GESEL: Webinar Internacional

“Tecnologia e Centros de Excelência de Hidrogênio em Portugal e Brasil”

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Managing Director

AGENDA

- A R&D Nester – Creating a Smart Energy Future
- B European Context for the Energy Transition
- C Hydrogen in the Energy Transition
- D Some Research Topics on Hydrogen
  1. Network
  2. Topology
  3. Logistics
  4. Flexibility
  5. Operation
  6. Modelling
  7. Regulatory
  8. Smart Buildings
  9. Asset Management
  10. Mobility
  11. Energy Systems Integration

A R&D Nester – Creating a Smart Energy Future

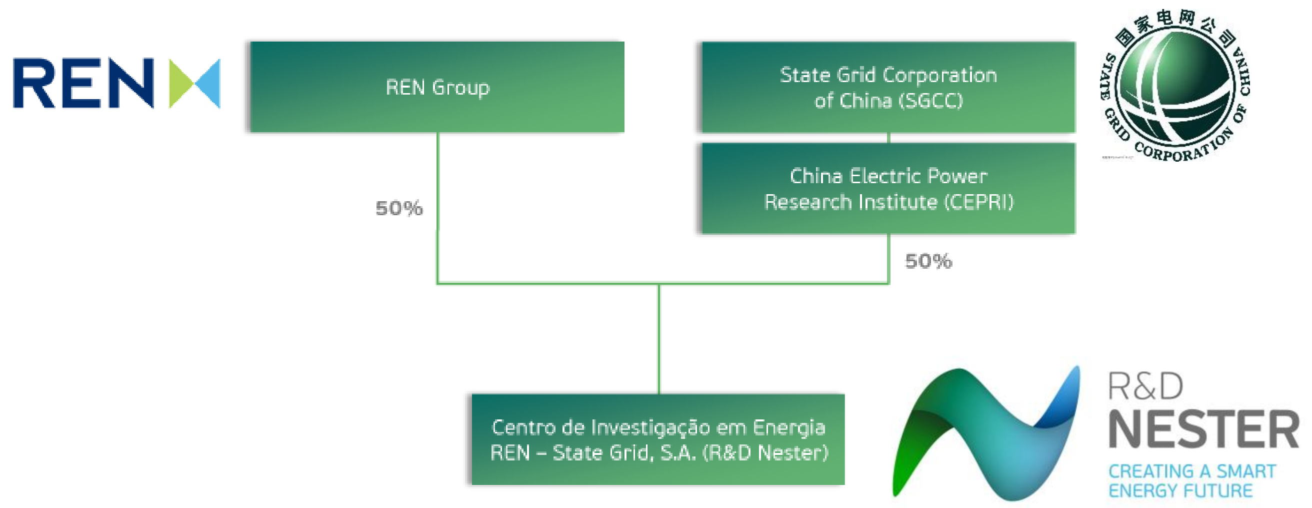
R&D NESTER

- R&D Center was created in **2013 in Portugal**

  (Centro de Investigação em Energia REN-State Grid, S.A.)

- Shareholders
  - REN (Redes Energéticas Nacionais – Portuguese TSO)
  - SGCC (State Grid Corporation of China),

    via CEPRI (China Electric Power Research Institute)



*"…The R&D Center shall embody an **international platform for knowledge**, delivering **innovative solutions, approaches and methods** to be applied into **power systems**, with the purpose of providing **new tools, strategies and processes**, well-tuned to the **new energy paradigm**, and serving as a driving force towards a more efficient power system operation and management. …"*

R&D Nester – Creating a Smart Energy Future

Renewables Forecast and Integration

P1: Renewable Energy Dispatch Tools
P5: ISSWINDemo: Integrated Supporting Services for Wind Power Industry Demonstrator
P6: SusCity: Modelação de Sistemas Urbanos … Sustentáveis
P7: Renewables Integration Tools
P16: New Energy Power Forecasting
P27: UltraFOR: Improve Very Short-term Forecast for Solar PV
P28: Research on Short-term Wind Power Ensamble Learning Forecasts

Flexibility / Storage

P3: Multi-atribute Energy Storage Planning
P19: OSMOSE: Optimal System-Mix of Flexibility Solutions for Europe
P14: FlexiTranStore: Integrated Platform for increased Flexibility …
P22: Geographical Islands Flexibility
P24: FlexUnity: Scaling-Up Power Flexible Communities with Blockchain and AI

Digitalization

P2: Substation of the Future
P8: Substation of the Future Demo
P12: Protections over IP/MPLS
P29: HighSpeedCarrier: Communications Standard Testing and Verification

System Operators Coordination (TSO/DSO)

P13: TDX_ASSIST: Coordination of Transmission and Distribution Data Exchange
P23: INTERRFACE: TSO-DSO-Consumer Interface Architecture
P31: OneNET: One Network for Europe

A R&D Nester – Creating a Smart Energy Future

R&D NESTER

System / Network Planning / Dimensioning

P11: Global Energy Interconnection
P15: ARCWIND: Adaptation and Implementation of Floating Wind Energy Conversion Technology for the Atlantic Region
P20: OptiGrid: Metodologias de Análise de Capacidade Dinâmica de Linhas e Gestão Optimizada de Redes Eléctricas
P25: FlexPlan: Advanced Methodology and Tools Taking Advantage Of Storage and Flexibility in Transmission and Distribution Grid Planning
P30: Integrated Energy System

Asset Management

P21: RESUCI: Space-based Services to Support Resilient and Sustainable Critical Infrastructures

Markets

P18: SIMMRES: Study on the Impact of Market Mechanism to Renewables
P32: Market Coupling

