Impact of Renewable Hydrogen on the Power System: Sector Development, Flexibility and Market Aspects

Public Webinar | 25 June 2025 11.00 - 12.30

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Agenda

11:00 - 11:05	**Opening Statement** • Marco Forteleoni (Vice Chair of the Research, Development and Innovation Committee, ENTSO-E)
11:05 - 11:10	**Background, objectives, and rationale of the Study** • Rodrigo Lopez Mendoza (RDIC WG4 – Future of Energy Systems, ENTSO-E)
11:10 - 11:30	**Study on Impact of Renewable Hydrogen on the Power System: Sector Development, Flexibility and Market Aspects** • Ksenia Tolstrup (Magnus Energy)
11:30 - 11:40	**Study key messages** • Antonio Iliceto (RDIC WG4 – Future of Energy Systems, ENTSO-E)
11:40 - 11:50	**Q&A**
11:50 - 12:25	**Panel discussion on Renewable Hydrogen: Trends, Impact on the Power System, Regulation and Market Design** • Ksenia Tolstrup (Magnus Energy) • Marco De Benedictis (European Commission, DG ENER) • Nils Melcher (ENNOH) • Claude Mangin (ENTSOG) • François Paquet (Renewable Hydrogen Coalition) • Javier Barrantes Egaña (ENTSO-E)
12:25 - 12:30	**Closing remarks** • Marco Forteleoni (Vice Chair of the Research, Development and Innovation Committee, ENTSO-E)

Recording and Q&A

- Please note that the webinar will be recorded.
- Questions can be shared via **Slido** and they will be answered in the dedicated Q&A sessions.

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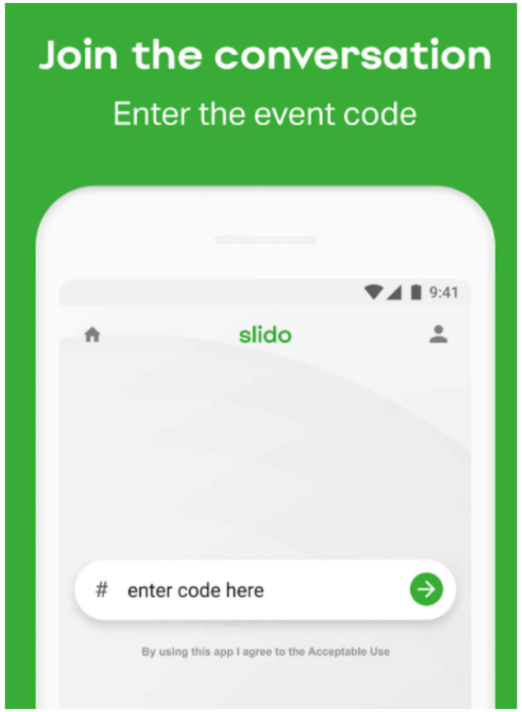
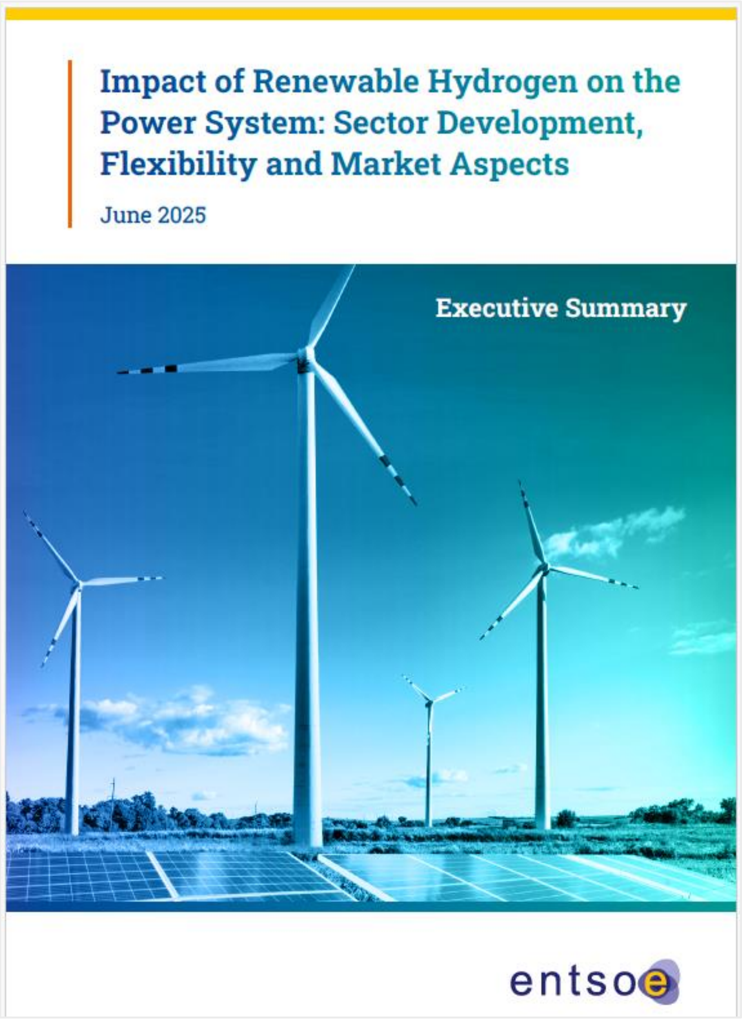


Opening Statement

Marco Forteleoni – Vice Chair of the Research, Development and Innovation Committee, ENTSO-E



Background, Objectives and Rationale of the Study

Rodrigo Lopez Mendoza – ENTSO-E

ENTSO-E Study “Impact of Renewable Hydrogen on the power system”

Background, objectives and rationale of the study

Previous papers:

- The role of hydrogen (2021) - link
- Study on Flexibility from P2H (2022) - link

RDIC & MC

Impact of Renewable Hydrogen on the power system: system planning, flexibility and market aspects (link)

Objectives	**Assessing the expected impacts of renewable hydrogen** value chain (especially electrolysers) **on electricity systems and markets**	Proactively propose the **TSO community perspective to facilitate** an **efficient development** of the future **energy system**	Proposing forward-looking **policy & market design recommendations**, to engage with **hydrogen stakeholders & policymakers**
Structure	Part 1: **Analysis of Hydrogen economy**: trends and key developments for system integration.	Part 2: Analysis of the **systemic role of hydrogen** ecosystem and its impacts on the power system.	Part 3: Analysis of **market design and regulatory framework** for a flexible hydrogen production.

Detailed report on market design & regulatory framework available here

RDIC – Research, Development and Innovation Committee, MC – Market Committee

Study on Impact of Renewable Hydrogen on the Power System: Sector Development, Flexibility and Market Aspects

Ksenia Tolstrup – Magnus Energy

Part 1: Hydrogen Economy
Trends, Developments, and System Integration

Key questions:

› What are **the main trends and developments** in the emerging hydrogen sector, including policy and regulation?

› What are use cases for **hydrogen demand** and how does it compare to expected **production capabilities**?

Policy and regulations rather than economics are the main enablers driving hydrogen demand

Future system needs require the development of significant system flexibilities to handle the increased complexity of the system and balance the gradual phase out of fossil fuel generation. Hydrogen is seen as one of the essential pieces of the puzzle.

However, **hydrogen investments,** both in large electrolysers and associated infrastructure, are **still in their infancy**. The low uptake of (renewable) hydrogen and the lack of sufficient domestic hydrogen production capacity make the ambitious objectives challenging to achieve.

Additional efforts are needed to convert this investment progress into actual project commitments: in Europe, only 3 % of hydrogen production projects are operational or are under construction.

