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DANISH HYDROGEN INSIGHTS

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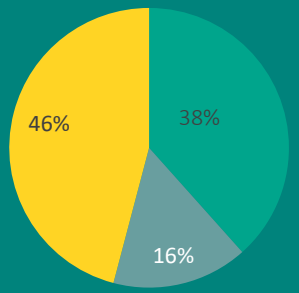
WE BALANCE, OPERATE, DEVELOP AND OWN THE DANISH ELECTRICITY AND GAS TRANSMISSION GRID

Danish gas balance, 2024 (76 PJ)

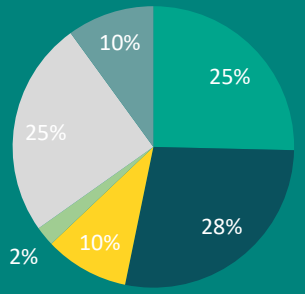


biomethane
net imports
natural gas

100% sec. of supply

38% green gas

Danish electricity balance, 2024 (37 TWh)



offshore
onshore
solar
other renewables
thermal
import

99.99% sec. of supply (2023)

63% solar+wind

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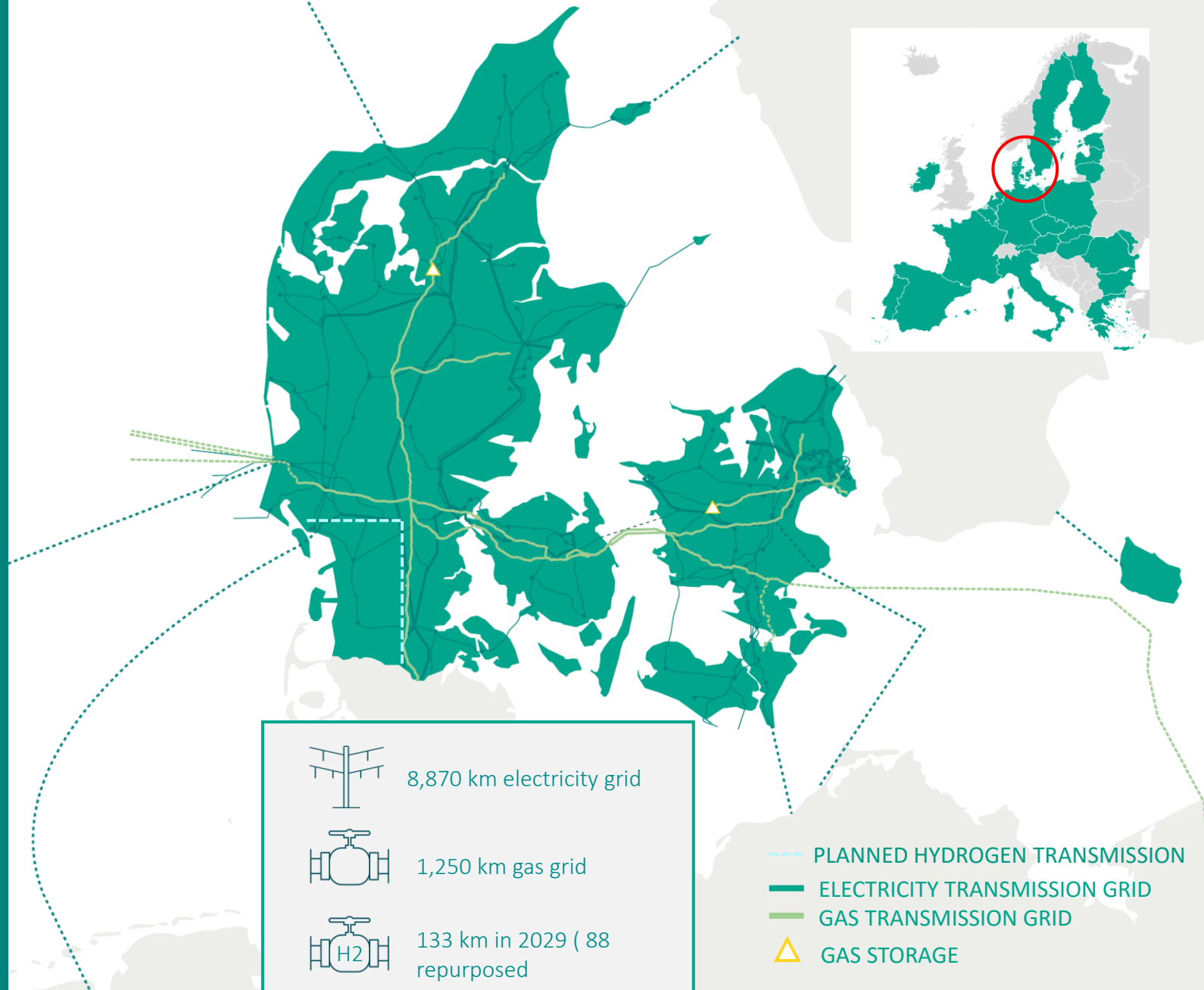