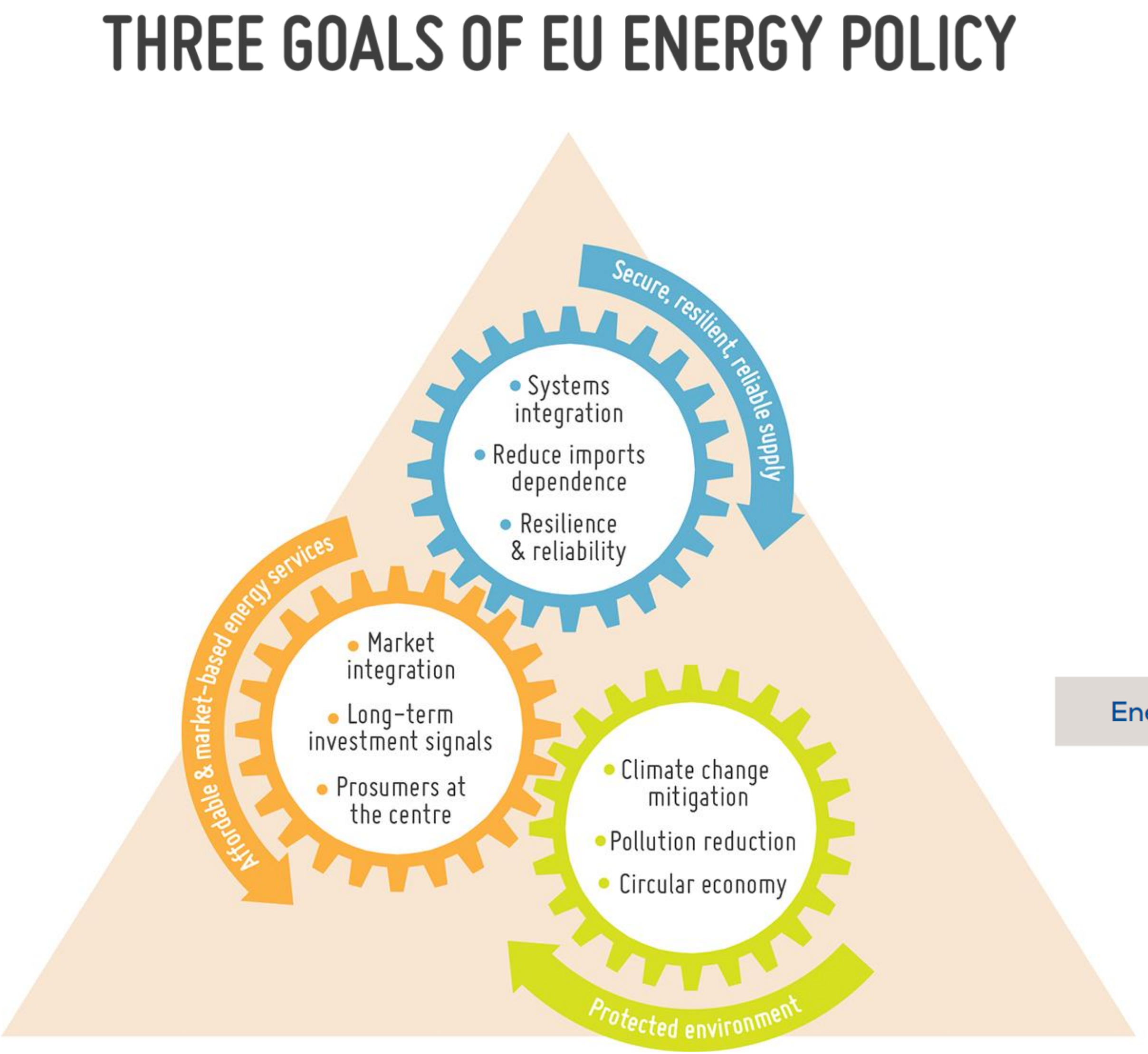
Network Simulation

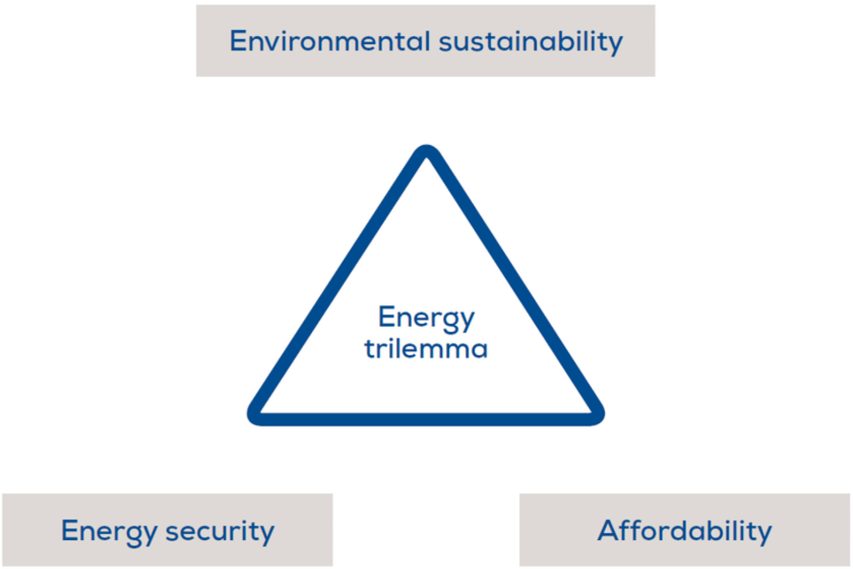
P4: Power System Simulation
P17: FlexUnity: Stability Study in Grids with High Penetration of Renewables

Analytics

P9: BigDataOcean: Exploiting Oceans of Data for Maritime Applications
P33: BD4NRG: Big Data for Energy
P34: i-NERGY: Artificial Intelligence for Next Generation Energy

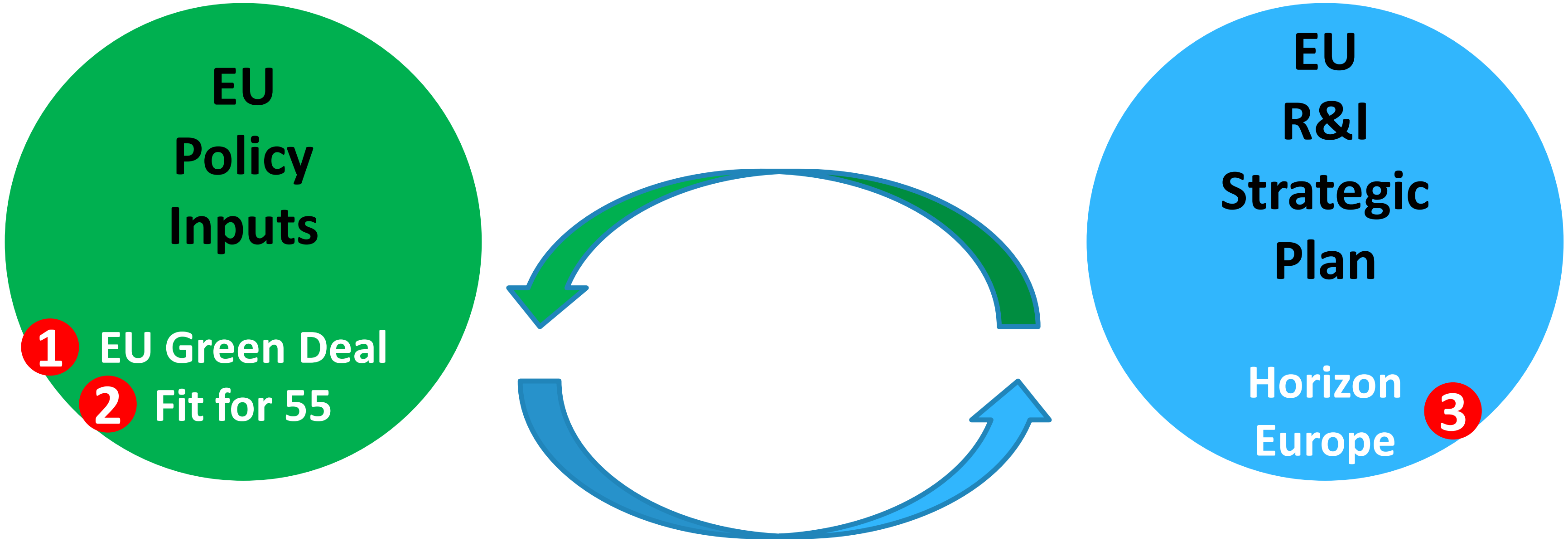
B European Context for the Energy Transition





B European Context for the Energy Transition

R&D NESTER



4 ETIP SNET

European Technology and Innovation Platform – Smart Networks for Energy Transition

The ETIP Smart Networks for Energy Transition (SNET) role is to **guide EU Research, Development & Innovation (RD&I)** to support Europe's energy transition

B European Context for the Energy Transition

R&D NESTER

1

The European Green Deal, COM(2019) 640 final

EUROPEAN GREEN DEAL

- EU TOWARDS SUSTAINABLE FUTURE
- LEAVING NO ONE BEHIND

- UN 2030 Agenda
- Sustainable Development Goals

Policies

ENERGY-RELATED KEY ASPECTS / IMPLICATIONS

Climate neutrality	Clean, Reliable & Affordable Energy	Sustainable transport	Buildings and Construction	Circular Economy	Zero pollution EU	… Farm-2-fork Ecosystem
50-55% emissions target by 2030	*Energy Efficiency*	*Sustainable smart mobility (road, rail, water)*	*Energy Efficiency in Buildings*	*Raw materials for clean technologies*	…	
…	*Renewable sources*	*Public charging points*	*Digitalization / automation*	*Fuel cells and H2*		
	Offshore wind	*Alternative fuels*	…	*Storage / Batteries*		
	Smart sector integration (E, G, H&G, H2)	*Low poluants emission technologies / standards*		*Digital technologies (IA, 5G, IoT, …)*		
	Cross-border and regional cooperation	*Digitalization*		*Energy Efficiency*		
	Regulatory framework	…		…		
	Smartgrids					
	Storage					
	Reduce energy poverty /affordable					
	Integ, Interc, Digital Energy Market					

B European Context for the Energy Transition

2

Fit for 55,
COM(2021) 550 final

FIT for 55 (2030)

FAIR | COMPETITIVE | GREEN

Proposals

8 updates on existing legislation + 5 new initiatives

Climate | Energy & fuels | Transport | Buildings | Land-use | Forestry

B European Context for the Energy Transition

R&D NESTER

2

Fit for 55,
COM(2021) 550 final

FIT for 55 (2030)

FAIR | COMPETITIVE | GREEN

Proposals

8 updates on existing legislation + 5 new initiatives

Climate | Energy & fuels | Transport | Buildings | Land-use | Forestry

ENERGY-RELATED KEY ASPECTS / IMPLICATIONS

Pricing

- Stronger Emissions Trading System including in aviation
- Extending Emissions Trading to maritime, road transport, and buildings
- Updated Energy taxation Directive
- New Carbon Border Adjustment Mechanism

Targets

- Updated Effort Sharing Regulation
- Updated Land Use Land Use Change and Forestry Regulation
- Updated Renewable Energy Directive
- Updated Energy Efficiency Directive

Rules

- Stricter CO_2 performance for cars & vans
- New infrastructure for alternative fuels
- ReFuelEU: More sustainable aviation fuels
- FuelEU: Cleaner maritime fuels

Support measures

- Using revenues and regulations to promote innovation, build solidarity and mitigate impacts for the vulnerable, notably through the new **Social Climate Fund and enhanced Modernisation and Innovation Funds.**