Investment boosters for hydrogen supply & infrastructure	Year	Policy objectives towards 2050 & hydrogen regulation
	2020	EU Hydrogen Strategy
Recovery and Resiliency Facility for Clean Energy	2021	Fit for 55
IPCEI HyTech CEF-T European Hydrogen Bank	2022	
	2023	REPowerEU AFIR RED III
European Hydrogen Bank Auctions IPCEI Hy2Move IPCEI Hy2Infra	2024	Hydrogen and Decarbonised Gases Package ▸ Only 1 % of hydrogen is produced low-emission ▸ Only 0.3 t of hydrogen is produced with electrolysis ▸ The current installed capacity of electrolysers is just 160 MW
	…	
▸ € 720 million rewarded to 7 renewable hydrogen projects to produce 1.5 Mt hydrogen by 2030 ▸ Fixed premium subsidy for certified and verified renewable hydrogen production ▸ To deploy over 2.5 GW of hydrogen electrolysers by 2026	2030	▸ 10 Mt domestic hydrogen production + 10 Mt imports ▸ Targeted capacity of 40 GW electrolysis ▸ Over 42 % of hydrogen used in industry should come from RFNBOs
	2050	▸ 75 – 81 % of electrolysers are estimated to be supplied power through the grid by 2050 ▸ Additional imported hydrogen of 10 MT is foreseen by 2050

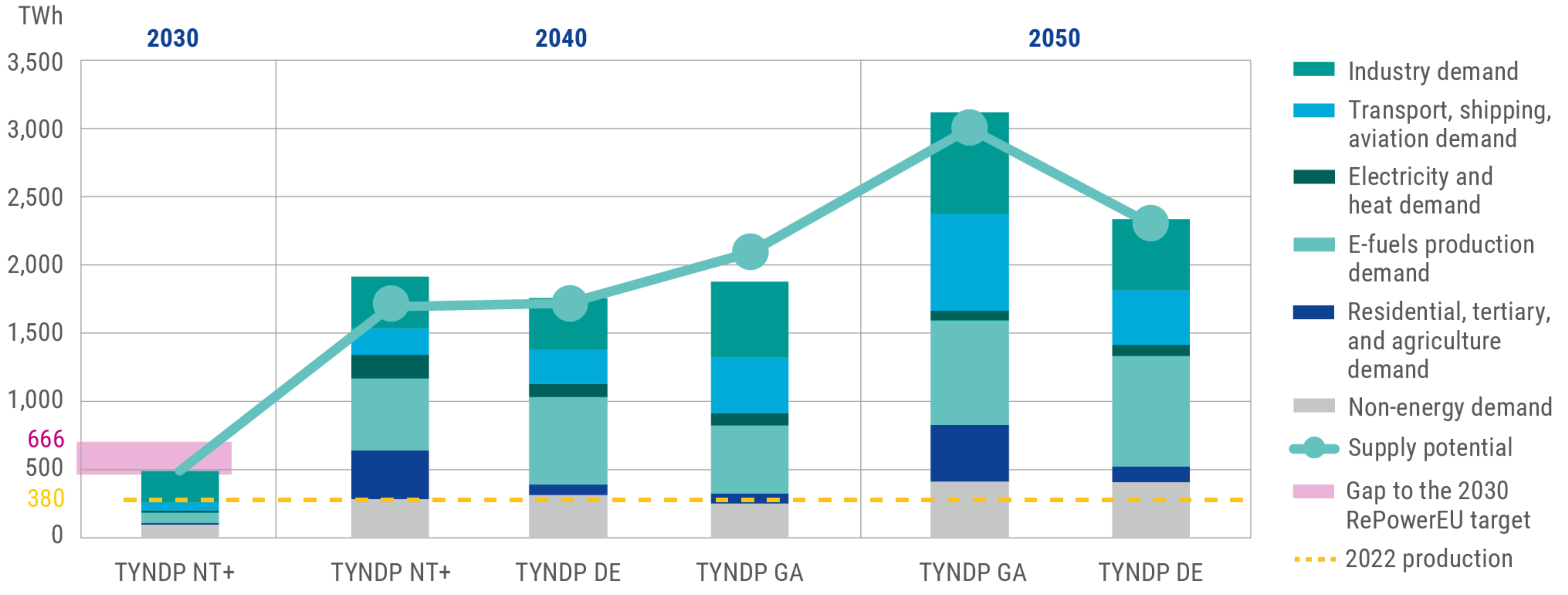
Future sectoral role of hydrogen expected in Europe towards 2050

Based on the TYNDP 2024, **the total EU hydrogen demand** is estimated to **soar eightfold in just 20 years.** Renewable hydrogen demand is the primary driver of electrolyser deployment.

1 **Industry** has been and will likely remain the main use case across all time frames.

2 **Heavy transport** and **e-fuels** are also anticipated to be major use cases for hydrogen in reaching 2050 carbon-neutrality goals modelled in the TYNDP 2050 scenarios.

Hydrogen Supply Potential and Demand per Sector in EU27

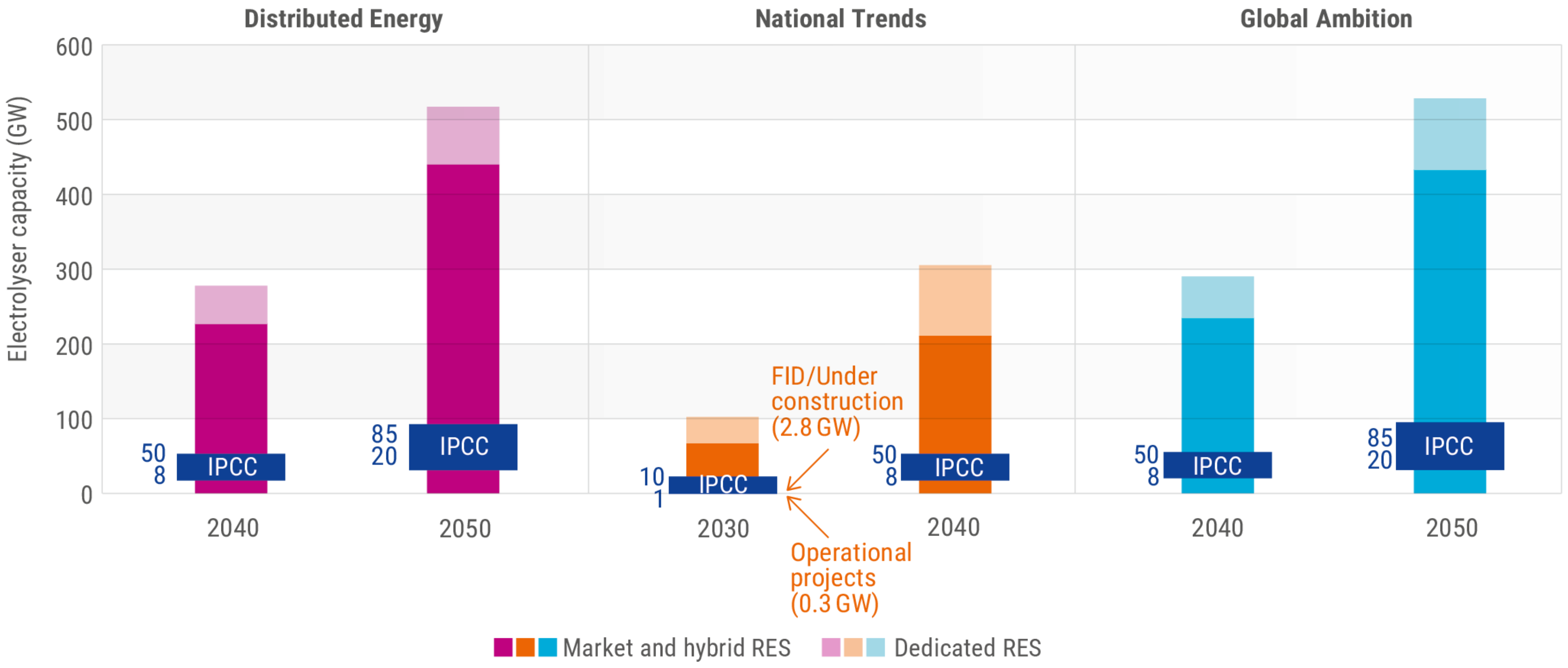


TYNDP scenarios: NT – National Trend; DE – Distributed Energy; GA – Global Ambition

TYNDP – Ten-Year Network Development Plan

Expected electrolyser capacity expansion in the EU

There is **a considerable gap** between bottom-up (IPCC) and top-down (TYNDP) **estimations** of future electrolyser installed capacity in the EU. Renewable hydrogen costs are another driving factor of hydrogen penetration, yet their development is highly uncertain. Despite **this multifold uncertainty regarding the volume, costs & timing of electrolyser deployment** it is essential to develop integration concepts and best practices in hydrogen business cases from the outset.