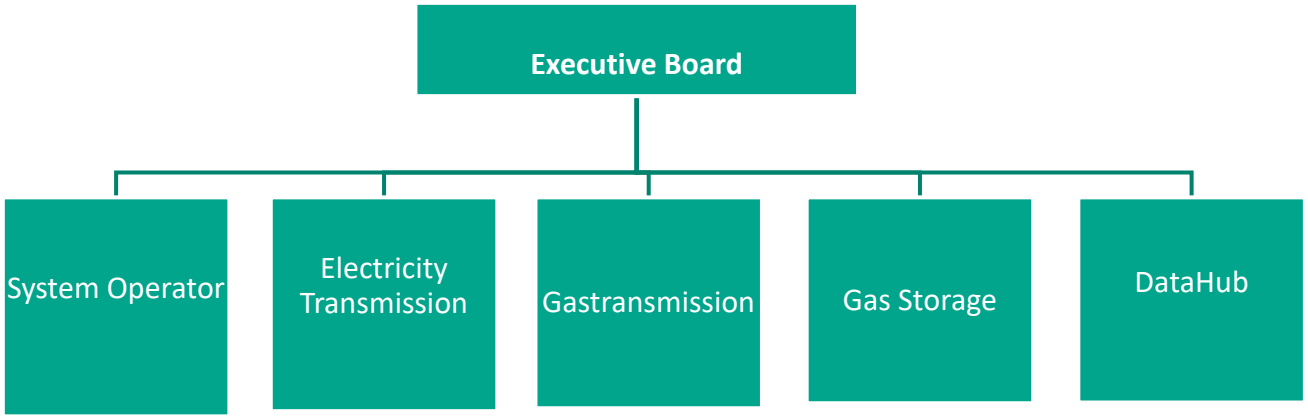
8,870 km electricity grid

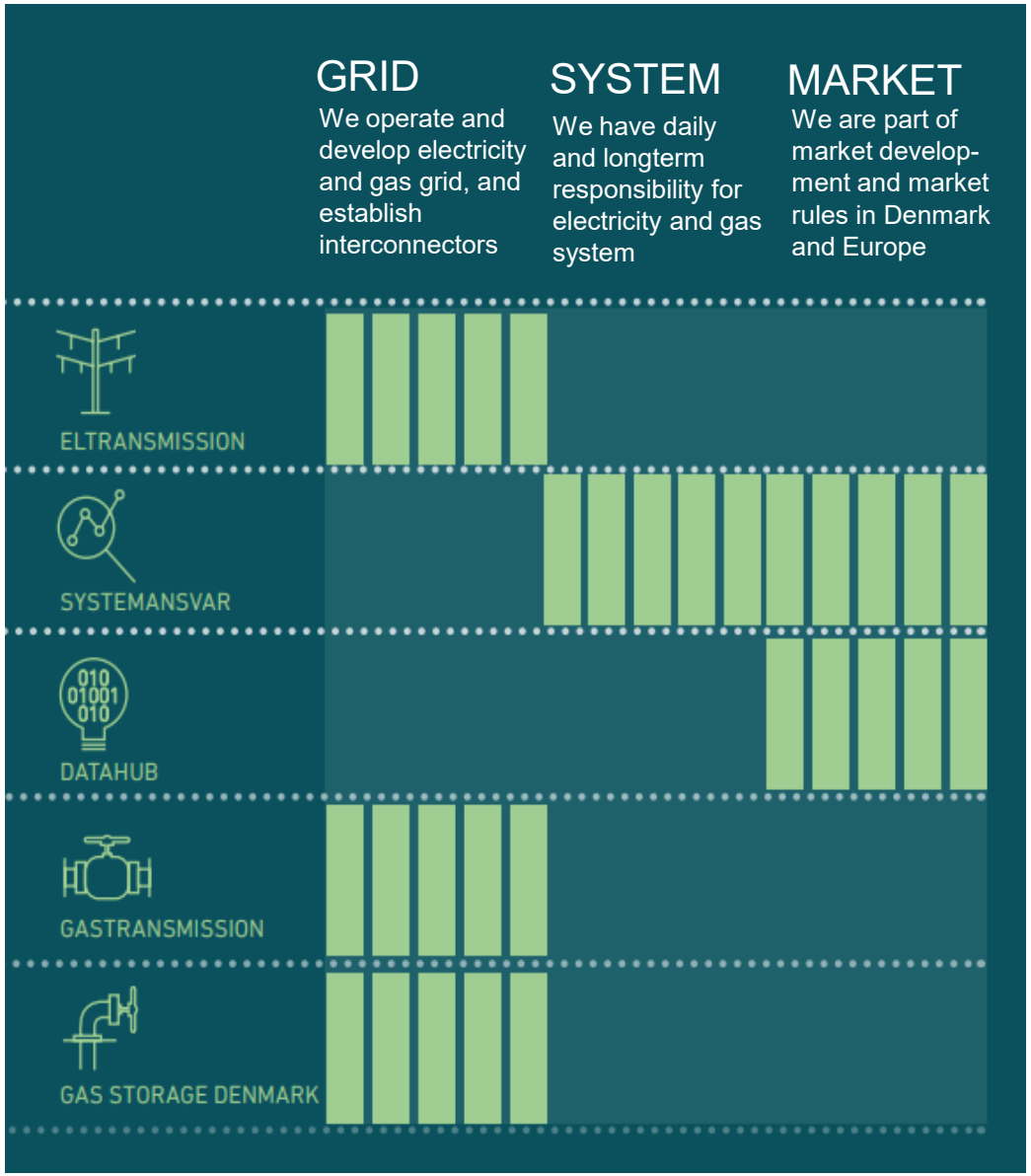
1,250 km gas grid

H2 133 km in 2029 (88 repurposed

PLANNED HYDROGEN TRANSMISSION
ELECTRICITY TRANSMISSION GRID
GAS TRANSMISSION GRID
GAS STORAGE

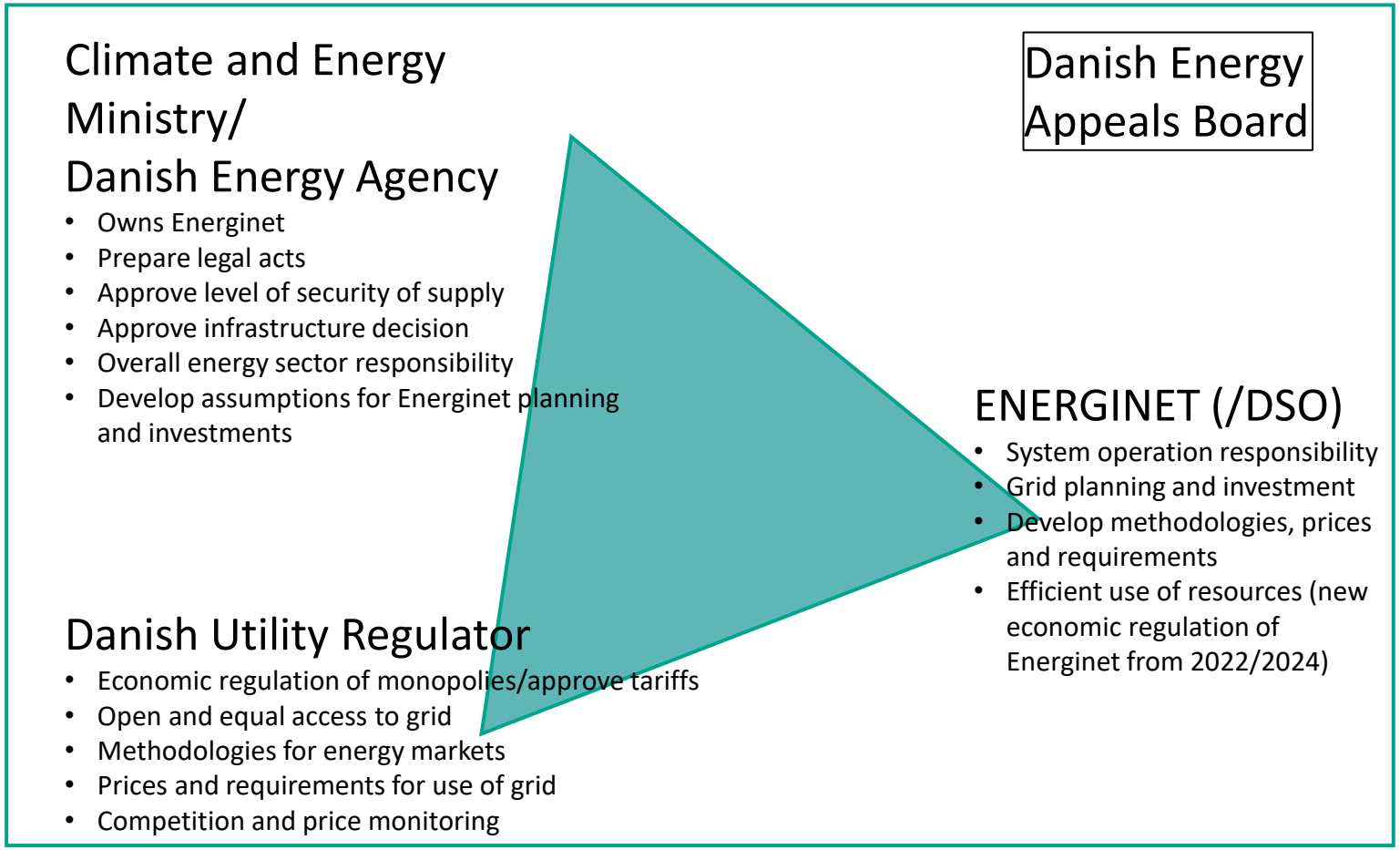
ENERGINET GROUP





OVERALL GOVERNANCE IN DENMARK

European institutions:
- Council
- Commission
- Parliament
- Court



European Agency for the Cooperation of Energy Regulators (ACER)

European network transmission system operators for Electricity and Gas (ENTSO-E and ENTSO-G)

THE DANISH ENERGY TRANSITION

MAIN TOOLS FOR GREEN TRANSITION

- Stable and holistic energy planning
- Clear mandate for TSO and transmission build out
- Flexible electricty production, consumption and interconnectors
- Market based regulation and electricity markets
- Digitalization of planning, operation and markets

DANISH GREEN TRANSITION

2024: 64% green VRE electricity

40% biomethane

Electricity security of supply:

99.997%

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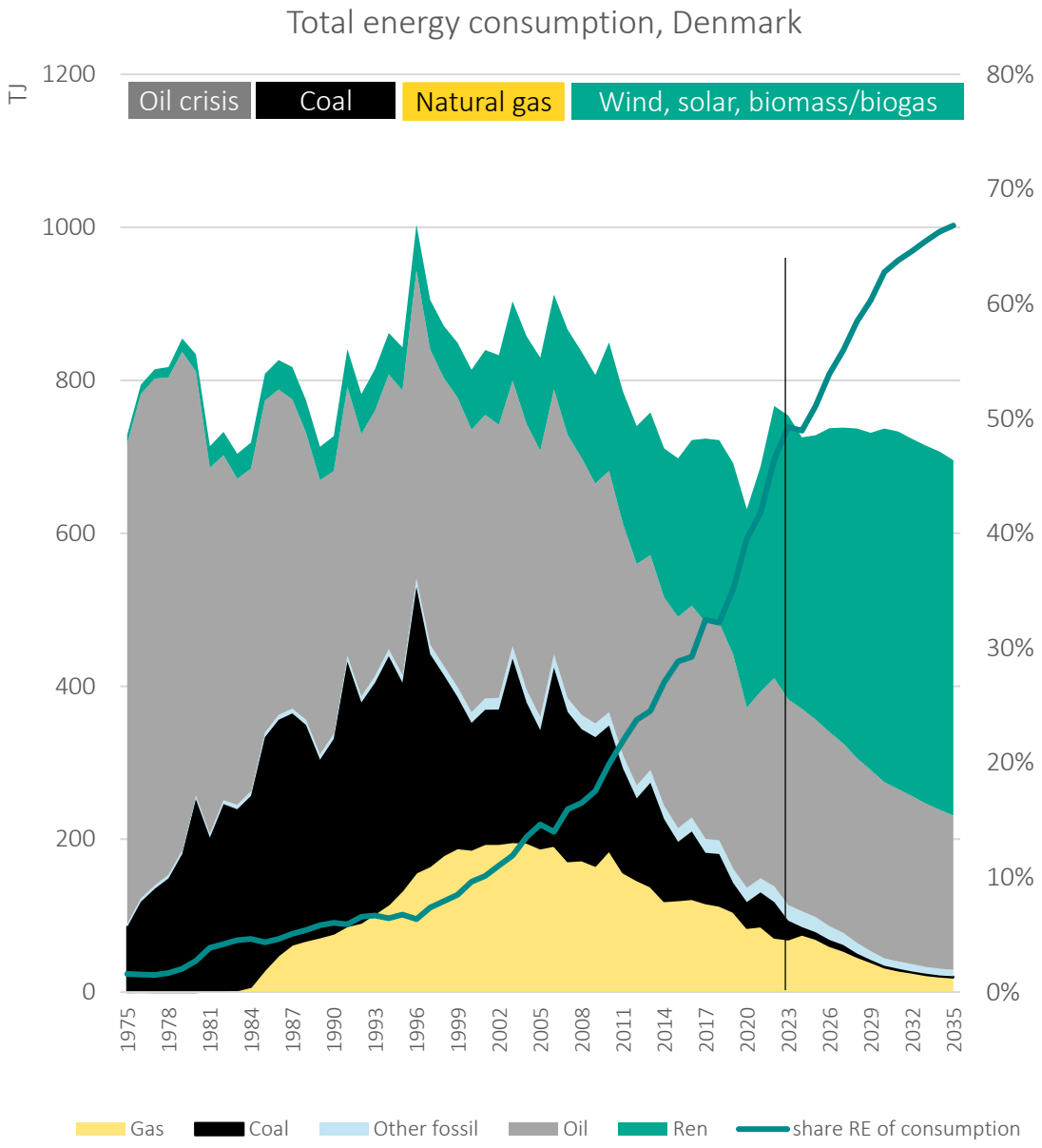
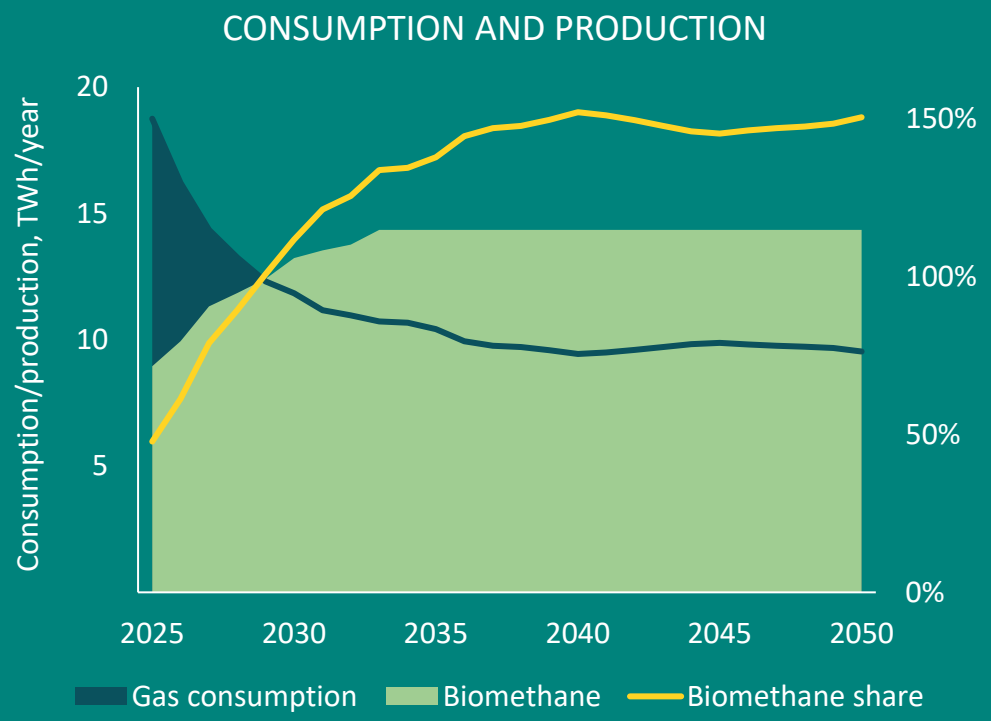
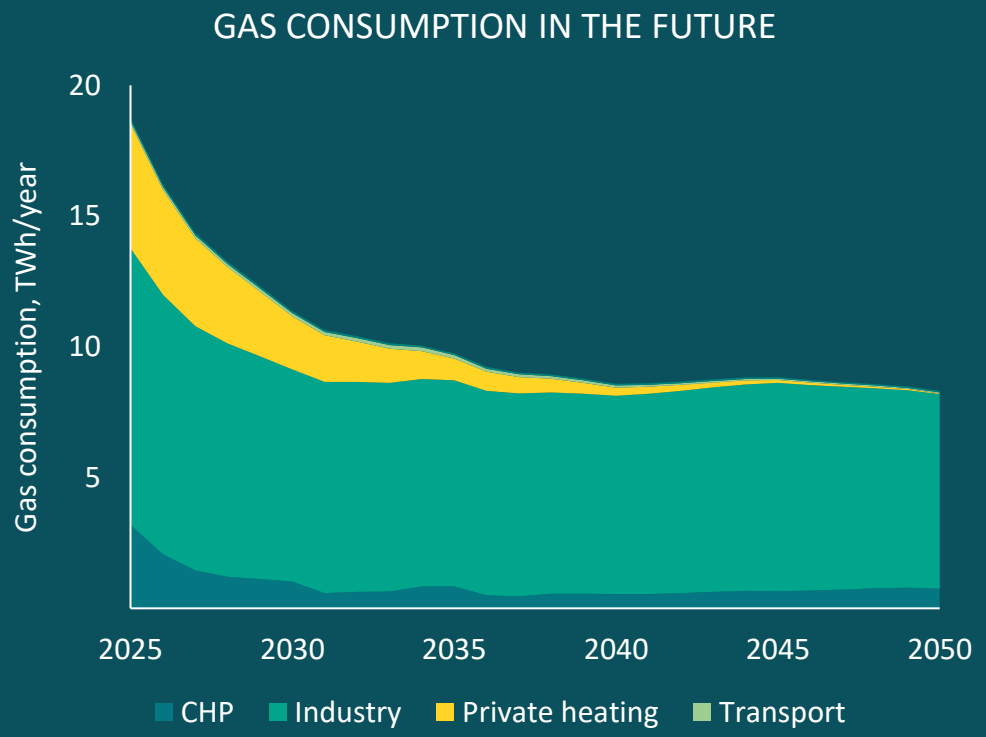