… 40% renewables …

… reduced burocracy …

… + integration of RES:
H&C, buildings, transport, industry …

… H2 in transport and industry …

… bio-energy …

… +9% energy efficiency than 2020
(e.g., public sector) …

… + focus on local authorities and communities …

… optimized technical solutions
for energy efficiency in buildings…

… infrastructure for low-emmission transport …

… ETS for buildings and transport…

3 Horizon Europe

Pillar 1 Excellent Science
- European Research Council
- Marie Skłodowska-Curie Actions
- Research Infrastructures

Pillar 2 Global Challenges and European Industrial Competitiveness

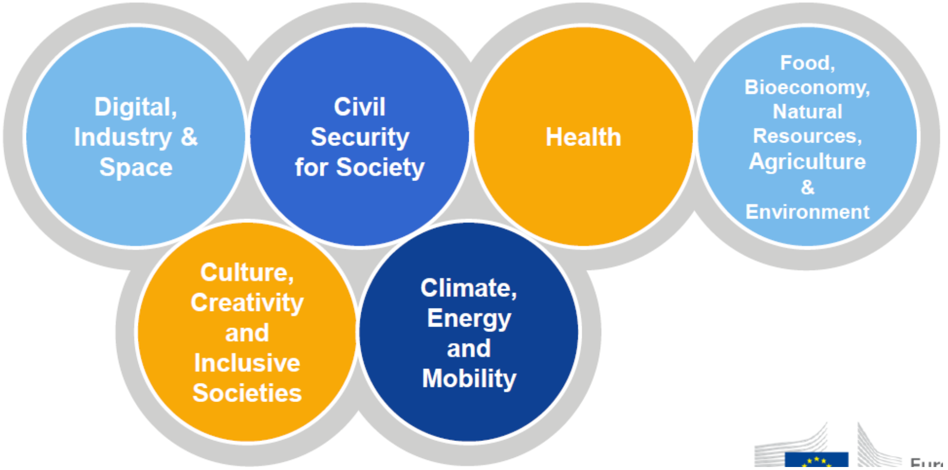
Clusters
- Health
- Culture, Creativity and Inclusive Society
- Civil Security for Society
- Digital, Industry and Space
- Climate, Energy and Mobility
- Food, Bioeconomy, Natural Resources, Agriculture and Environment

Joint Research Centre

Pillar 3 Innovative Europe
- European Innovation Council
- European innovation ecosystems
- European Institute of Innovation and Technology

Widening Participation and Strengthening the European Research Area
- Widening participation and spreading excellence
- Reforming and Enhancing the European R&I system

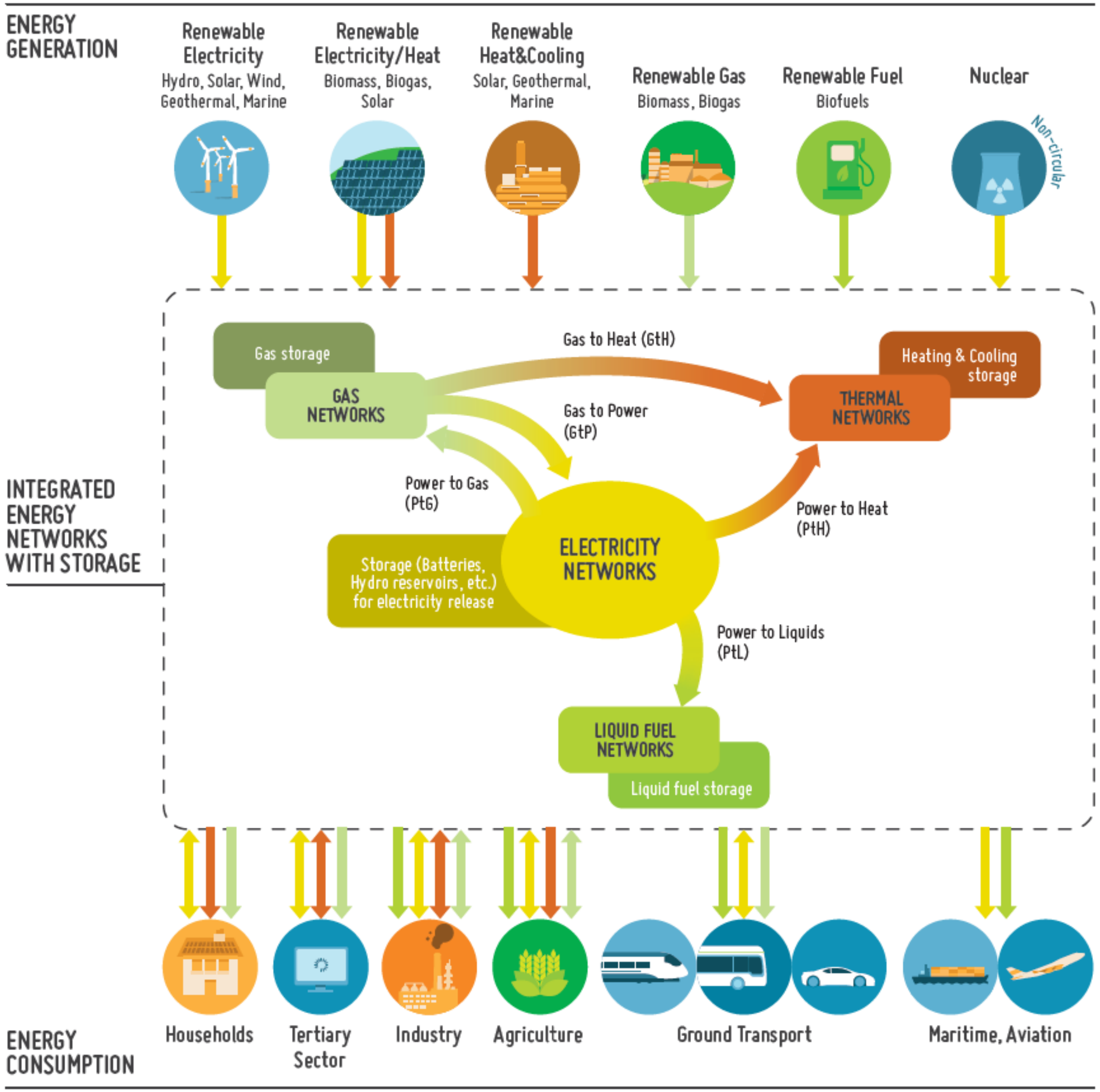
Clusters

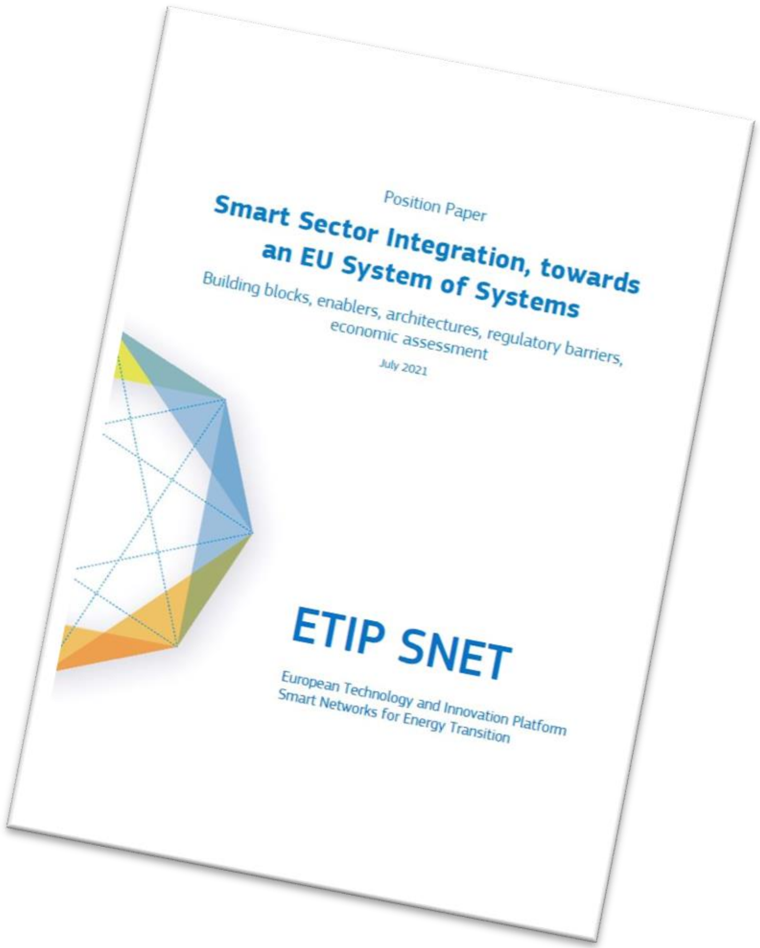


Climate, Energy and Mobility	• Climate science and solutions • Energy systems and grids • Communities and cities • Industrial competitiveness in transport • Smart mobility	• Energy supply • Buildings and industrial facilities in energy transition • Clean, safe and accessible transport and mobility • Energy storage