TYNDP scenarios (bars) are compared to IPCC AR6 scenarios of the 1.5 °C climate target ("IPCC" dark blue area) regarding future electrolyser capacity. The bottom-up potential (FID / under-construction and operation hydrogen projects in EU) from IEA 2024.

IPCC – International Panel on Climate Change

MAGNUS energy entsoe

Part 2: Systemic Role of Electrolysers and Other Hydrogen-Based Facilities and Their Impact on the Power System

Key questions:

- What are **the main constraint capabilities** of electrolysers **and the associated effect** on the power system?
- What **degree of electrolyser capacity expansion** in the EU can be expected in the ramp-up and mature phases?
- What kind of **flexibility potential can be expected** from electrolysers based on different operational modes?

Electrolyser operational modes and expected impacts on the power grid

Electrolysers can provide power system flexibility. But their **positive and negative impacts will depend on different electrolyser operational modes as well as on the availability of storage.**

- **Baseload operation** focuses on maximising the electrolyser load factor, particularly through long-term RES PPA supply contracts – ideally using a flat operational profile (minimising CAPEX).
- **Demand-driven operation** must strictly adhere to hydrogen demand, is an obliged mode in the absence of a sufficient hydrogen logistics system.
- **System-supportive operation** - an electrolyser systematically provides flexibility to the power system in addition to its hydrogen production, depending on remuneration incentives.
- **Market price-driven operation** - operations based solely on electricity prices (minimising the OPEX cost component), using low- or zero-cost electricity. This mode requires a mature and fully available hydrogen infrastructure to optimise a more variable production profile.

Installed electrolyser capacity in the EU: TYNDP scenario; IPCC scenario

Impacts on the power grid (positive and negative)

Operational mode	Storage & Transport	Grid congestions risk	Flexibility short-duration	Flexibility long-duration
Baseload	Without storage	YES	NO	NO
Baseload	With storage	NO	YES	NO
Demand-driven	Without storage	YES	NO	NO
Demand-driven	With storage	NO	YES	YES
System-supportive	Without storage	NO	YES	NO
System-supportive	With storage	NO	YES*	YES
Market price-driven	Without storage	NO	NO	NO
Market price-driven	With storage	NO	YES*	YES

*Potential provision of implicit flexibility

Example of 2030 based on Iliceto, A. et al. 2023 33).
*Note that potential implicit flexibility is marked by * in the rightmost table.*

RES – Renewable Energy Sources, PPA – Power Purchase Agreement, CAPEX – Capital Expenditures, OPEX – Operational Expenditures

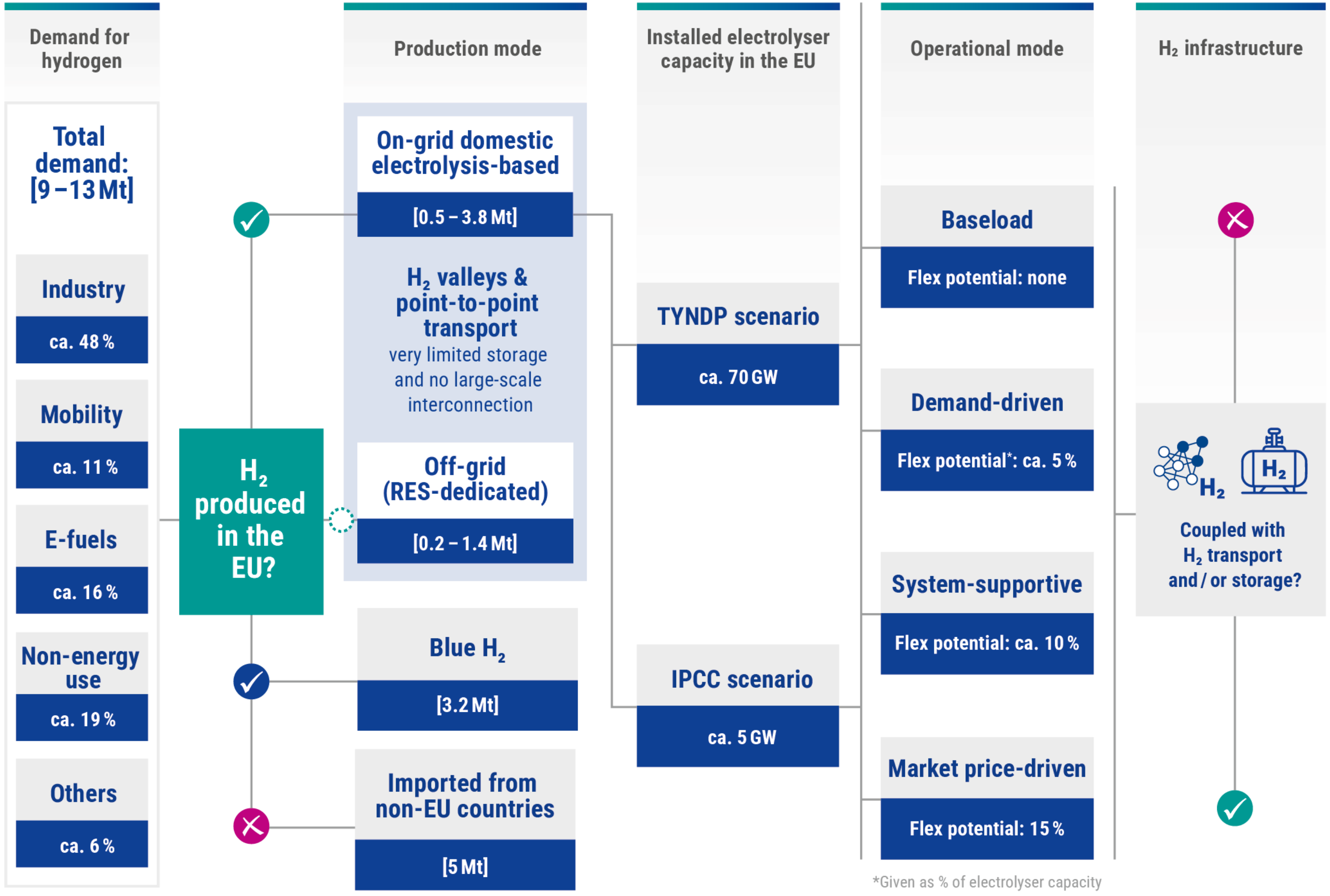
Flexibility potential expected from electrolysers: 2030 Ramp-up phase

EU domestic production will also compete with imported hydrogen.

Direct impact on power grids will come only from renewable hydrogen produced domestically through electrolysers connected to the power grid.

The flexibility potential of electrolysers mainly depends on their connection type and operational mode or (likely combination of) modes.

Downstream hydrogen storage and transport facilities are also necessary for both standalone grid-connected electrolysers and off-grid electrolysers to enable a more flexible operation.