THE DANISH ENERGY AGENCY SETS OVERALL DIRECTION…



- Green gas production expected to almost double
- Future gas consumption expected half of current level
- 100% green gas in 2030



- Gas for private heating negligible in the future
- Gas for industry is expected to stay at current level: some will disconnect, but new users will be connected.

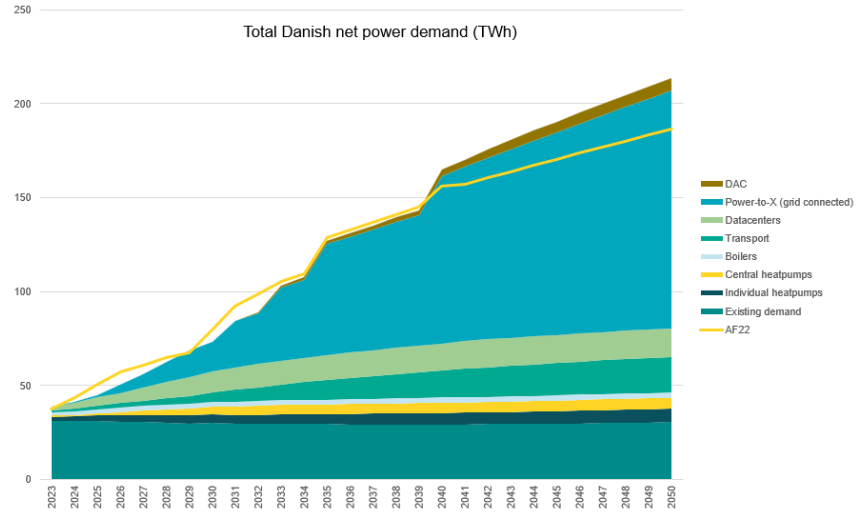
GREEN TRANSITION
CALL FOR MASSIVE INVESTMENTS

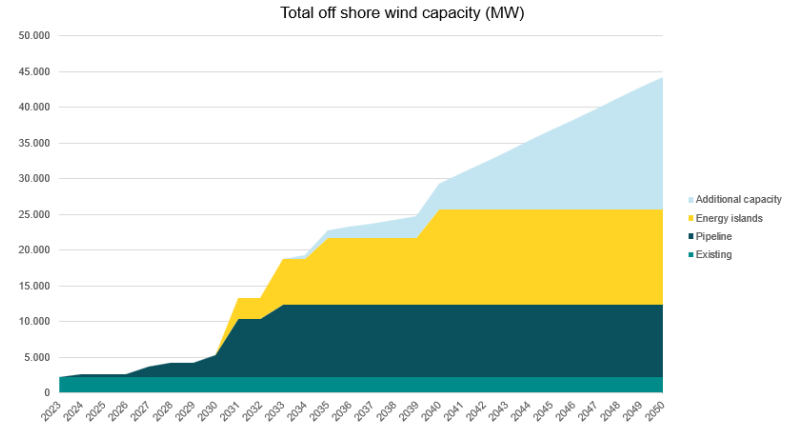
Driven by ambitious political agreements and declarations aiming for CO2 neutrality by 2045.

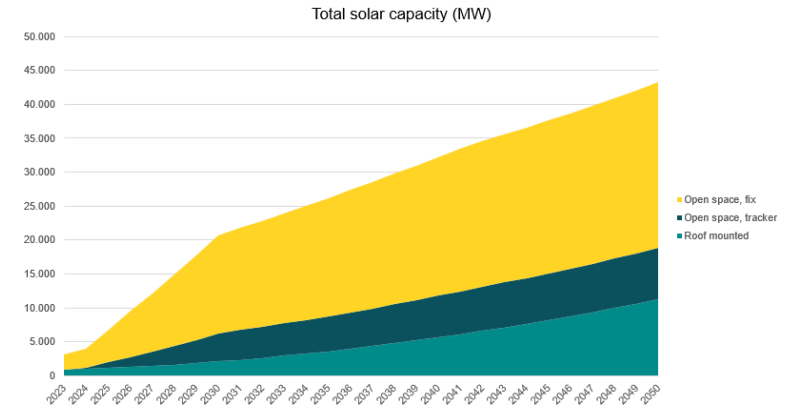
Off shore wind and solar capacities are projected to grow dramatically during the next 25 years:

- Off shore wind x 15 by 2050
- Solar x 10 by 2025

The vast majority of the green power production will be converted into hydrogen and PtX derivatives*



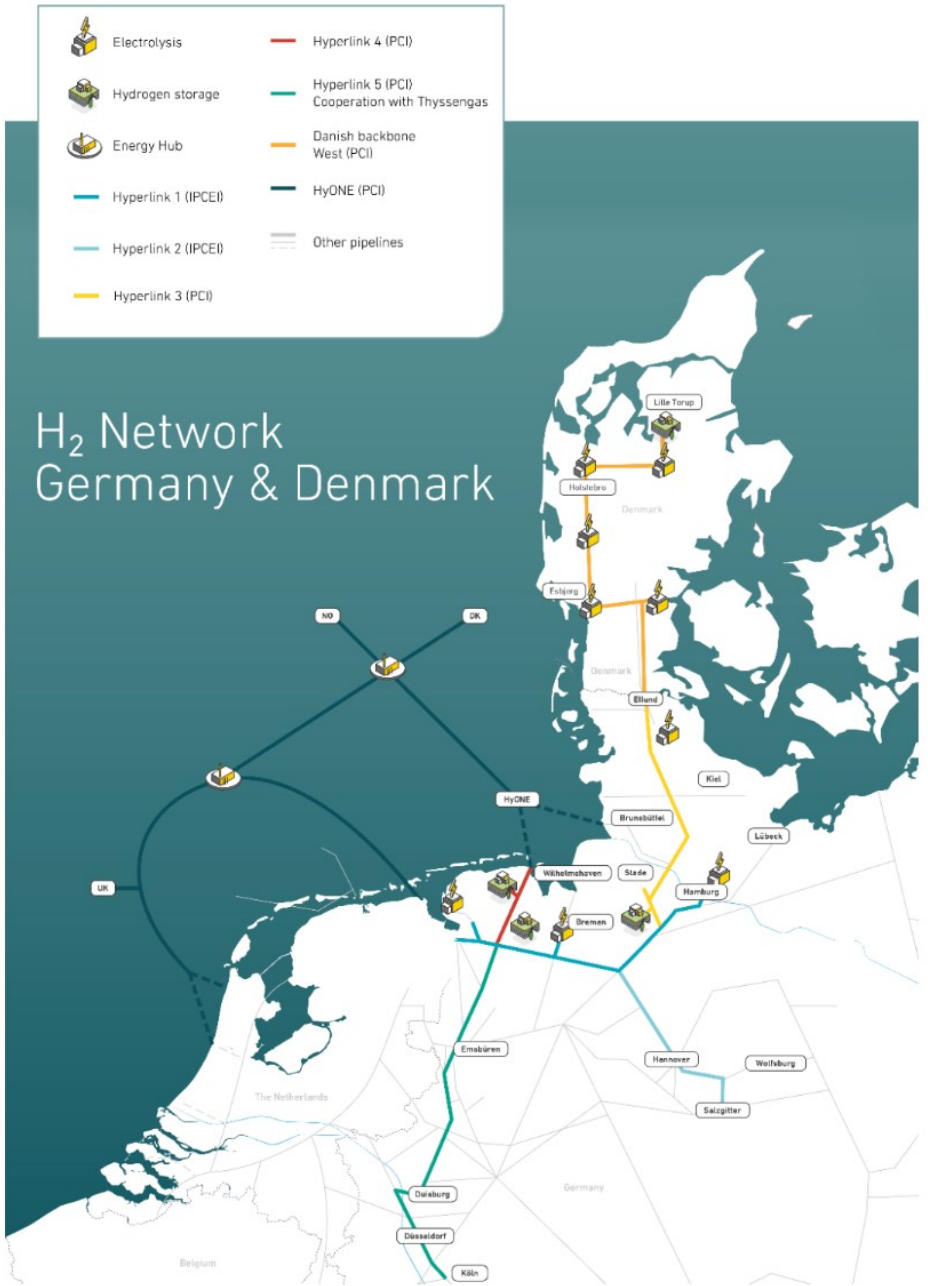




H2 CONNECTION TO GERMANY

Scope: high-pressure H2 pipeline system (90 barg, new build and repurposed) connecting storage (north), offshore wind power (west) with Germany in the south:

- Full Danish Hydrogen Backbone received PCI status in 2023. Denmark becoming an integrated part of the North Sea corridor or HI West
- Initial project 135 km, 4 GW export system as more than 90% of H2 destined for export to supply the NW Europe
- We co-operate with Gasunie on the planning and construction of a cross border connection
- Gasunie network will be part of the German Kernnets (core network) subject to specific financing and a legal commitment to build



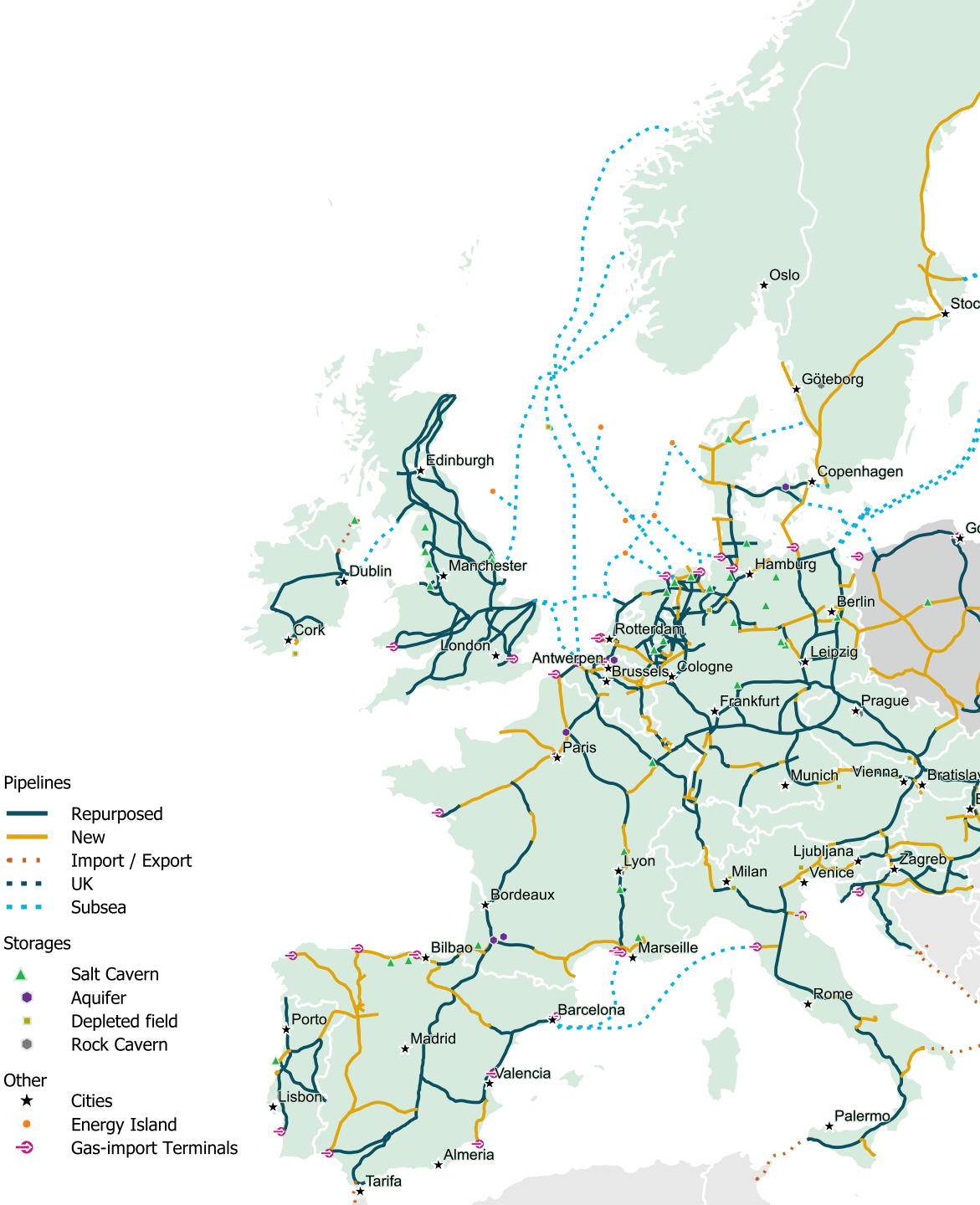
HYDROGEN: A EUROPEAN PERSPECTIVE

~53,000 km
Pipelines

31 TSO's
28 countries

RePowerEU estimates investments in hydrogen infrastructure of €34-49 billion towards 2030.

Over 60% is based on the conversion of existing gas pipelines.



DANISH HYDROGEN BACKBONE

- Total capacity of “Number 7” is 4 GW.
- 45 km new build pipeline; Esbjerg to Veerst.
- 88 km of repurposed pipeline; Veerst to German border.
- Mainly export to Germany since domestic demand will be limited (in early stages).

NEW POLITICAL AGREEMENT ON FINANCIAL FRAMEWORK

Secures state funding for the development of the first hydrogen infrastructure – the socalled "Seven":

- Available loan framework for Energinet: DKK 7.4 billion in loans, corresponding to the CAPEX budget.
- Operational support: Up to DKK 8.3 billion over a period of up to 30 years to ensure competitive tariffs and viable revenue streams for Energinet.
- DEVEX financing: Up to DKK 0.1 billion from April 1 2025 to Q2 2025 to cover expenses if they cannot be passed on to tariffs.

New Terms for Booking Requirements and Capacity Sales:

- State funding conditioned on:
  - Binding agreement on joint development with Gasunie
  - Minimum pre-booking requirement lowered to 0.5 GW during a 10 year period
- If bookings exceed 0.5 GW annually over 30 years, the need for operational support is reduced.

NECESSITY OF TARIFF CURTAILMENT

The HTNO infrastructure will be subject to traditional "Revenue Cap Regulation" but….

We face a start-up dilemma:

- The cost related to new assets is high in the start-up period due to the capital cost (CAPEX)
- In an emerging market the volumes will be low in the start-up period, hence
- Traditional regulation would result in extraordinaly high transportation tariffs during the early years of operation

The curtailment model focuses on postponing the tariff revenue, not permanent discounts…..

Figure 1: Classic tarif base from new assets

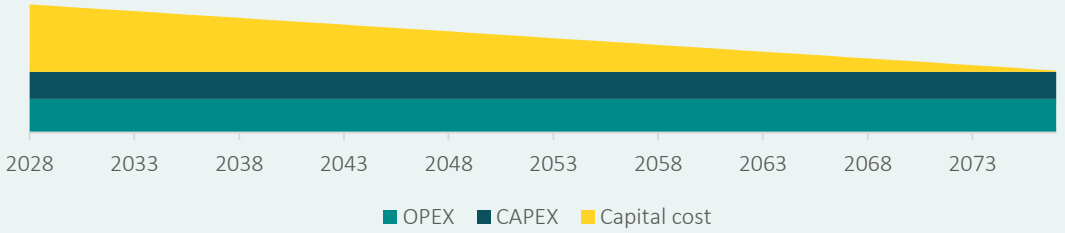


Figure 2: Volume expectations from an emerging marked

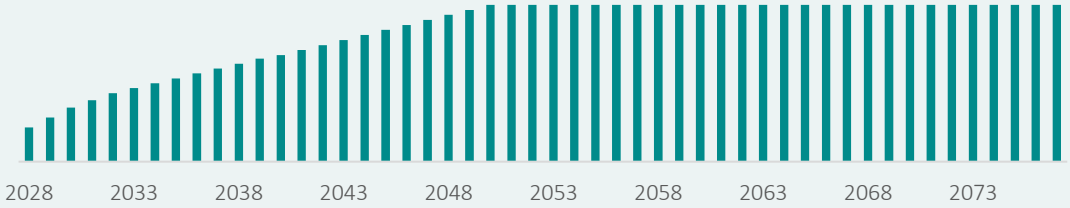
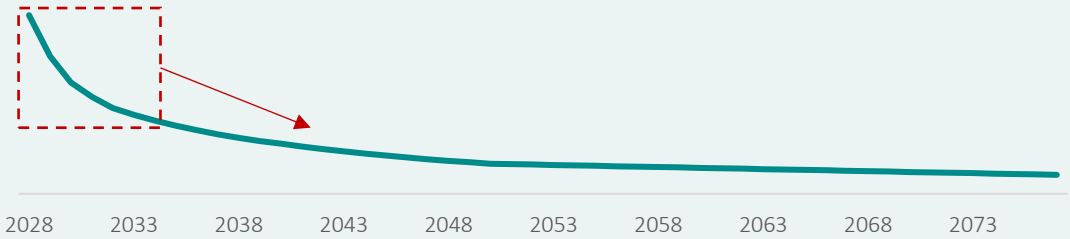


Figure 3: Tarifs without curtailment



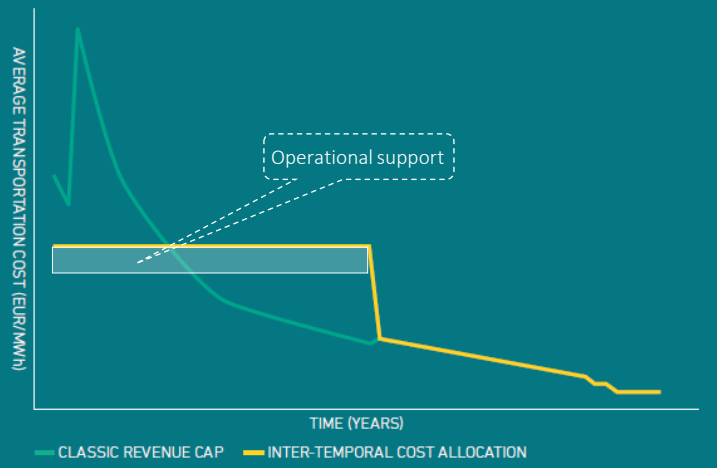
SUPPORTING AN EMERGING H2 MAKET

Expected regulation:

- The EU gas package introduced a intertemporal cost allocation principle
- This will allow for regulated revenues to be postponed in time by offering tariffs based on an average expected cost of transportation during a 30 year period
- The yearly revenue cap is calculated as the estimated average transportation cost multiplied with the expected volumes in the current year
- Operationel support will bridge the gab between the calculated revenue cap and the shippers ”willingnes to pay” i.e. the market based tariff

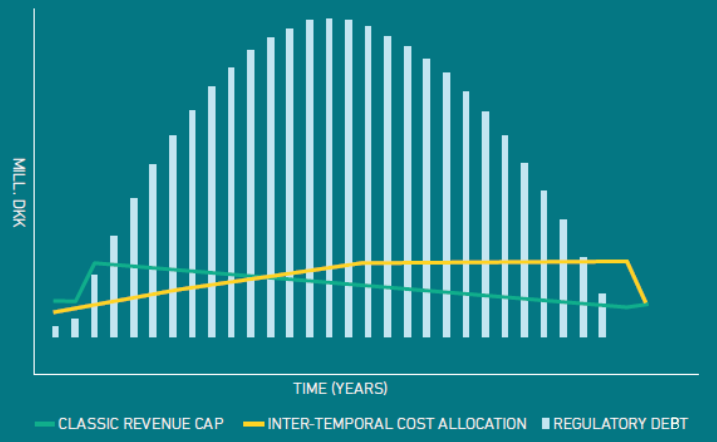
AVERAGE TRANSPORTATION COST

The expected effect of the Inter-temporal cost allocation mechanism on the average cost of transportation over time



TARIFF BASE

The effect of the inter-temporal cost allocation mechanism on the yearly tariff base and the scale of the regulatory dept



TIMELINE INFLUENCED BY POLITICAL AGREEMENT

Danish Hydrogen Backbone – 'Syvtallet' **Construction Time schedule (based on Construction law)**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**
Financial Approvals								
Confirmation of scope for DHB								
Approval updated business case								
Updated ministry approval (§4)								
FID (Award of Construction Contracts)								
Basic design of pipeline infrastructure								
FEED study								
Tendering Detailed Design								
Detailed Design and pipeline infrastructure and tendering								
Detailed Design								
Tendering for materials and construction works								
Fabrication of materials								
Delivery of materials								
Environmental process, Legal basis and archaeology								
Preparation for EIA process and field investigations								
EIA Process (incl. adoption of legal basis)								
Archaeological preliminary investigations								
Archaeological excavations (potentially)								
Construction and commissioning phase								
Preparation for construction works								
Construction & Commissioning works						Construction		

CHALLENGES

1

Linking H2 infrastructure and offshore wind tenders – including the necessary user commitment

How do we link future H2 production and H2 infrastructure appropriately with the upcoming offshore wind tenders to the benefit of all parties?

2

Timing of infrastructure and project development nationally and across borders

How do we coordinate the development of Danish H2 infrastructure (and the capacity of this) with the developments in Germany as well as the expectations for commissioning and scaling up Danish projects?

3

Developing rules, regulation and processes in parallel with infrastructure and projects

How do we ensure progress for both infrastructure and projects with the many interdependencies when developing rules, regulation for e.g. financing, market terms and conditions, safety, and environment?

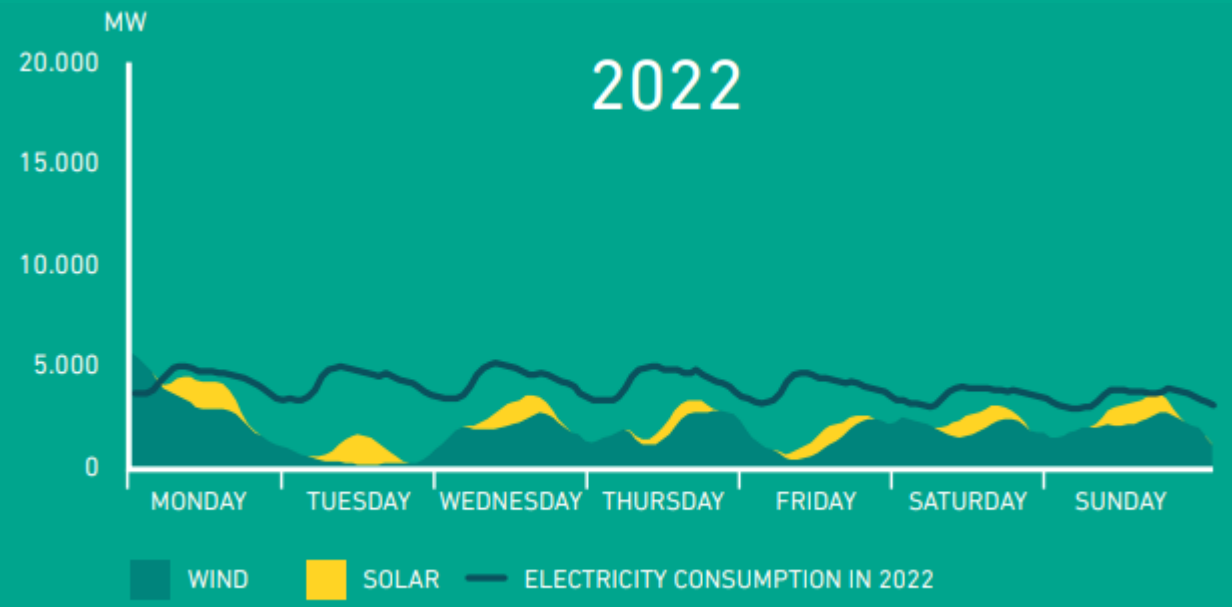
POTENTIAL OF HYDROGEN

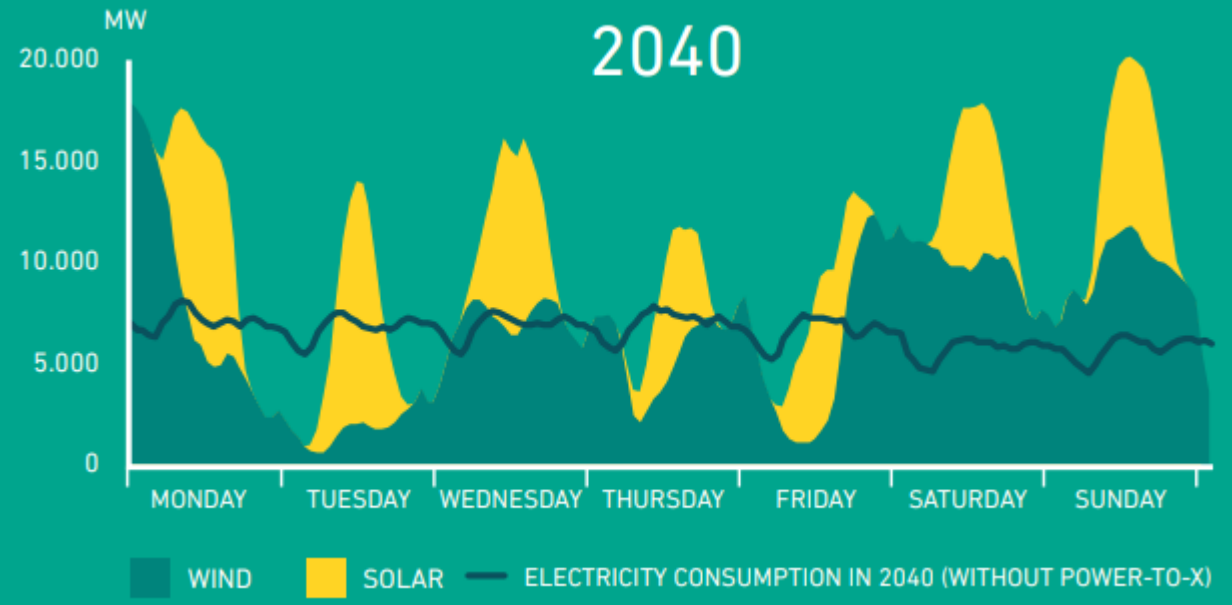
- Hydrogen will enable the green transition of shipping, aviation and parts of the industry
- Electrolysis plants can reduce the need to expand the power grid
- Electrolysis plants can maintain high security of electricity supply and integrate large volumes of fluctuating green power generation

HOW TO BALANCE A HYDROGEN SYSTEM

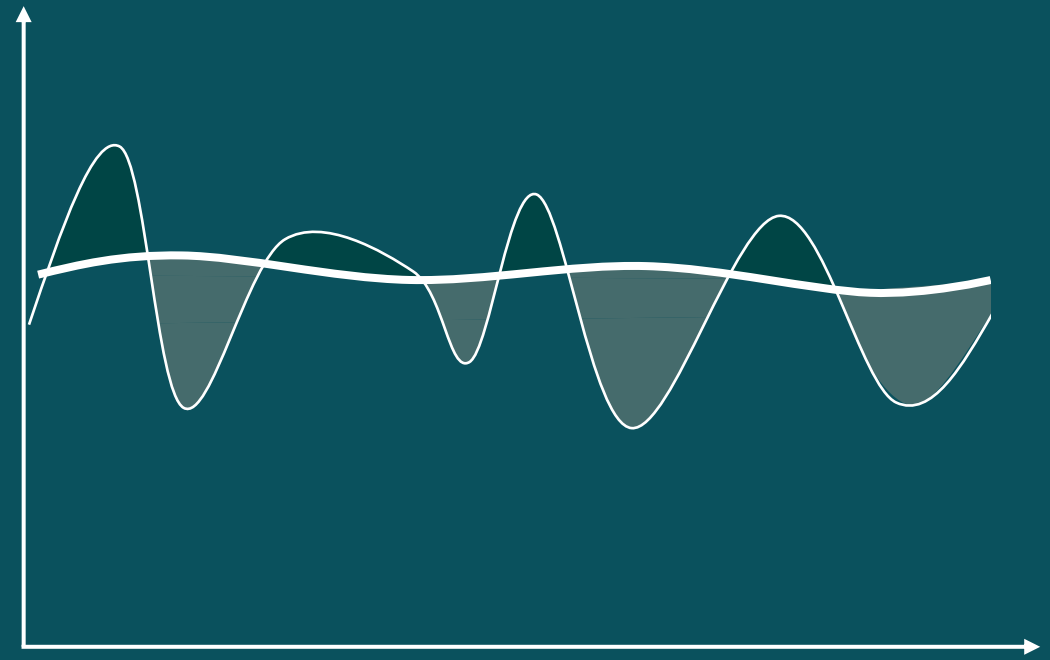
MAJOR FLUCTUATIONS IN 2040

- Fluctuations in wind and solar energy production will increase significantly by 2040
- New technologies are needed to fit and balance the large amounts of green power
- Electrolysis plants can contribute with flexibility enabling us to utilize our wind and solar resources