European Context for the Energy Transition

4





B

European Context for the Energy Transition

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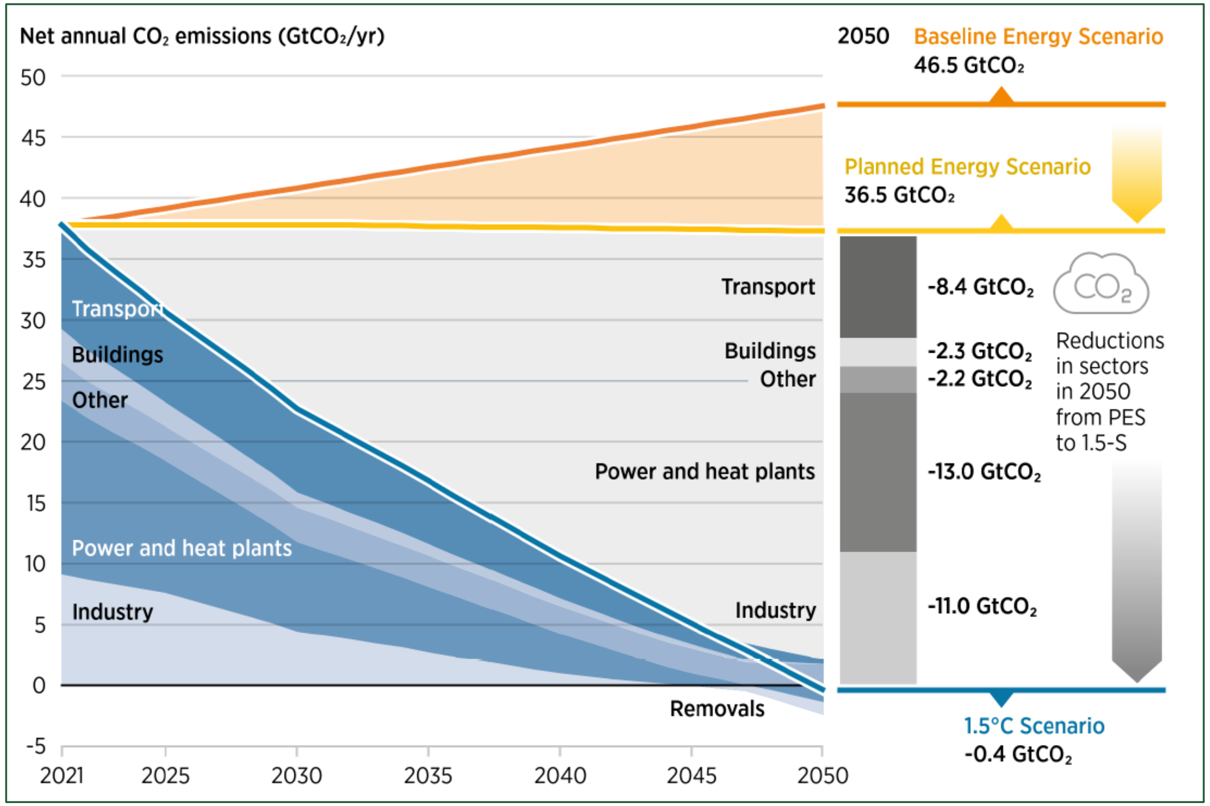
4

RA No.	Research Area (RA)	RA-Explanation
1	CONSUMER, PROSUMER and CITIZEN ENERGY COMMUNITY	Citizen and prosumer empowerment and engagement
2	SYSTEM ECONOMICS	Business models, market design and market-governance
3	DIGITALISATION	Digitalisation, communication and data handling (including Data, Cyber and System security)
4	PLANNING - HOLISTIC ARCHITECTURES and ASSETS	Energy system architectures, design and planning; new materials, technology solutions, asset management, maintenance; System Stability and resilience, multifunctional-system interfaces and system compatibility
5	FLEXIBILITY ENABLERS and SYSTEM FLEXIBILITY	Adapting all energy components to provide flexibility to the system (Flexibility in Demand, Generation, Storage & Energy Conversion, Network, Transport)
6	SYSTEM OPERATION	Reliability, forecasting, monitoring, control and automation (State estimation and supervision, short-term, medium and long-term control)