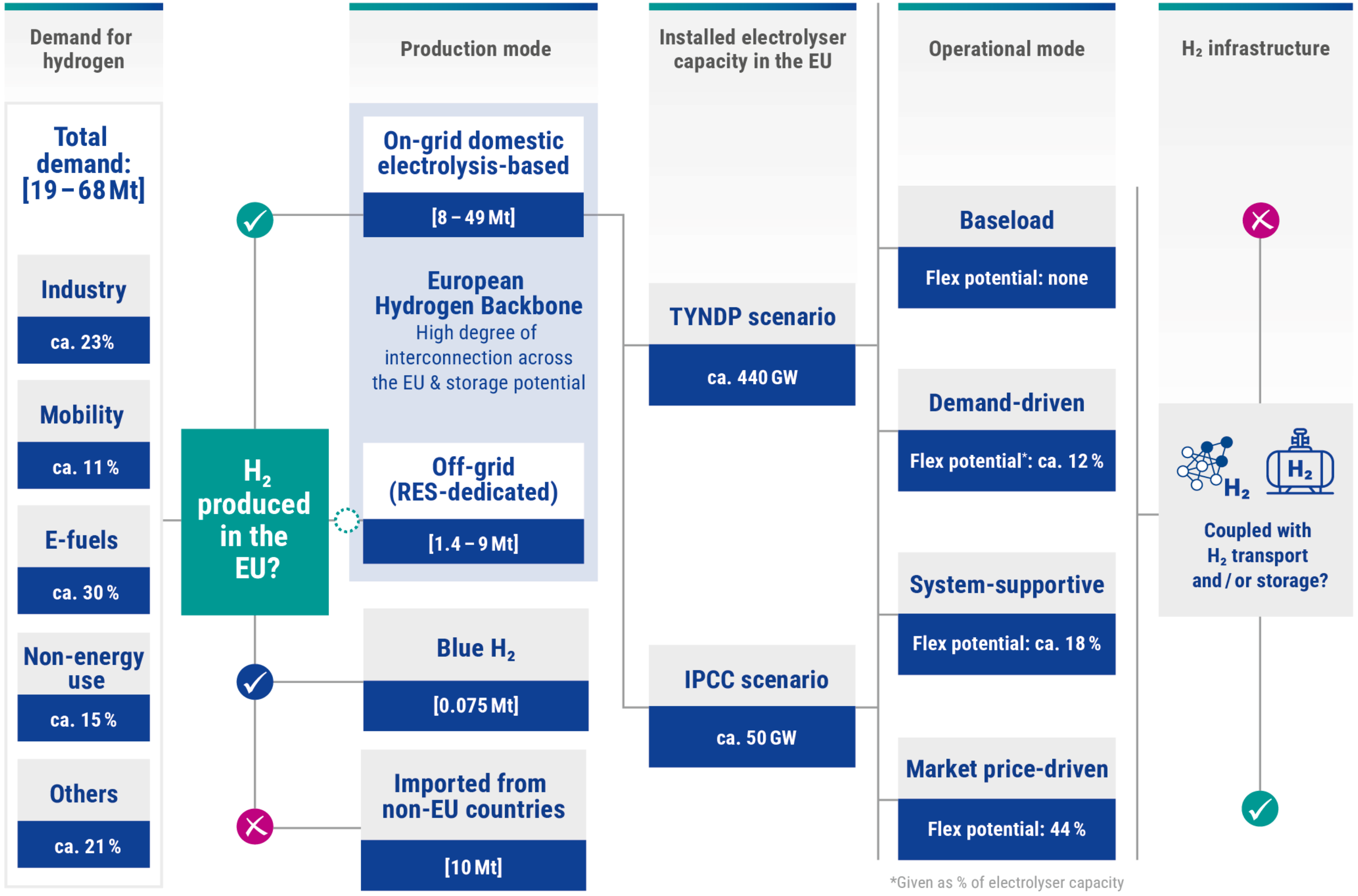


** Flexibility potential estimates for different electrolyser operational modes (2030 ramp-up phase) given as % of electrolyser capacity*

Flexibility potential expected from electrolysers: 2050 Mature phase

The incentive to provide implicit or explicit flexibility will depend on the evolving economics of electrolysers, the available revenue streams, and any applicable support schemes.

From a holistic perspective, regulation and market design should incentivise the operational modes and configurations (including siting decisions) that are most beneficial for both the electricity and hydrogen systems.



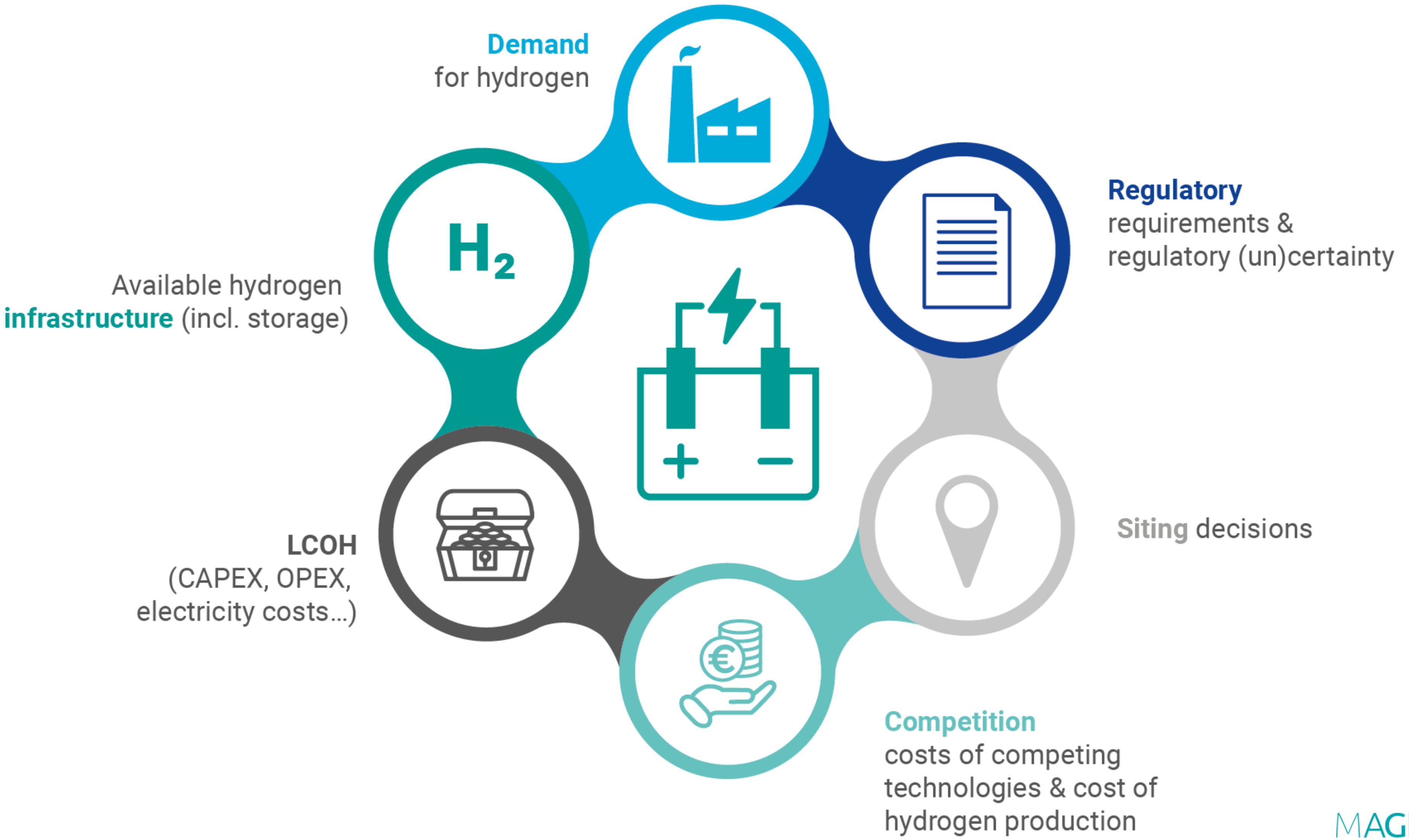
** Flexibility potential estimates for different electrolyser operational modes (2030 ramp-up phase) given as % of electrolyser capacity*

Part 3: Market Design and Regulatory Framework for Viable and Flexible Hydrogen Production

Key questions:

- What are **the main cost and revenue drivers** of electrolysers?
- What kind of **support schemes, market rules and other arrangements** are conceivable for a viable investment case?
- What **measures can be taken** to enable cost-efficient and flexible hydrogen production?