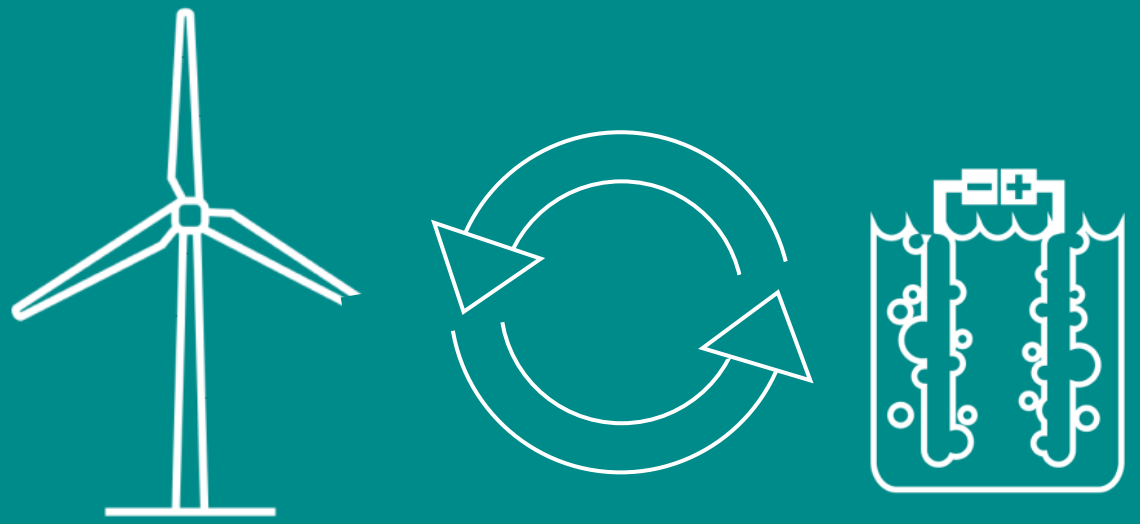


WIND CURTAILMENT

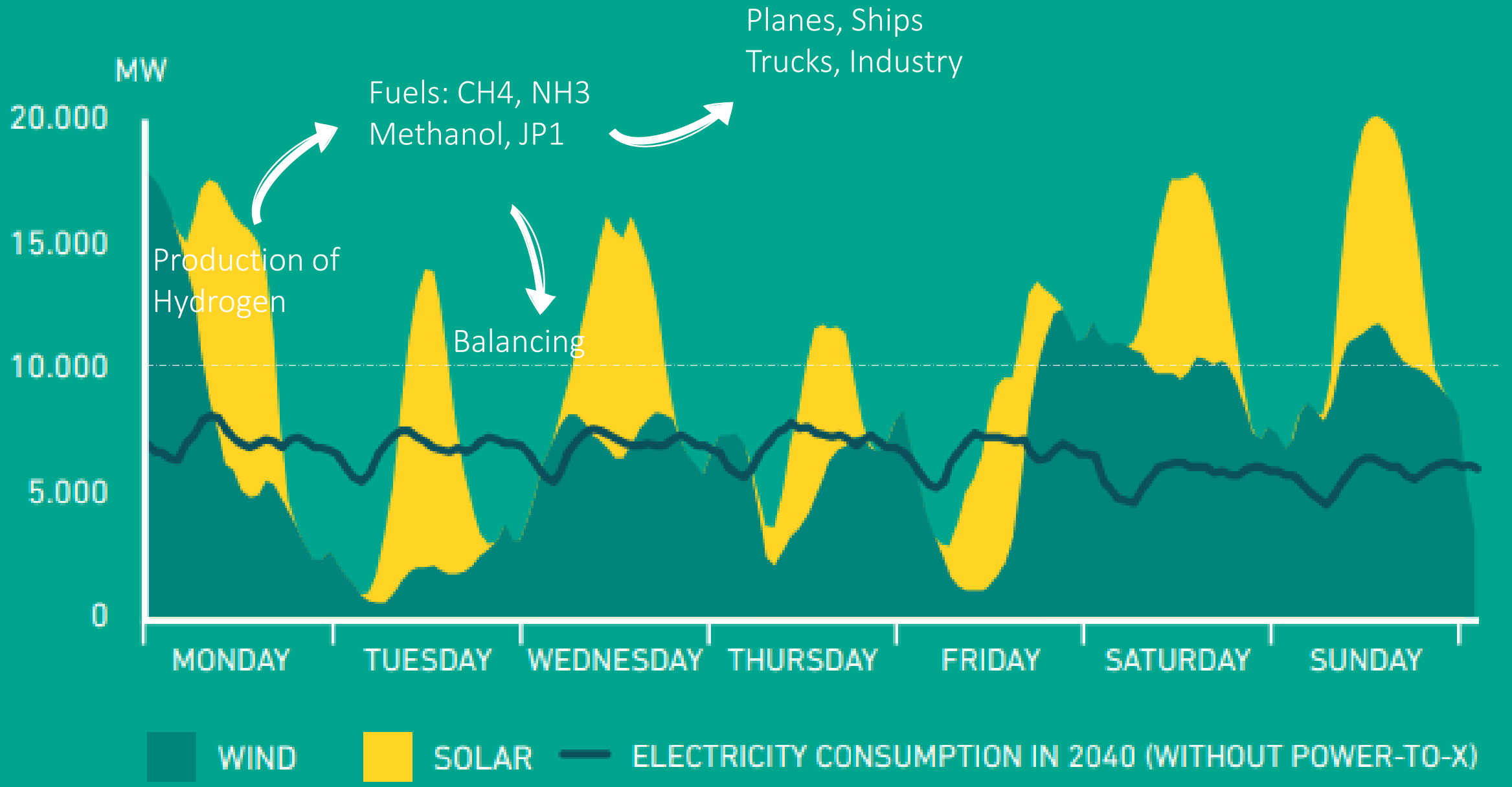


A ONE WAY STREET

WIND & ELECTROLYSIS



SYNERGY & BUILDOUT


Planes, Ships
Trucks, Industry
Fuels: CH4, NH3
Methanol, JP1
MW
20.000
15.000
10.000
5.000
0
Production of
Hydrogen
Balancing
MONDAY
TUESDAY
WEDNESDAY
THURSDAY
FRIDAY
SATURDAY
SUNDAY
WIND
SOLAR
ELECTRICITY CONSUMPTION IN 2040 (WITHOUT POWER-TO-X)

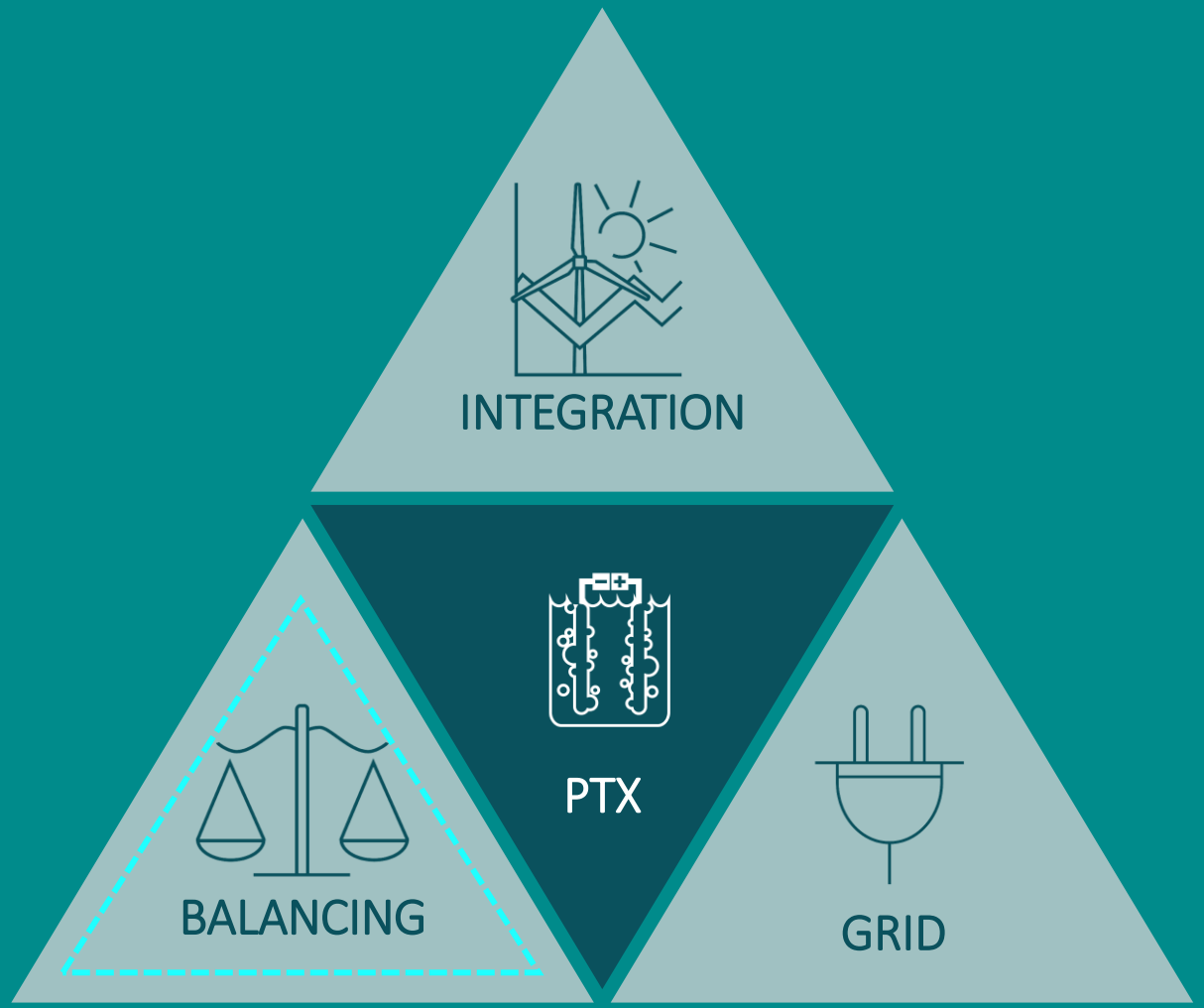
THE PTX ‘TRINITY’

PtX is expected to be flexible and support the system with at least 3 different things:

Integration: Support integration of renewable energy and maximize its value (price lifting).

