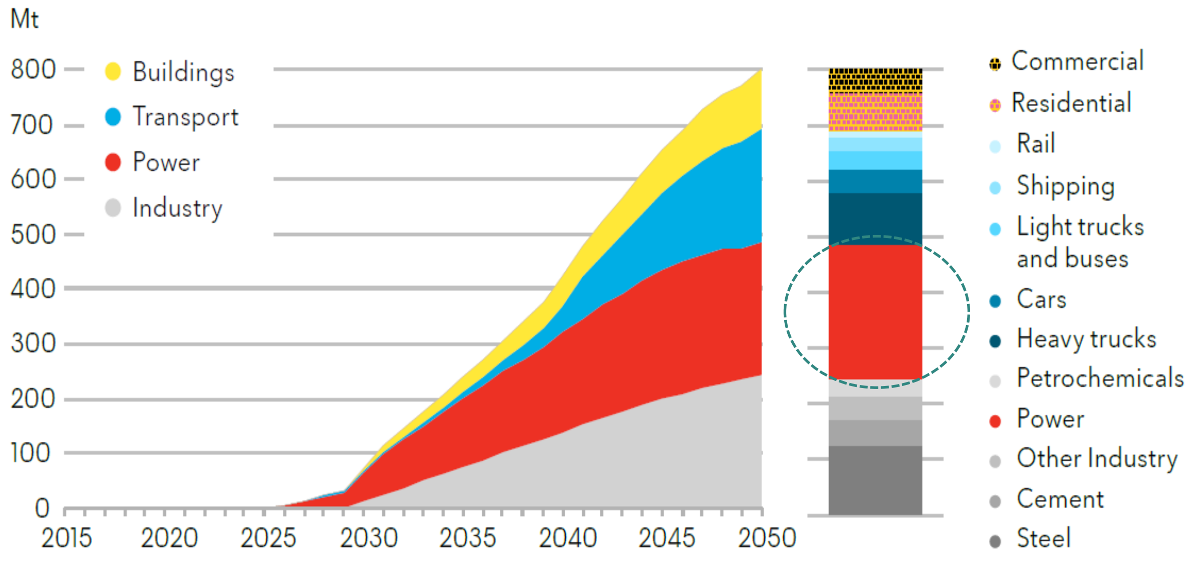
Molecules to play important role in securing security of supply and residual load, however, only being CO2 neutral.