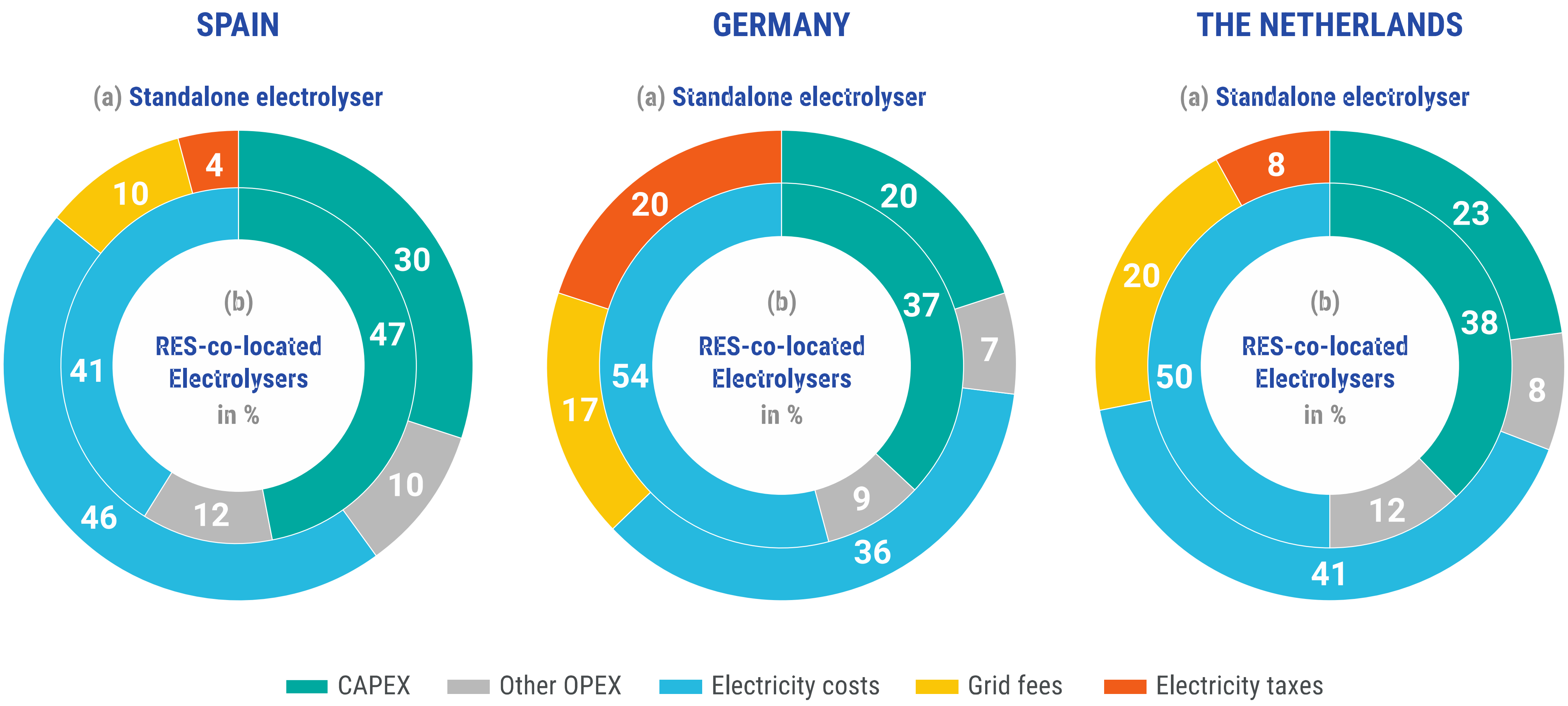
Main cost drivers affecting the business case of electrolysers



LCOH – Levelised Cost of Hydrogen

Hydrogen cost is driven by multiple country-specific CAPEX and OPEX factors

The electricity costs alone account for 36–54 % of the total LCOH. The share of grid fees and taxes is highly country specific. Generally, the LCOH decreases as the number of operating hours increase and is also dependent on lower electricity costs.

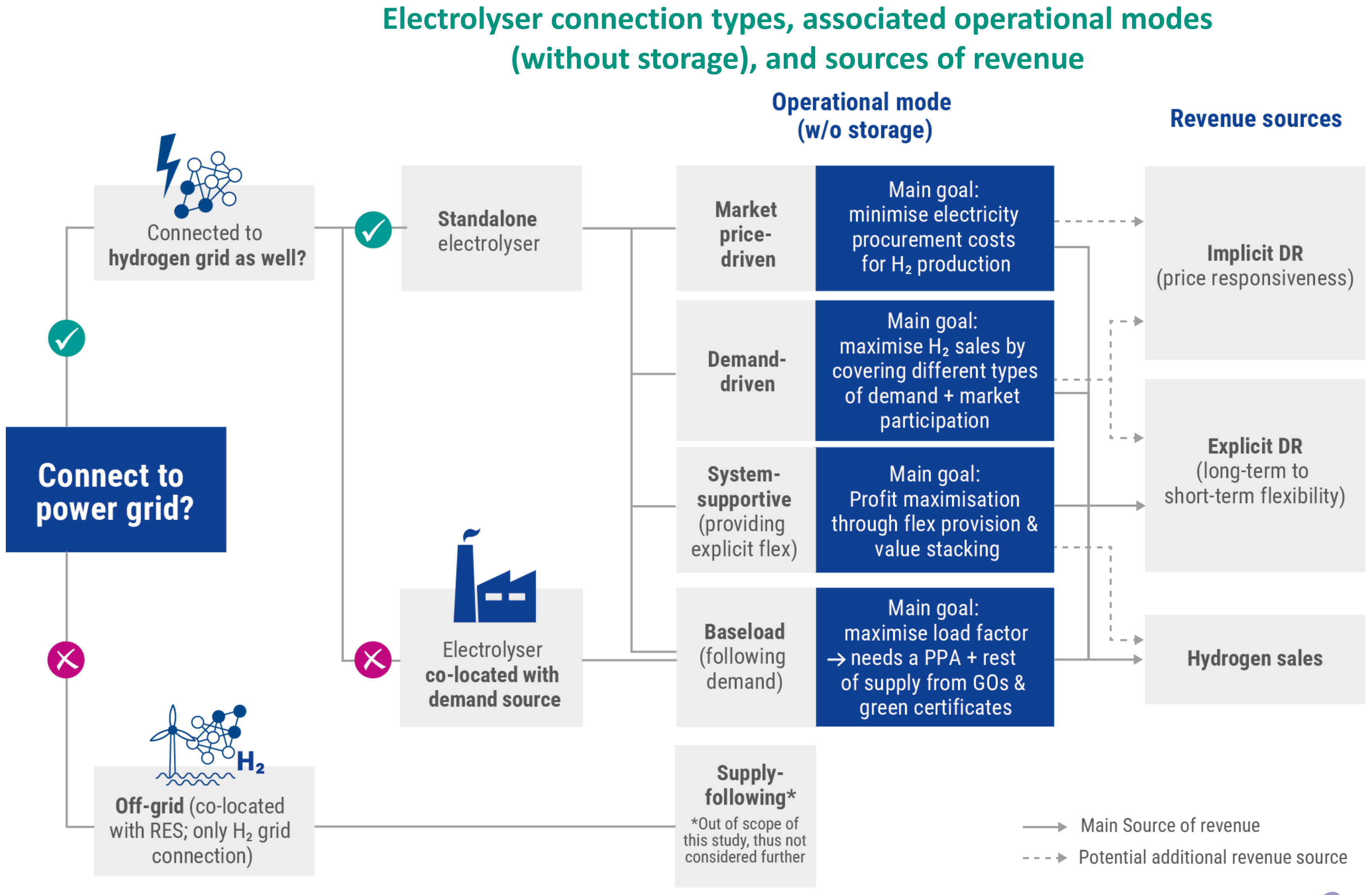


Potential revenue streams beyond hydrogen production

Hydrogen sales are the principal revenue source for electrolysers. Costs are heavily influenced by electricity prices, which make up the majority of OPEX.

System services offer a revenue potential, but competition from established technologies, such as battery storage, and stringent technical requirements, significantly limit practical opportunities.

For instance, electrolysers may be able to provide balancing services however, this involves significant OPEX to ensure operational flexibility, while requirements and price levels differ significantly among EU countries.