Hydrogen in the Energy Transition

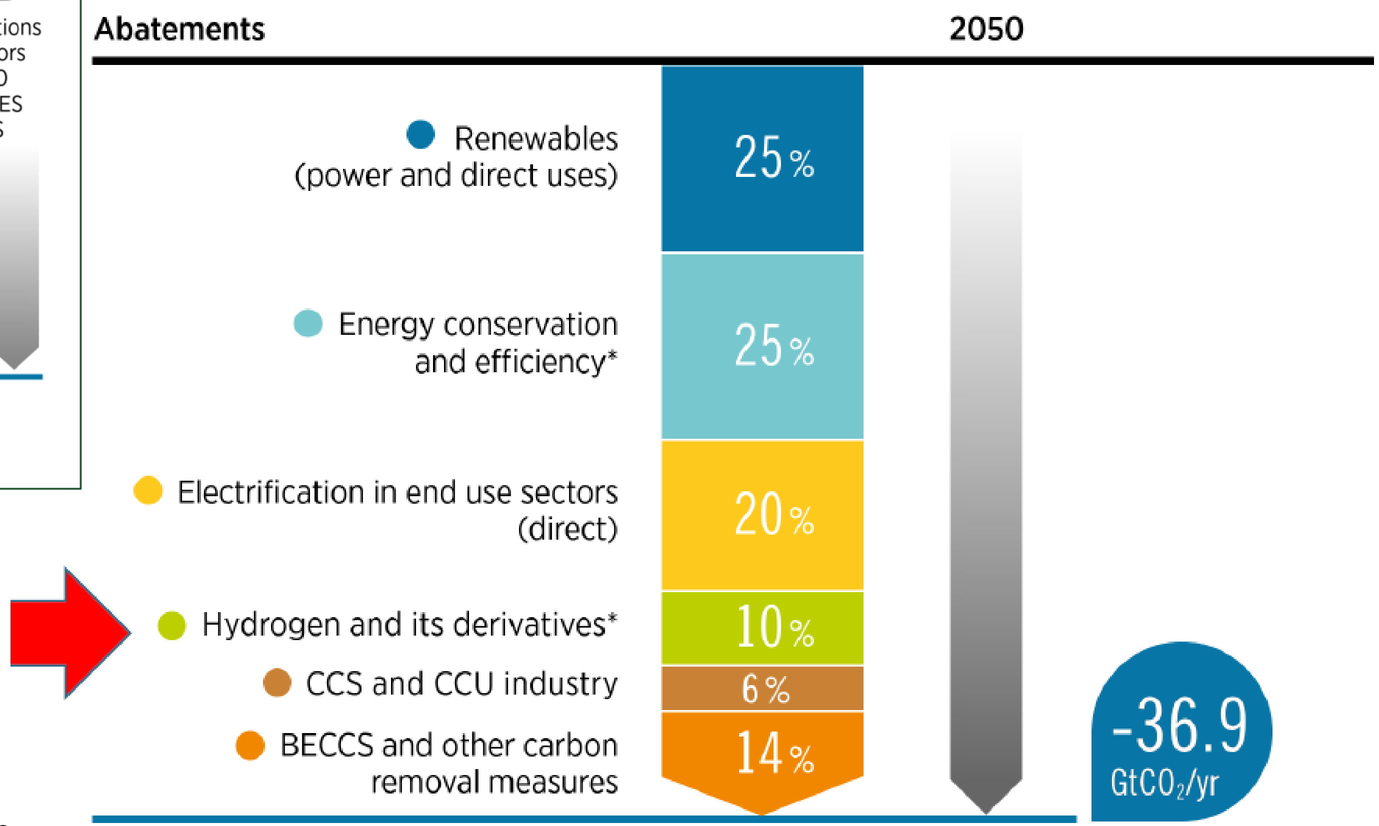
Deep decarbonization needs



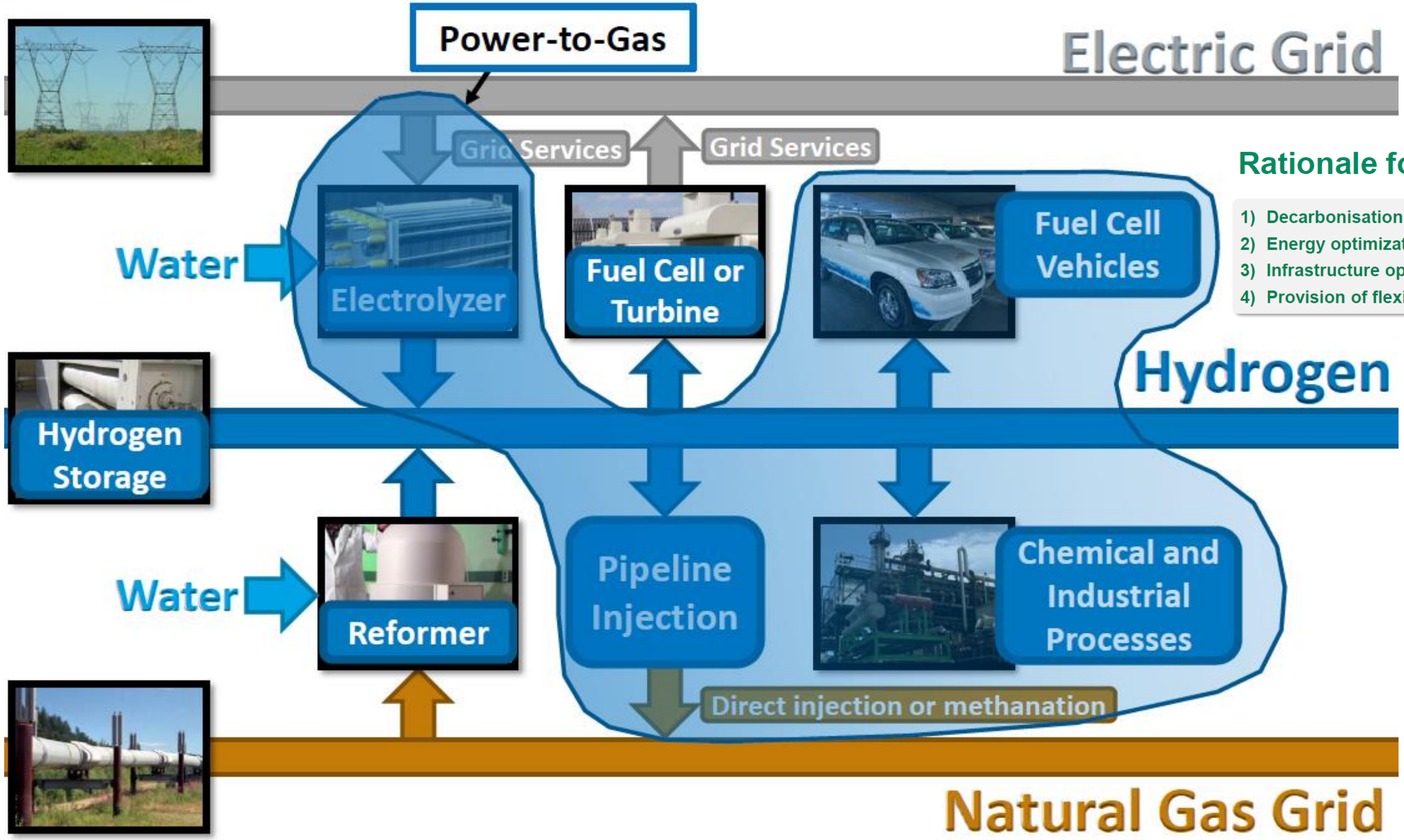
Source: World Energy Transition Outlook IRENA, March 2021 preliminary

FIGURE 2 **Six components of the energy transition strategy**

CO_2 emissions abatement options between the 1.5°C Scenario and PES



Hydrogen System Configurations



Rationale for Sector Coupling initiatives

1) Decarbonisation of energy sector and energy sources
2) Energy optimization = best use of energy primary resource mix
3) Infrastructure optimization = best use of existing grids and best planning of future assets
4) Provision of flexibility to operation of subsystems (foremost to electricity grids)

Source: Gardiner, NREL;CIGRE

Benchmarking on energy efficiency

Does it make really sense to convert **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:

- ✗ (red) Doesn't make sense.
- ✓ (yellow) Has to be evaluated.
- ✓ (green) Makes really sense.

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

Source: Terna

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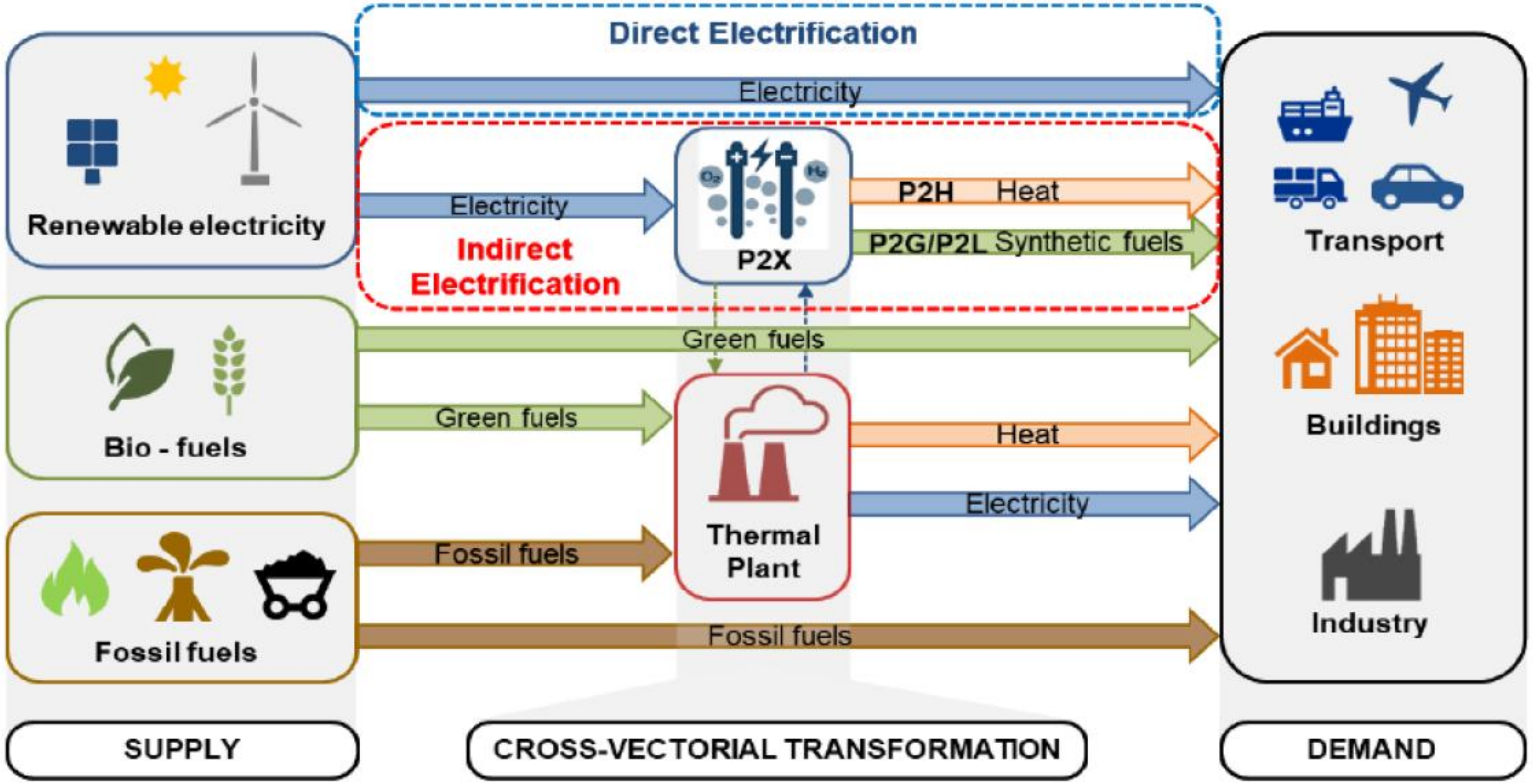
Power-to-Gas in the broader framework



Source: Terna

Sector Coupling and P2G assets in particular are required to decarbonize those sectors that struggles to be electrified. The potentiality of such assets to work as storage systems, in relation to the electricity system flexibility needs, has to be assessed.

C Hydrogen in the Energy Transition

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"**RD&I efforts are needed to ensure that hydrogen** can be widely adopted in many new applications to contribute fully to the energy transition.

New and affordable solutions need to be developed and tested in areas such as **materials for electrolysers and fuel cells**, **efficiency**, **durability**, **costs**, **safety**, **business models** so that hydrogen can become a technically feasible option, as well as an efficient and competitive one.

There are increasing fields of application for hydrogen, **not only in the energy sector (power, heating and gas) but also industry and transports**, and **research and innovation are necessary** to fulfil the potential of hydrogen in all these areas, and investment needs to be directed to **production and supply chain**, **storage**, **transport and transformation** of clean hydrogen for the whole economy and replace fossil fuels."