Additional demand on top of existing hydrogen use[1], PJ, EU-27



1. Existing hydrogen uses include refining, ammonia, and other chemicals.

Source: McKinsey

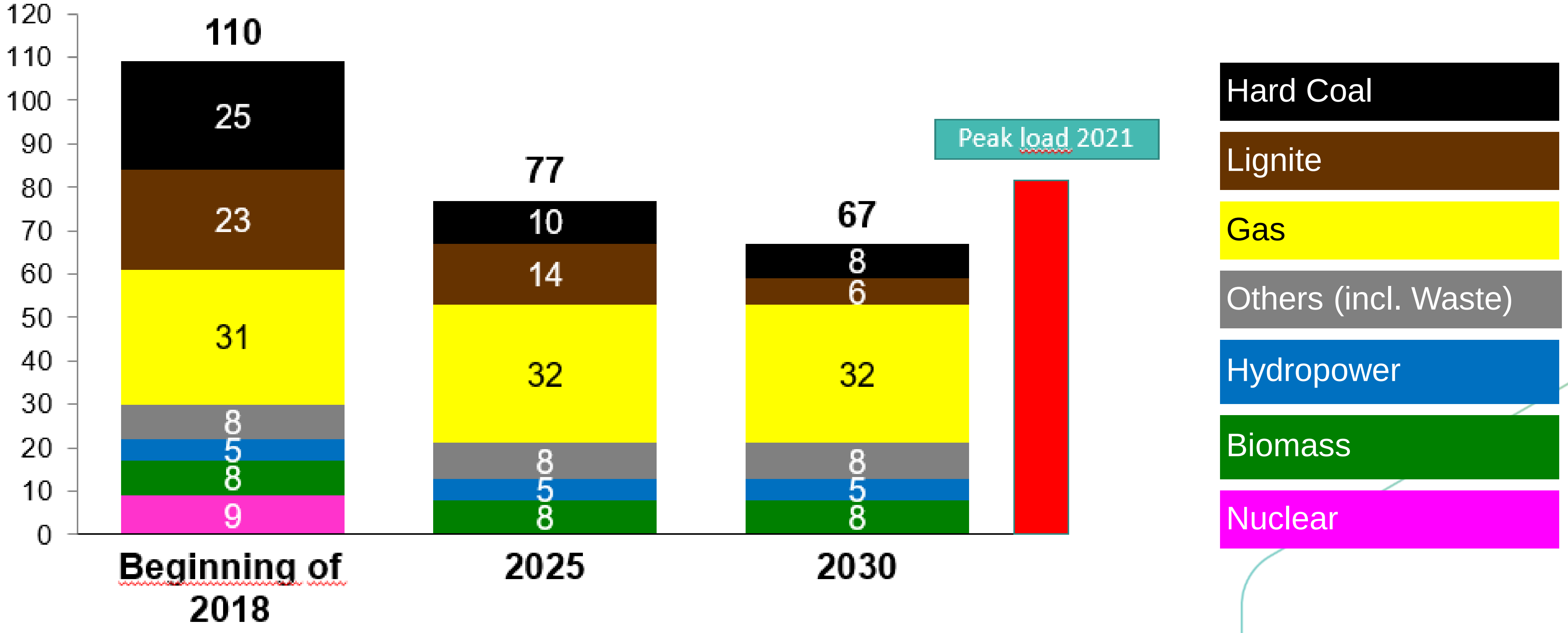


Source: BloombergNEF. Note: NCS-CEHP is NEO Climate Scenario: Clean Electricity and Hydrogen Pathway.

Sources: left figure, Mckinsey 2021(Eu27 demand), right figure: BloombergNEF 2020 (global demand)

Germany: Development of market-active dispatchable power plant capacity – gap to be filled to meet peak load

in GW



* Complete phase-out of hard coal and lignite by 2030 would reduce dispatchable capacity to 53 GW..

Source: EWI 2022 (29.09.2022) Analysis of security of supply up to 2030 (approaches for nuclear energy, biomass, hydroelectric power, other forms of waste incineration and gas). Conv. and waste incineration plants as well as gas); Coal-fired Power Generation Termination Act and Act to Accelerate the Lignite Phase-out in the Rhenish Mining Area (approaches for lignite and hard coal).

Hydrogen will inevitably contribute to system adequacy

Summary

- Dispatchable generation capacity will decrease in the next 5 – 10 years
- Growing gap has to be filled – for Germany, Federal Grid Agency assumes a need for 17 -21 GW additional new build, based on quite optimistic assumptions for contributions from abroad and DSM/storage
- Gas-fired power plants will play important role:
  - Aligned with taxonomy regulation
  - Funded by CRMs, e.g. as peakers
  - Highly flexible (no need for CCUS)
  - At locations which serve system needs
- But only, if they are H2-ready and if they are fired with hydrogen as soon as they can!

Wordcloud poll

Is hydrogen compelling relative to the alternatives that might create the same outcome in the context of the longer-term strategy (e.g., to develop potential long-term storage solutions)?

048

Need Hydrogen-Forex
Need more development.
have to overcome high costs
What about embrittlement?
As long time alternatives
Storage hydrogen is complicate
Repurposed
Massive
Country specific
Which alternatives?
Yes, of course
pv
off-shore electrolysers
LowCost
Depends on cost
Yes
Not sure, efficiency?
yes, but long-term
Promising
Yes, low carbon
Dispatchable power
costdependent
No
inevitable
Seasonal
Yes, more versatile than other
Absolutely
LetMarketsJudge
have to overcome scalability
H2 storage complicated
No for long-term purposes
among other solutions
For sure but needs policy push
Depending on the alternative

Multiple-choice poll

0 9 8

Which among the following shall be the driver for electrolysers operational modes?

Sale of Hydrogen under a long-term agreement to dedicated clients

18 %

Sale of Hydrogen on an open market

10 %

System services provision

4 %

Suitable combination of above

67 %

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Session 3: Electrolyser business models, barriers, assumptions, and recommendations

Panel discussion with 5 speakers and moderation by ENTSO-E

Join the poll in slido.com by scanning the QR Code on the right,

Or going to slido.com and including the code

#FLEXP2H2

Open text poll

What type of business models, markets and regulation are suitable to conducively combine private investors needs with system needs?

(1/2)

013

- the use of H2 should be prioritised in an order of ecological efficiency (highest positive effect on climate change) and not following conventional business cases (at least during the transition phase, when the availability of RES and therfor also Green H2 is still a rare good
- Incentives for low carbon energy system services
- business models focus on the balance between goods and prices
- System needs are already market products in some countries. Hydrogen will definitely participate to these markets if it is competitive.
- Combination of PPAs with large consumers with the provision of ancillary services
- Market-based would be great: label hydrogen as green in hours during which it does not trigger additional fossil-based electricity. Can be established a

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Open text poll

What type of business models, markets and regulation are suitable to conducively combine private investors needs with system needs?
(2/2)

0 1 3

day ahead, by publishing a reference electricity price as the lowest of the marginal cost of gas electricity and that of coal electricity.