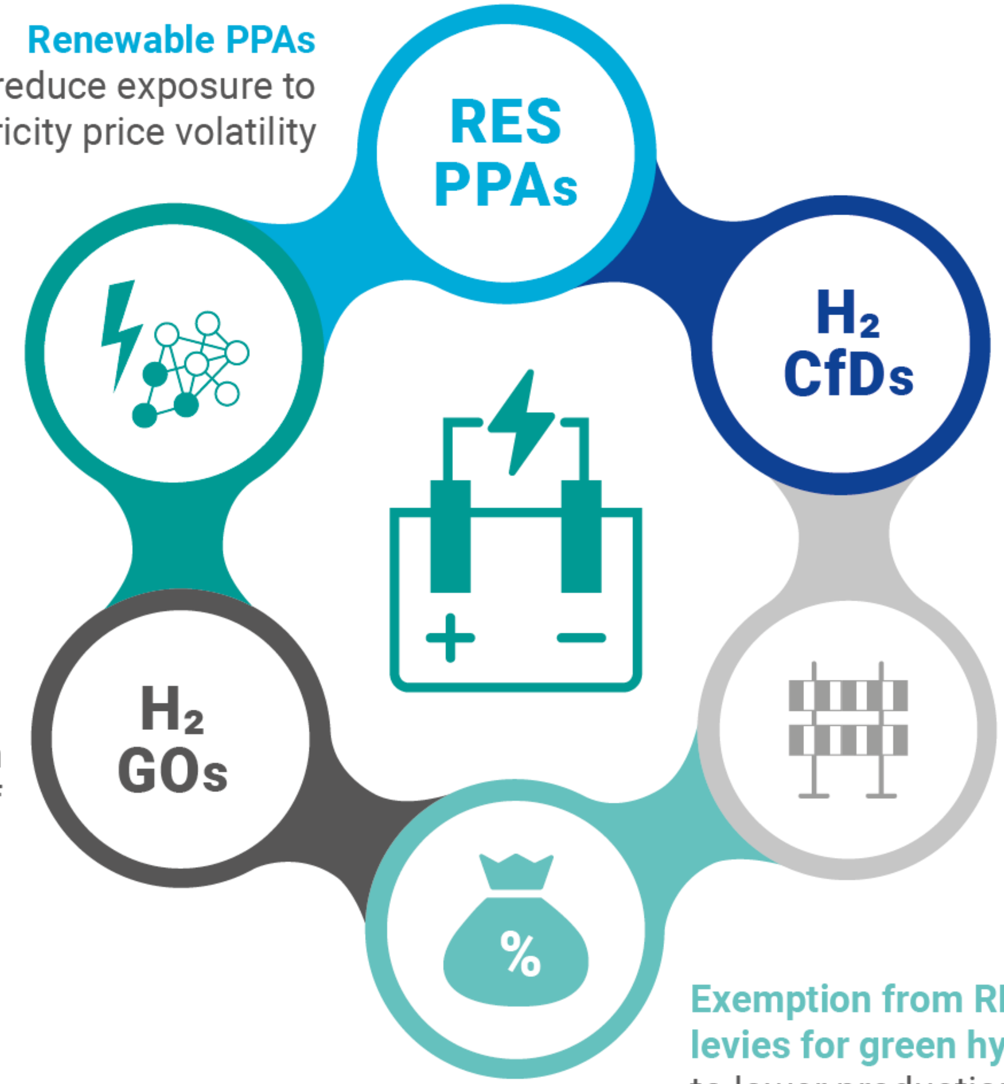


Potential enablers of the business case for electrolyser operation

Renewable PPAs to reduce exposure to electricity price volatility

Hydrogen CfDs or off-take agreements to reduce exposure to H_2 price or volume volatility

Flexible connection agreements to incentivise grid-friendly production patterns



Removal of barriers to grid service provision to enable effective integration

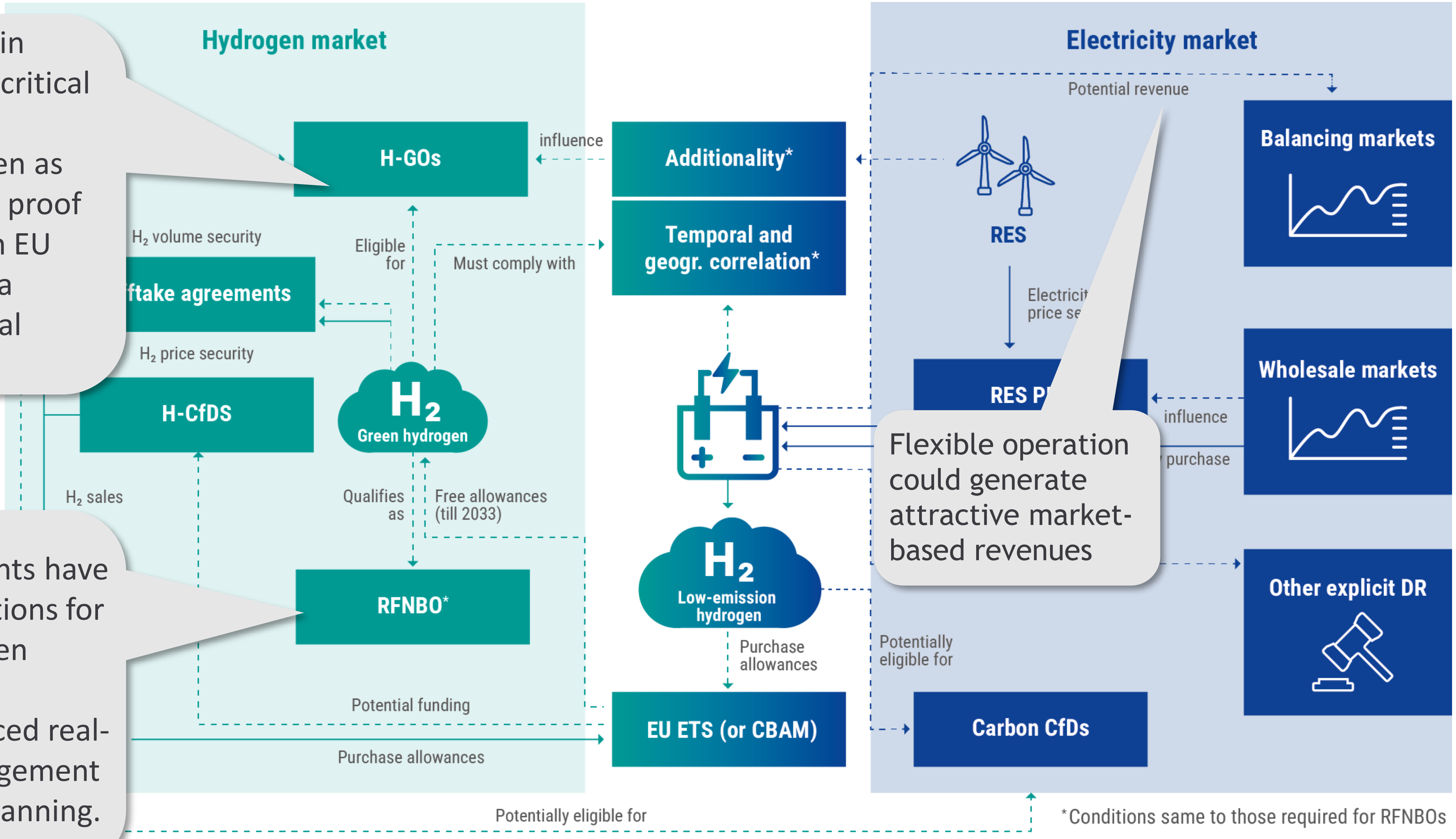
H_2 Guarantees of Origin justifying a premium of green hydrogen

Exemption from RES levies for green hydrogen to lower production costs

CfD – Contracts for Differences

Hydrogen-associated revenue streams and possible support mechanisms

Guarantees of origin (GOs) could play a critical role in certifying renewable hydrogen as RFNBOs, providing proof of compliance with EU requirements and a potential additional source of revenue.



Flexible operation could generate attractive market-based revenues

RFNBO requirements have significant implications for renewable hydrogen production and necessitate advanced real-time energy management and site-specific planning.