Source: ETIP-SNET, Smart Sector Integration, towards an EU System of Systems

Some Research topics on Hydrogen

R&D NESTER

Research and insights on Network aspects:

- H2 is **complementary** to electricity for decarbonisation (green H2 + green power).
- H2 can provide **long term storage** plus optimisation of primary energy (v RES) and infrastructures.
- Key numbers on volumes of H2 are relevant for **scenarios definition** and consequent analysis of **impact in grids**.
- Hydrogen and green gases will impact on system development paradigms, requiring to perform **planning and operation in cross sector coordinated manner**, also with natural gas infrastructures.
- Large RES volumes required for green hydrogen **risks to cannibalise** other RES usage.
- Large electrolysers can provide **grid services**: demand response, ramping as well as storage.

Table 3 Flexibility capability of electrolysers

	Alkaline electrolyser	PEM electrolyser
Load range	15–100% of nominal load	0–160% of nominal load
Start-up	1–10 minutes	1 second–5 minutes
Ramp-up	0.2–20% per second	100% per second
Ramp-down	0.2–20% per second	100% per second
Shutdown	1–10 minutes	Seconds

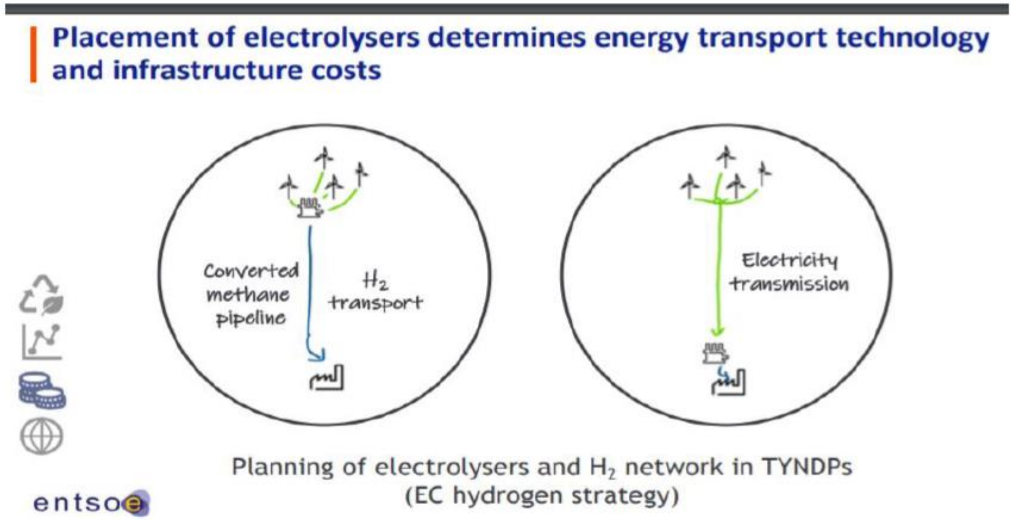
Source: IRENA: "Renewable Power-to-Hydrogen"

Note: The ramp-up and ramp-down figures are percentage of nominal load.

Some Research topics on Hydrogen

Research and insights on Topology aspects:

- The **location of an on-grid electrolyser** determines whether electricity or hydrogen has to be transported from the site of RES generation to hydrogen load centres.
- Hence, the locations of electrolysers will play a crucial role in causing potential **network bottlenecks and congestions**.
- To gain the synergies between hydrogen and the electric network, there is a need for **coordination** when deciding the location of the electrolysers and thus the link to potential hydrogen infrastructure.
- Such a coordination could be reached via appropriate **market mechanisms, tariff structures,** etc.



D Some Research topics on Hydrogen

Research and insights on <u>Logistics aspects</u>:

- To unlock hydrogen applications, a **cost-efficient transmission and distribution** will be required.
- **Long-term**, a network of pipelines offers the most cost-efficient means of distribution, while in the **short- to medium-term**, the most competitive setup involves co-locating hydrogen production on- or near-site that connects resource-rich regions to demand centers via trucks, trains, refueling stations, and smaller industrial users.
- **Longer distances** can be covered by shipping, where hydrogen needs to be converted to increase its density. While several potential hydrogen carrier approaches exist, three carbon-neutral carriers – liquid hydrogen (LH2), liquid-organic compounds (LOHC) and ammonia (NH3) – are gaining most traction. The **end use of hydrogen** needs to be considered to determine the most cost-optimal solution.

Exhibit 12: Overview of distribution options

<0.1 USD/kg | 0.1–1 USD/kg | 1–2 USD/kg | >2 USD/kg

		Costs				
		Distribution		Transmission		
		0–50 km	51–100 km	101–500 km	>1,000 km	>5,000 km
Pipelines[1]	Retrofitted	City grid	Regional distribution pipelines	Onshore transmission pipelines	Onshore/Subsea transmission pipelines	N/A
	New	City grid	Regional distribution pipelines	Onshore transmission pipelines	Onshore/Subsea transmission pipelines	N/A
Shipping	LH_2	N/A	N/A	N/A	LH_2 ship	LH_2 ship
	NH_3[2]	N/A	N/A	N/A	NH_3 ship	NH_3 ship
Trucking	LOHC[2]	N/A	N/A	N/A	LOHC ship	LOHC ship
	LH_2 trucking	Distribution truck LH_2	Distribution truck LH_2	Distribution truck LH_2	N/A	N/A
	Gaseous trucking	Distribution truck CH_2[3]	Distribution truck CH_2[3]	Distribution truck CH_2[3]	N/A	N/A

1. Assuming high utilization
2. Including reconversion to H_2; LOHC cost dependent on benefits for last mile distribution and storage
3. Compressed gaseous hydrogen

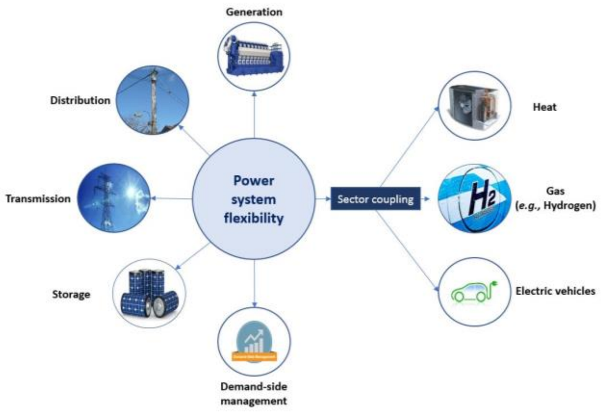
Source: Bloomberg NEF

D Some Research topics on Hydrogen

R&D NESTER

Research and insights on Flexibility aspects:

- Electrolysers could only provide flexibility to the electricity system if they are connected to the electricity grid. To **provide flexibility on the system level** the operational mode is essential.
- A trade-off between economic aspects (e.g. CAPEX, OPEX, **operation hours**) of electrolysers vs. system needs has to be found in order to have a **viable business case**.
- To provide flexibility to the electrical system, the hydrogen system must have **flexible elements** (like a hydrogen grid or storage).
- It is imperative to develop the business case to use hydrogen in an electricity system operation support function. **This business case does not currently exist**. Nevertheless the development of the hydrogen technologies for future use are already necessary today. **The viability as well as the impact on electricity grids is case- and country-dependent**, and no pre-determined conclusion can be applied until the use case has been analysed in its entire framework, boundary conditions and externalities



Source: IRENA

D Some Research topics on Hydrogen

R&D NESTER

Research and insights on <u>Operation Modes</u>:

- Several **operational modes of electrolysers** do exist with different interactions and impact with the electrical system. Some of them need flexibility from the electrical system (not desirable from a TSO perspective) and only few provide necessary flexibility to the electrical system (crucial to TSOs).
- Operation modes have impact on **hydrogen economics**.
- The EU and Member States should consider the role and impact of European **production vs. imports**.
- Development of a safe hydrogen fuel starting methodology.

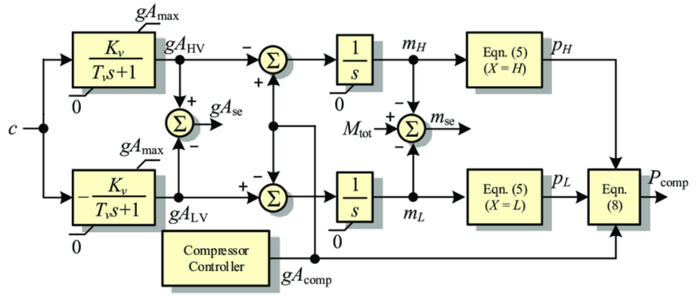
Source: Hydrogen Council; McKinsey & Company

D Some Research topics on Hydrogen

R&D NESTER

Research and insights on Energy system modelling, optimisation and planning tools:

- **Non-renewable energy conversion**: refineries producing fuels or hydrogen; modelling the cost and performance (including GHG emissions) of the conversion from the primary energy carrier to secondary energy carriers, including CCS where applicable .
- **Renewable energy conversion**: production of hydrogen and other renewable or low-emissions gaseous or liquid fuels; modelling of their cost and performances (power, efficiency …); modelling the conversion from the primary energy carrier to secondary energy carrier and by-products (O2, CO_2, including GHG emissions …)
- **Energy storage** models: stationary batteries (large scale and house), electric vehicle batteries, hydropower storage, thermal storage, methane storage, hydrogen storage … ; modelling of their cost and performances: power, efficiency, capacity, life expectancy, state-of-charge (for dynamic modelling), life cycle GHG emissions.
- **Transport pipelines** (including recompression stations): cost (per km) and performance (capacity, efficiency, GHG emissions) of existing and new natural gas, hydrogen, CO_2 pipelines, district heating/cooling pipelines or of upgrading pipelines to admixtures of renewable gasses or to pure hydrogen or to CO_2; as well as **other infrastructure (e.g. LNG terminals) or logistics** (e.g. transport by ship).