- Hybrid market configuration or price driven
- Capex subsidies during scale up, then broad market instruments (ETS)
- Some form of Cap and Floor model
- Tech neutrality Market based Customer choice respectful

Whole System Approach 100% Emissions focused

- Market model, off course
- Market model, definitely
- Policy push. Non-biased subsidies.
- TechNeutrality

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Wrapping up

Closing remarks –

Norela Constantinescu, Head of Innovation Section, ENTSO-E

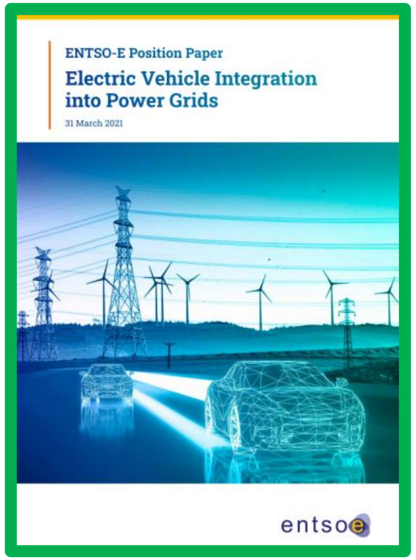
TIME: 5 mins

Current Sector Coupling ENTSO-E initiatives

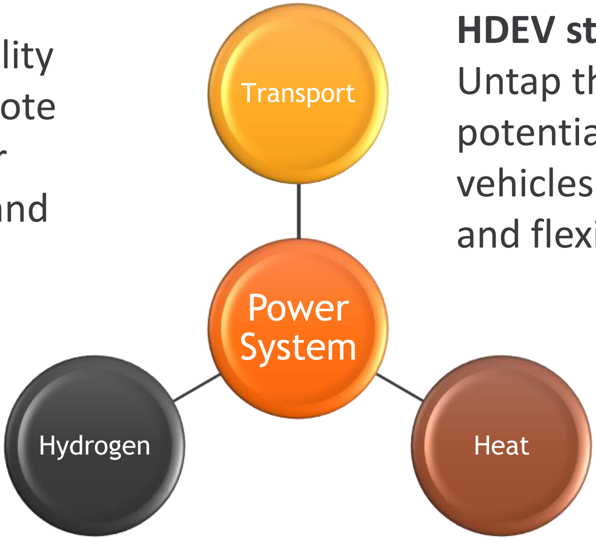
Published / hyperlinked

To be published

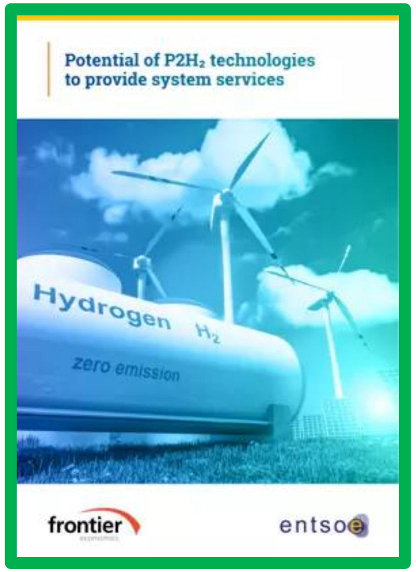
Under development



EV Position Paper
Impact on TSOs – Flexibility Opportunities and promote coordinated planning for charging infrastructure and electric grid

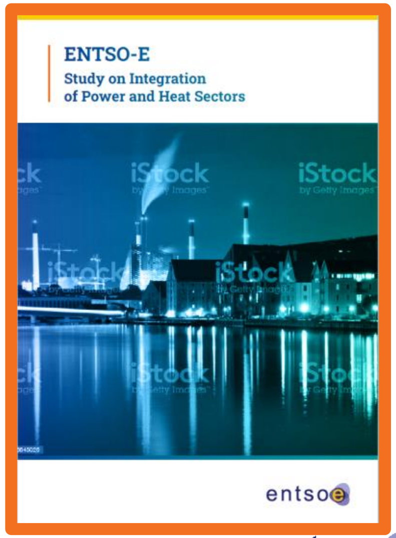


HDEV study
Untap the electrification potential of heavy-duty vehicles segment (use cases and flexibility)



P2H2 study
Electrolysers can provide a wide range of services and long-term storage potential

Power-to-Heat study
Impact on load profiles and increased flexibility potential by demand side and thermal storage



Our values define who we are, what we stand for and how we behave.
We all play a part in bringing them to life.

EXCELLENCE

We deliver to the highest standards. We provide an environment in which people can develop to their full potential.

TRUST

We trust each other, we are transparent and we empower people. We respect diversity.

INTEGRITY

We act in the interest of ENTSO-E

TEAM

We care about people. We work transversal and we support each other. We celebrate success.

FUTURE THINKING

We are a learning organisation. We explore new paths and solutions.

We are ENTSO-E