RFNBO – Renewable Fuels of Non-Biological Origin, ETS – Emission Trading System, CBAM – Carbon Border Adjustment Mechanism, DR – Demand Response

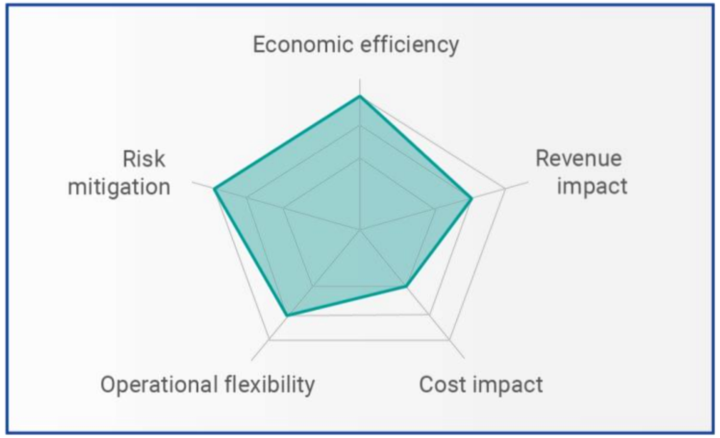
Measures to enable cost-efficient and flexible hydrogen production

Six support mechanisms for electrolysers based on economic efficiency, revenue impact, cost impact, operational flexibility, and risk mitigation are all associated with trade-offs to be aware of.

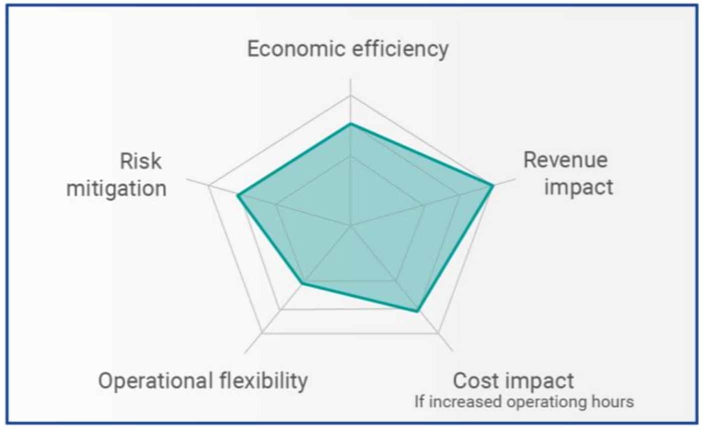
PPAs

H-CfDs

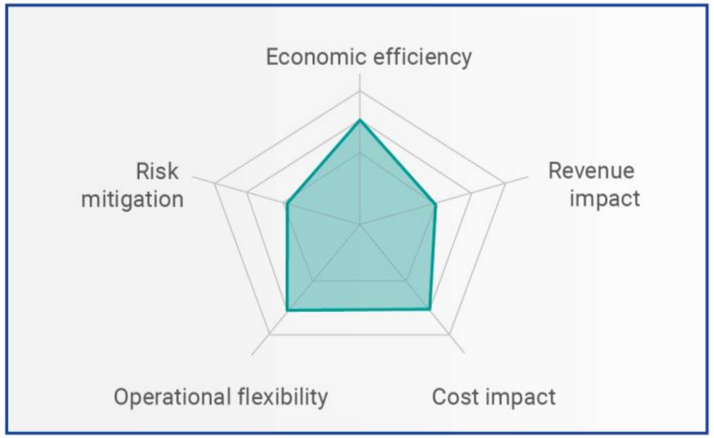
Cap- and floor contracts



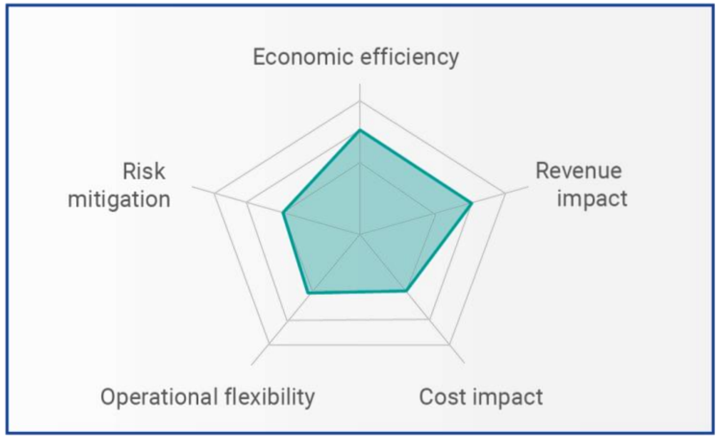
Off-take agreements



Reduced RES levies



GOs



From the system perspective, what measures can be taken to support system-friendly hydrogen expansion?

RAMP-UP
by 2030

Setting up the foundation

- TSOs to coordinate with electrolyser operators on their power grid location
- TSOs/ENTSO-E, gas TSOs/ENTSOG and HNOs/ENNOH to coordinate on infrastructure planning
- TSOs to plan for electrolyser participation in system service markets (connection requirements, baseline methodologies…)
- Offer direct financial support (e. g., capital grants, investment subsidies with a phased reduction combined with demand quotas – in line with cost-efficient compliance with decarbonisation objectives

GROWTH

Scaling & Stabilisation

- Flexibilisation of the electrolyser technology itself as a crucial prerequiste for the scale-up
- Reduce levies or taxes for operators prioritising electricity consumption during high-RES output periods and enable flexible connection agreements in congestion-prone areas
- Use off-take agreements or cap-and-floor agreements to shield electrolyser operators from volume or price risks and improve project bankability

MATURITY
2050

Route towards subsidy-free and flexible operation

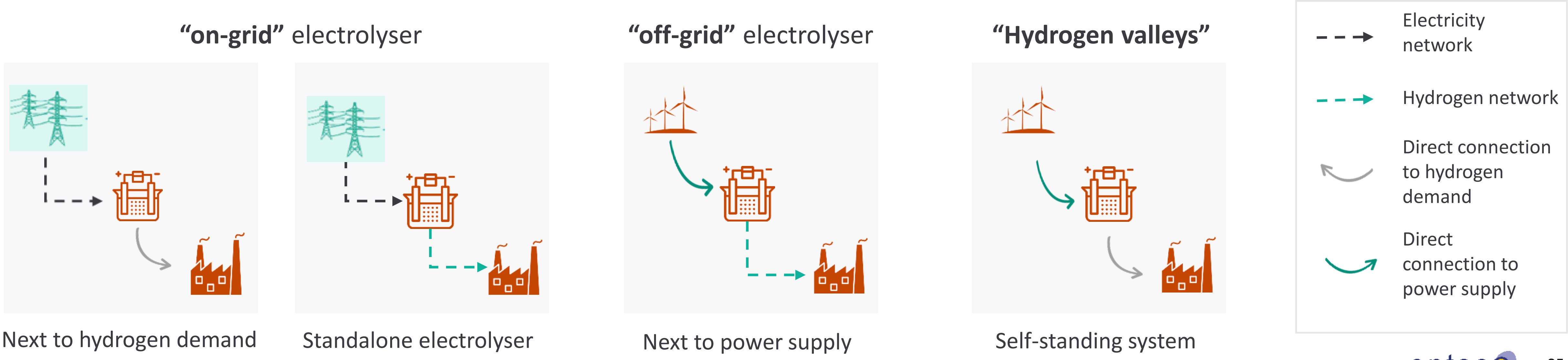
- Phase out direct subsidies
- Use of competitive PPAs to maintain operational cost stability under stricter additionality and correlation criteria
- Provide explicit demand response and system services (e. g., balancing, congestion management)
- Make use of advanced hydrogen storage and infrastructure