Grid: Maximize the utilization of the existing grid capacity by its temporal and geographical flexibility.

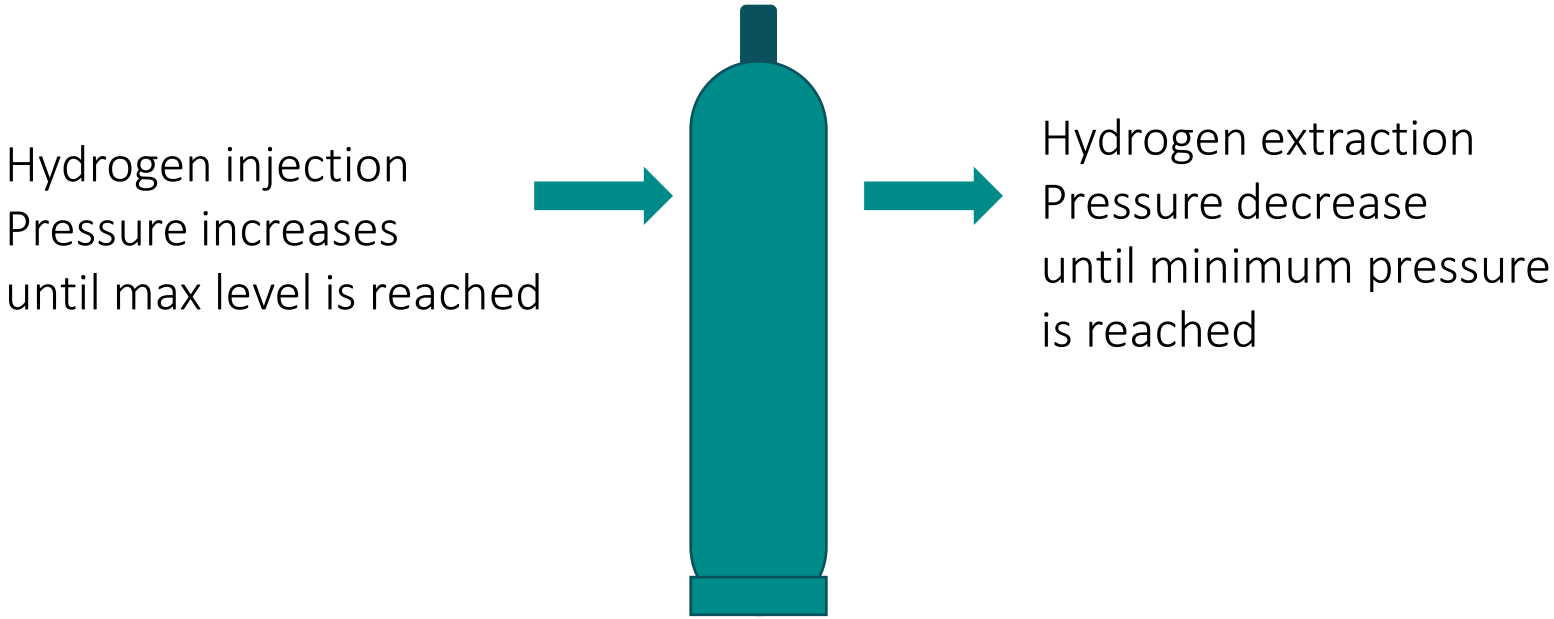
Balancing: Flexible operation in the different power markets and a new technology in the ancillary service market.



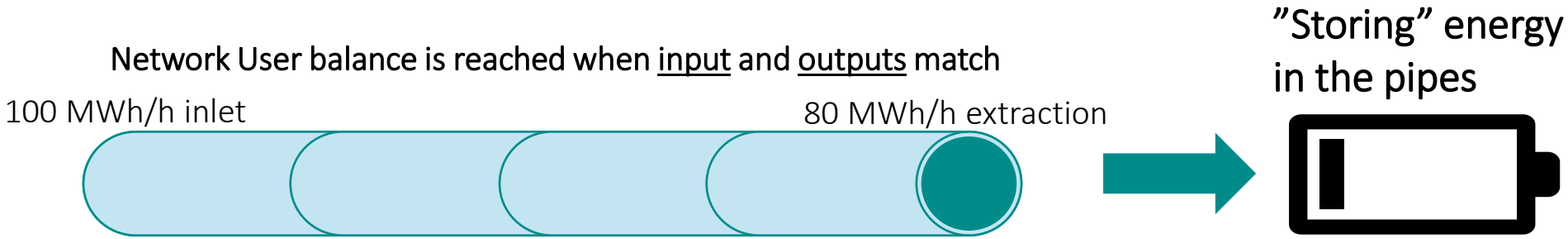
	Natural gas	Hydrogen	Electricity
Market matureness	Mature, many actors	immature, few actors	Mature, many actors
Balancing band	Collective	Combination of individual and collective	None
Survival time	Within 3 hours	Within 1 hour *	Within few seconds
Balancing period & cash-out	24 hours and cash-out end-of-day (EoD)	No EoD cash-out but imbalance quantification	Imbalance quantification per market time unit (MTU)
TSO balancing actions	Yellow-zone trades	At First: Cut-off Future: balancing market *"Key" for integrating with electricity system…*	Ancillary service markets
Storage / flexibility	Abundant flexibility from linepack and storage (Lille Thorup)	Limited flexibility from linepack. Potentially much flexibility from storage (Lille Thorup)	No embedded flexibility in the system

THE HYDROGEN BACKBONE CAN STORE ENERGY

By utilizing that the pressure in the hydrogen system can be higher than required for transport capacity – energy can be stored. We call this **linepack flexibility**



Network User balance is reached when input and outputs match



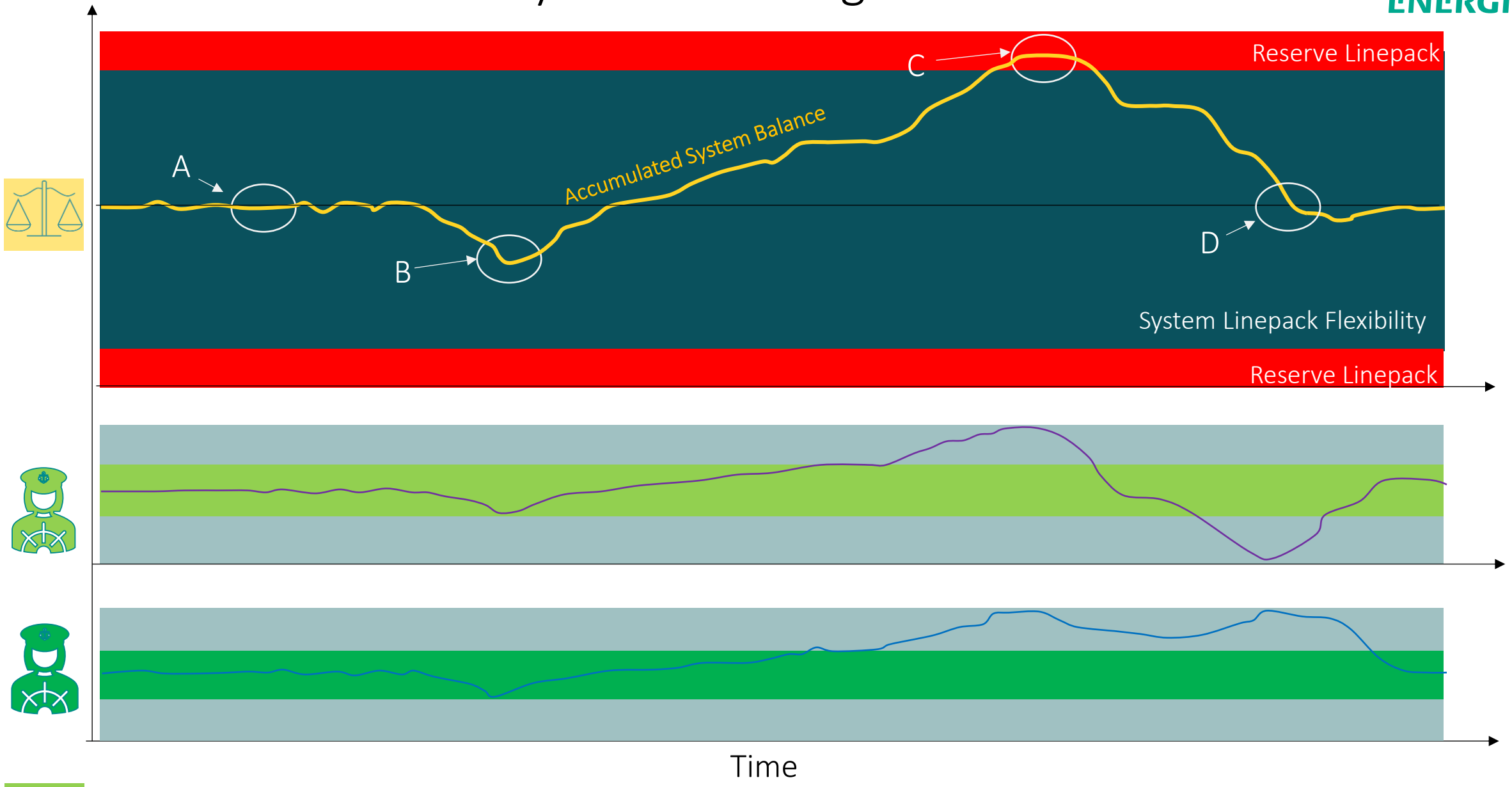
STORAGE FOR FLEXIBILITY

The hydrogen backbone vs large-scale hydrogen storage

- Hydrogen Backbone 1-15 GWh of storage as Linepack flexibility.
  Hours of storage
  Very fast
  Limited expandability
- Underground storage ~100 GWh/cavern
  Days to months of storage
  Slower injection
  Can be expanded