D Some Research topics on Hydrogen

R&D NESTER

Research and insights on Regulatory aspects (1):


Gas Infrastructure Europe

Regulation of Hydrogen Infrastructure

GIE Position Paper

- Development of **H2 infrastructures** raises questions about how to regulate it.
- Current **gas regulation does not cover** transport/markets of pure H2.
- Regulation for gas and electricity networks was introduced with networks already in place, while H2 sector still need to be developed
    - Gradual approach, depending on how H2 sector will evolve -> in case of natural monopoly/essential facilities or risk of **abuse of dominant position** (number of players, volumes, routes, market design) coherent approach across sectors for infrastructure planning
    - Regulatory principles: **Third party access** (TPA), Transparency, Non discrimination, Unbundling, Consumers' protections.
- If H2 sector will have characteristics like those of natural gas, gas regulation can be used, with technical and market differences
    - **Additional challenges** due to integrated energy system perspective -> coherent approach across sectors for infrastructure planning
    - Avoiding **cross subsidisation** between the gas and H2 network users.

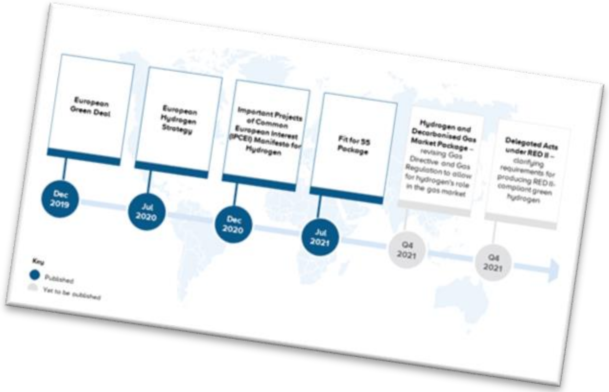
D

Some Research topics on Hydrogen

R&D NESTER

Research and insights on Regulatory aspects (2):

- Bring clarity on “**colour debate**” around hydrogen options and explore analysis on carbon content/equivalence.
- Facilitate access to low-cost renewable electricity.
- Partial **exemptions** of grid charges, taxes and levies for electrolysers.
- Create a level playing field for flexibility services to **unlock access** to electrolysers.
- Promote market uptake de-risking/insurance instruments (“take or pay”) (?).
- Harmonized **blending limits** in natural gas grid (?).
- Allow hydrogen mixed with natural gas to be used in existing natural gas infrastructure by defining a **remuneration mechanism** to encourage renewable hydrogen injection into gas networks.
- Allow use of existing gas networks for transporting renewable hydrogen and set relevant standards, including **safety standards** (e.g. encourage blending of hydrogen with natural gas in appropriate proportions, harmonise blending limits).



D Some Research topics on Hydrogen

R&D NESTER

Research and insights on Regulatory aspects (3):

- Allow electrolysers to **participate across the power sector** (e.g. in some countries, only generators can access frequency containment reserves and frequency restoration reserves).
- Stimulate the creation of **regulatory sandboxes** for initial deployment of Hydrogen related solutions.
- Natural gas infrastructure may be converted to hydrogen transportation in some cases. A mechanism to **modify the regulatory asset base** (RAB) of natural gas transmission system operators, and adjustment of their tariffs, would need to be established.
- **Tariffs for natural gas networks** need to be revised to facilitate the injection of hydrogen and tariffs for pure hydrogen networks need to be set so that a viable rate of return is reached by their investors ideas to discuss.

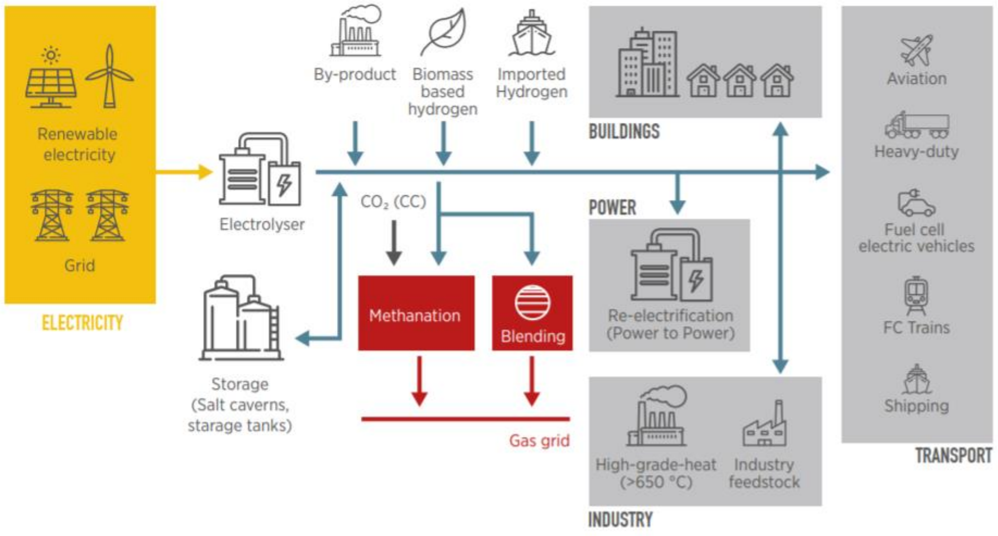
- A properly designed regulated environment is necessary to support the development of hydrogen technologies, especially in the early phase when the market is not yet ready to invest.

D Some Research topics on Hydrogen

R&D NESTER

Research and insights on Smart-grid ready and smart-network ready buildings, acting as active utility nodes:

- Enhance interoperability and synergies between **buildings and grids, electricity and other energy carriers** (e.g. district heating networks, hydrogen, etc.) and where relevant, other relevant sectors (e.g. e-mobility).
- **Citizen energy communities**, with **energy management systems** for local multi-energy streams operation, including electrical-storage, P2x generation and storage, and x2P (including CHP based on hydrogen and fuel-cells).



Source: IRENA

D Some Research topics on Hydrogen

R&D NESTER

Research and insights on Asset Management:

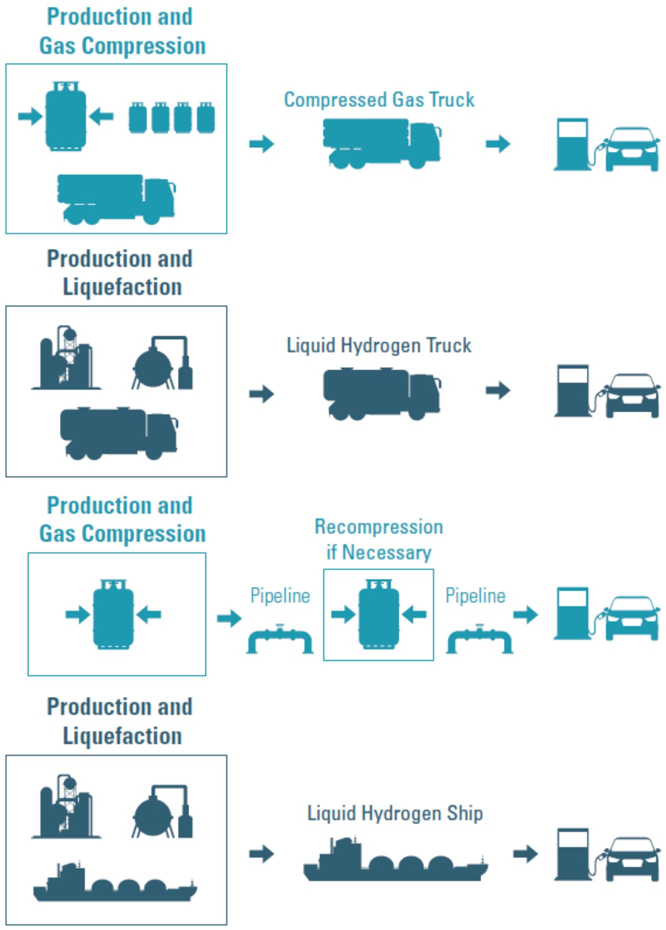
- Techno-economic feasibility assessment of **retrofitting existing assets** for low-carbon flexible power generation, including the re-use of natural gas infrastructure for decarbonized gases such as hydrogen.
- Development of highly **efficient, integrated cogeneration units** of varying size with decoupled use of heat & power, powered by hydrogen, biomass and biofuels.
- Increase **fuel flexibility** of thermal power plants for using (mixing and switching) different sources of CO2-neutral fuels (hydrogen, biomass and biofuels).
- …