Key Messages & Recommendations

Antonio Iliceto – ENTSO-E

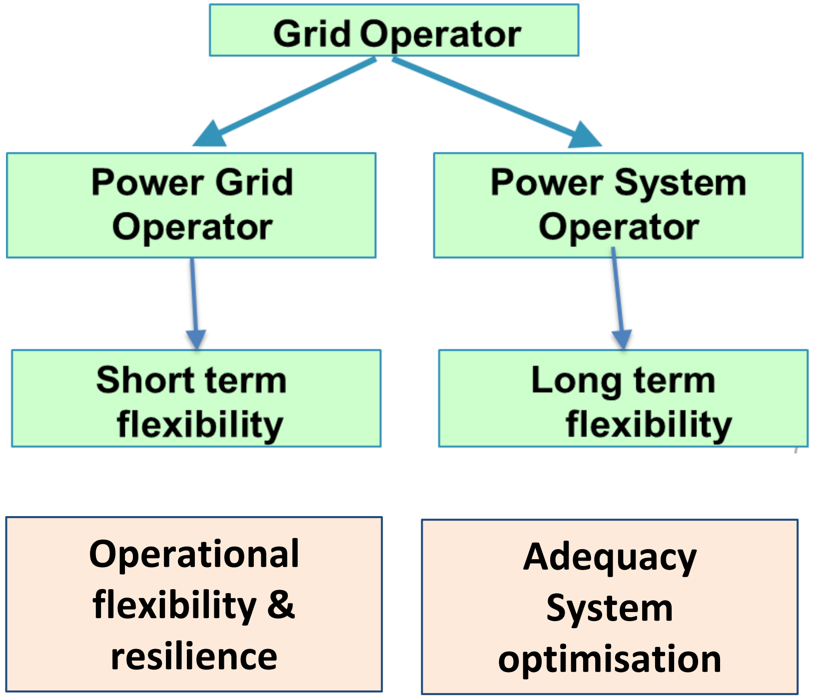
Key messages: grid planning & infrastructure investments

1. Electrolysers and hydrogen-fuelled generation will become new components of an **integrated energy system**.
2. Electrolysers configuration, connection type and siting impact both power grid **planning and its operation**.
3. Only a fraction of final hydrogen demand shall impact the electricity system, **excluding imports, blue hydrogen and off grids** electrolysers.
4. Planning coordination of **electricity, gas and hydrogen infrastructures** (including H2 grids, distribution, storage, ports and logistics) is paramount to best **satisfy connection requests**, to **optimise siting decisions**, to avoid over dimensioning and **stranded assets** → targeting overarching system benefits.

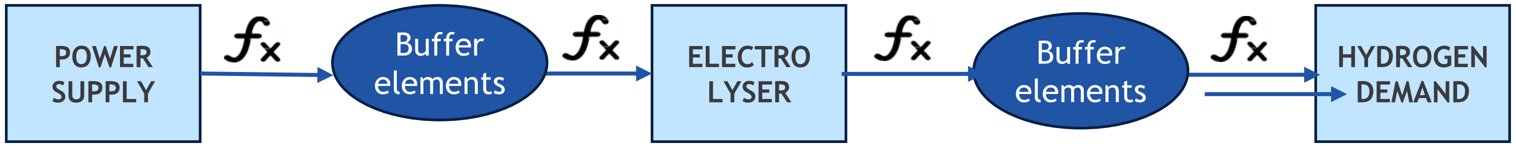


Key messages: operational modes and flexibility provision

1. **Operational synergies** should be pursued, depending on **business model**, operational modes (base load, electricity price-driven, demand-driven), leading to win-win situations. Today, grid issues are **not in the radar** of hydrogen developers/operators.
2. **Electrolysers can become a promising source of short-duration flexibility** through implicit and explicit demand response, for balancing and congestion management.
3. **Long-duration** flexibility can in the future be provided through well-developed hydrogen **transport & storage facilities** for re-electrification in prolonged RES scarcity periods.
4. **Hydrogen-fuelled generation** can contribute to resource **adequacy** (demand response and last resource reserve).



Flexible operation: decoupling profiles through grids, storage, demand response



Decoupling electrolyser input from electricty generation

Decoupling electrolyser output from hydrogen demand

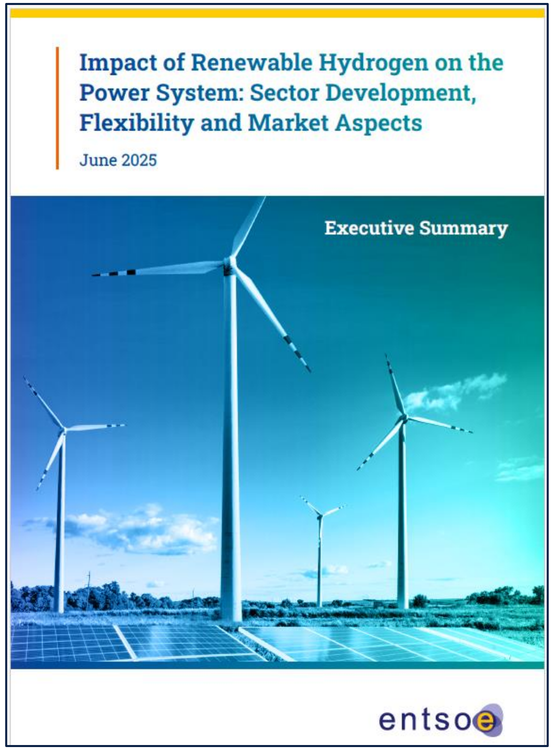
Key messages: Market Design & Regulatory Framework

1. **Public support mechanisms & regulatory incentives** facilitate the development of renewable hydrogen ecosystem targeting either **hydrogen production or hydrogen demand**, especially in the ramp-up phase. They should be carefully designed to achieve an **efficient decarbonisation effect & to incentivise** flexibility for the power system.

2. **Supply side:** OPEX incentives (cap & floor, CfDs, reduced RES levies) need to be well designed to incentivise operation **in line with market conditions** (e.g. low spot prices) **& system needs** (e.g. avoiding grid congestions), not only with hydrogen demand; **CAPEX incentives** can be more appropriate for that.

3. **Demand side**: supporting hydrogen offtake and investments in hydrogen storage can solve the **chicken-egg** problem unlocking the potential of the full value chain. Facilitating and **de-risking PPAs** can also support reaching this aim.

4. **Constraints for labelling renewable hydrogen** (e.g. RFNBO requirements and GOs) could contemplate in the ramp-up phase some **flexibility of application**, to balance impacts on hydrogen sector and on power system, under an overarching frame of efficient decarbonisation.



Q&A

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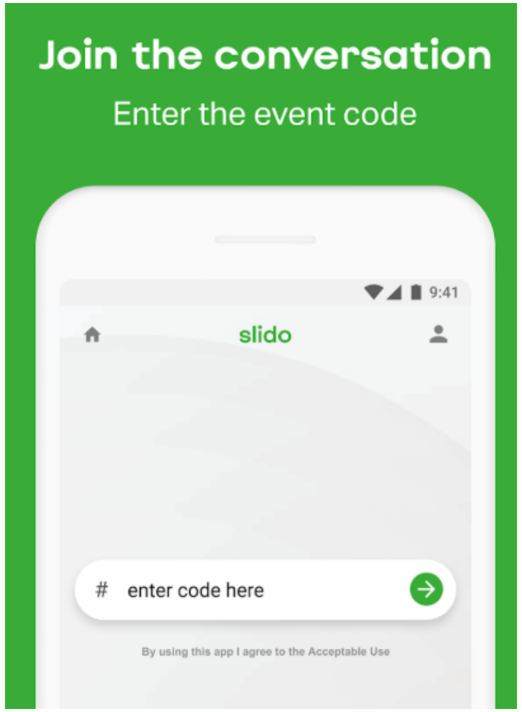

Panel discussion on Renewable Hydrogen:
Trends, Impact on the Power System, Regulation and Market Design

Marco De Benedictis
European Commission, DG ENER

Claude Mangin
ENTSOG

Ksenia Tolstrup
Magnus Energy

Nils Melcher
ENNOH

François Paquet
Renewable Hydrogen Coalition

Javier Barrantes Egaña
ENTSO-E

Closing remarks

Marco Forteleoni – Vice Chair of the Research, Development and Innovation Committee, ENTSO-E

Thank you very much for your attention

E-mail us in case of extra questions: rdi@entsoe.eu

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