Hybrid Balancing Model

Unit for Balance, GWh



Network User 1: DLF

Network User 2: DLF

Non-designated Linepack Flexibility

ANCILLARY SERVICES: THE TECHNOLOGIES BEHIND

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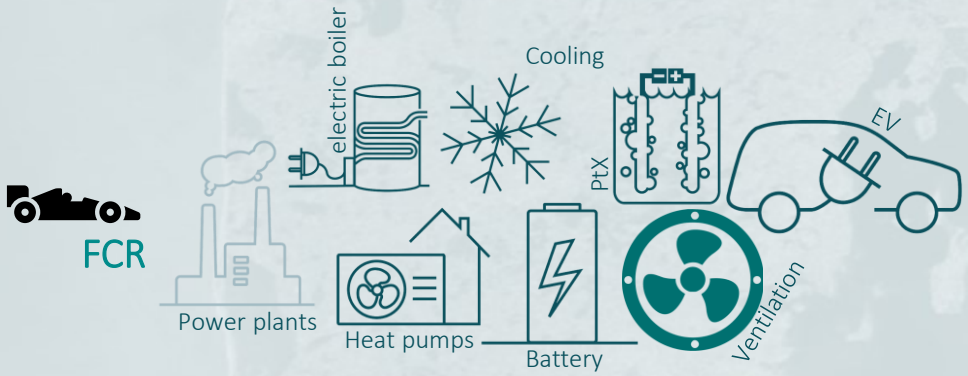
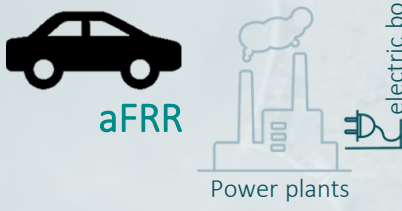
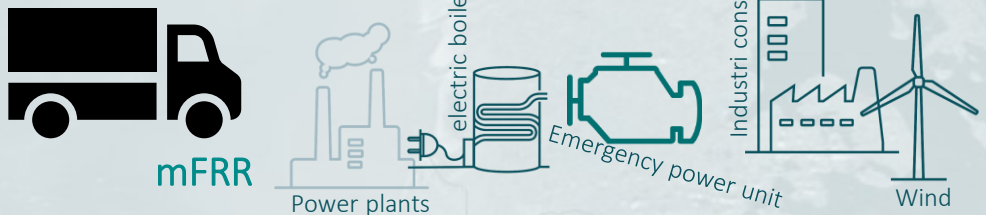
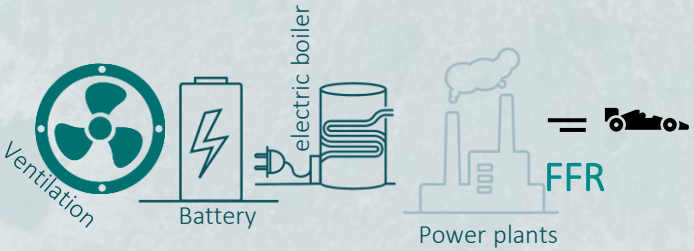
DK1

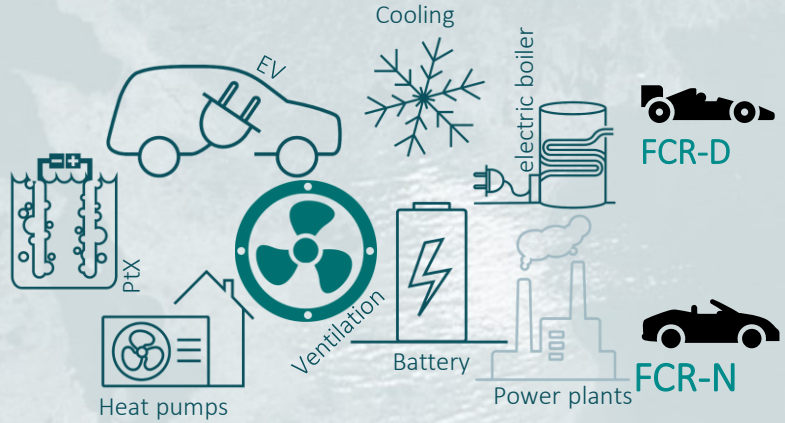
DK2



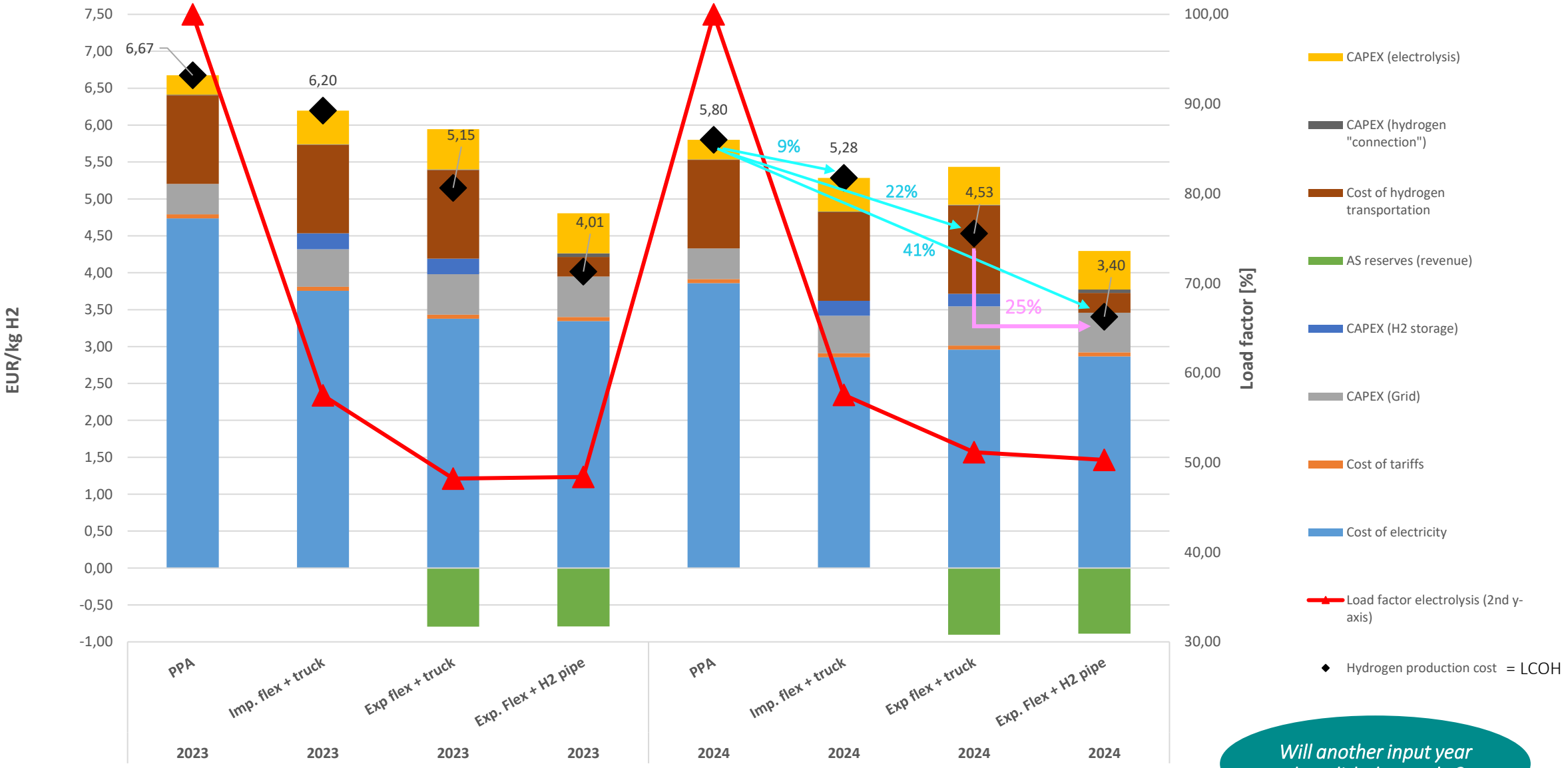








RESULTS: COMPARISON OF ECONOMIC FEASIBILITY



2023, average DK1 electricity price: 86 EUR/MWh

2024, average DK1 electricity price: 70 EUR/MWh

Will another input year demolish the results?

WHAT IS NEEDED TO START A HYDROGEN BACKBONE?

Regulation in place

Financing in place

Renewable electricity production in sufficient amounts

Hydrogen production

Hydrogen demand

Storage?

A plan for the hydrogen backbone

Commitment

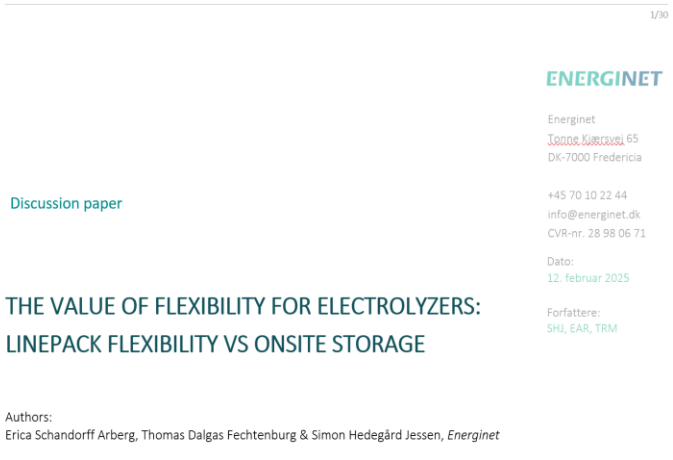
FINAL REMARKS ON **SECTOR COUPLING EFFECTS** AND **HYDROGEN BALANCING MODEL**

- The hydrogen backbone **ENABLES** the electrolyzers to operate ””dynamically”, and thereby react on dynamic prices (ID or DA) and provide ancillary services

- Unlocking ancillary service participation is a way of hedging towards electricity price volatility

- Corporate point of view: 40% reduction in LCOH by leveraging ancillary service participation and harnessing linepack flexibility in the hydrogen pipe

Hydrogen market dialogue (energinet.dk)



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Discussion paper

THE VALUE OF FLEXIBILITY FOR ELECTROLYZERS:
LINEPACK FLEXIBILITY VS ONSITE STORAGE

Authors:
Erica Schandorff Arberg, Thomas Dalgas Fechtenburg & Simon Hedegård Jessen, *Energinet*

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