D Some Research topics on Hydrogen

R&D NESTER

Research and insights on Mobility (land and maritime) aspect:

- Enabling the **safe and efficient on-board storage** and integration within **ships** of large quantities of ammonia and hydrogen fuels .
- Demonstration of the **feasibility to store and use hydrogen** based fuels (generally in liquid form) on a **medium and large scale** (capacities equivalent to +300 tons of conventional marine fuel) in a realistic environment on-board.
- Demonstrate **Modular multi-powertrain zero-emission systems** for Heavy Duty Vehicles (BEV and FCEV) for efficient and economic operation.
- …

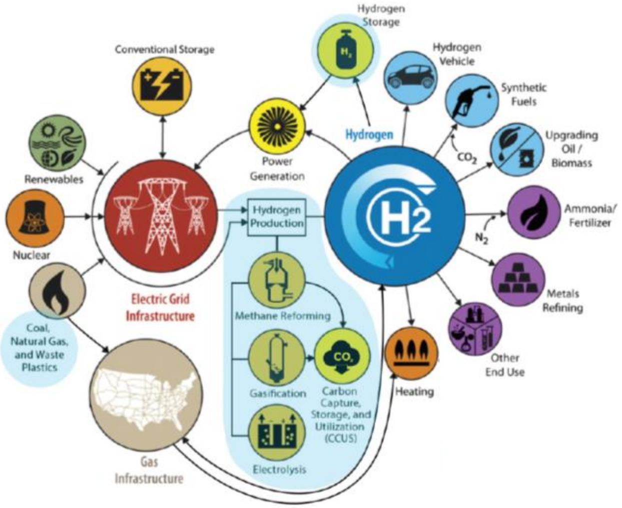


Source: US DoE

Some Research topics on Hydrogen

Research and insights on <u>Energy Sector Integration –</u>
<u>Integrating and combining energy systems to a cost-optimised and flexible energy system of systems (1)</u>:

- Demonstrated benefits of sector integration in **different geographic, climate and economic conditions**.
- **Improved planning** of integration of power, heat, gas, industry with a production site(s) of renewable energy.
- **Optimised operations** of coupled networks (e.g. electricity vs. heating).
- **Validated tools and platforms** enabling effective sector coupling as tested in large demonstration projects.
- Consolidated methodology to evaluate the **impacts on OPEX, CAPEX and overall value creation** connected to the integration of flexibility from storage and other energy flexibility solutions.
- Development of an **optimised natural gas system operating** with varying hydrogen concentrations.
- Identification of **the potential, the barriers and the role of grid operators** in the integration of energy sectors, considering the cost of coupling of complementary energy systems (electricity, natural gas system, green molecules (hydrogen), liquid fuels, district heating and cooling, electromobility).



Source: US DoE

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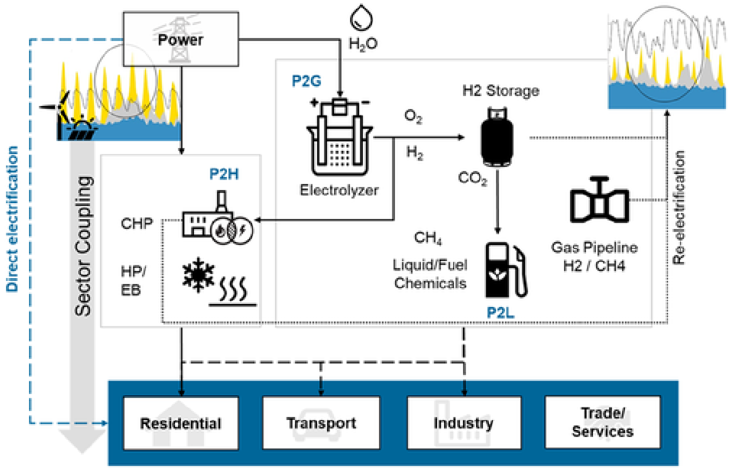
Research and insights on Energy Sector Integration – Integrating and combining energy systems to a cost-optimised and flexible energy system of systems (2):

- Demonstrate the **benefits of the integration of different elements**. This includes in particular electricity and gas networks, district heating and cooling, and long term energy storage systems (for example Hydrogen, power-to-X, thermal storage, hydro-storage).
- **System planning toolboxes** to determine the **optimal sizing, location and distribution** of energy storage systems and technologies to facilitate their optimal use at different grid levels, as well as system planning toolboxes to determine the **optimal location and utilisation rate** of available energy conversion plants.
- Tools to **quantify the flexibility** provided by sector integration
- **Integrated planning**: A multi-sectorial planning (MSPS) from scenarios to cost-benefit analysis could optimise the locations and operational patterns of electrolysers and thus the grid enforcement measures.
- Assessment of **capabilities, performance and constraints of conversion plants** (P2X: heat, gas and or hydrogen) within the electric system as validated in pilot projects.



Some directions from Hydrogen-related research (1):

- **Hydrogen is a tool** for reaching decarbonisation targets and not an end in itself. It should be benchmarked against other available options.
- **Direct electrification should be prioritised** as the most energy efficient solution. Molecules such as hydrogen should be used to support decarbonisation in sectors of the European economy when direct electrification is not technically viable or cannot be implemented cost-efficiently.
- **Decarbonising the already existing hydrogen demand** will be key in accelerating technological maturity, reducing costs and rapidly extending its deployment into other harder to reach applications and sectors.

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Some directions from Hydrogen-related research (2):

- A **Hydrogen network** is essential for hydrogen transport and flexibility, not only within a member state but also cross-border. It should not only be used to transport hydrogen, but also to enable flexible operation of electrolysers, hydrogen import and storage on EU scale.
- A **Hydrogen storage** is the element in the hydrogen system to balance the future variable hydrogen supply and demand. Furthermore, hydrogen and it derivatives can bridge the gap of the future system need for substantial long term storage, complementing hydro reservoirs and in competition with other means, like Compressed Air Energy Storage and heat long term storage.
- **Transition phase**: Since no relevant hydrogen infrastructure exists at the moment, **adapting the natural gas infrastructures** to accommodate hydrogen, as a blend of natural gas and hydrogen, is a viable transitory solution that enables a rapid creation of hydrogen delivery infrastructure and therefore a liquid market.

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Some directions from Hydrogen-related research (3):

- A unified system perspective (**one system view**) is necessary.
- Making **hydrogen a flexibility provider** to the electrical system will require structural investments beyond the electrolysers (**hydrogen grids and storage**).
- The **operational mode of electrolysers** connected to the grid will play a crucial role in the cost and decarbonisation of future integrated energy systems.
- The **location of electrolysers** is a strategic structural question. Appropriate coordination between hydrogen and the electric network system operators is needed to ensure that new assets effectively decarbonise the system without increasing costs.
- Multisectoral planning of the development of assets with a gradual **bottom-up approach** from regions to Europe will maximise the potential benefits of hydrogen investments.

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Some directions from Hydrogen-related research (4):

- Significant divergences are emerging across countries and regions, as national hydrogen strategies reveal varying attitudes towards hydrogen's role in energy transitions, different use cases and different topologies. This signals a **need to embrace diversity** – eliminating a one size fits all mindset – and enable differing technologies and use cases to be explored.

- **Demand-centric hydrogen perspectives** are needed. The current hydrogen conversation often focuses heavily on supply, and not so much on the role of hydrogen users. Research could further explore what's needed to trigger demand, with a specific focus on the development of hydrogen infrastructure and a global supply chain.

- Identify **relevant policy tools, regulation and economic barriers, incentive mechanisms**.

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Some directions from Hydrogen-related research (5):

- **Ensure that the electricity prices do not geopardize the competitiveness of hydrogen** solutions (facilitate access to low-cost renewable energy).
- Implement mechanisms that help to **monetize the hydrogen flexibility** (partial exemptions of grid charges, taxes and levies for electrolysers, similarly to other situations in the market).
- Allow electrolysers to participate across the power sector (e.g. in some countries, only generators can access frequency containment reserves and frequency restoration reserves).
- Stimulate a **dedicated H2 refuelling infrastructure, to boost H2 mobility**.
- **Harmonized blending limits**, to facilitate transport and distribution.
- **Promote technology scale-up**.

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