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Hydrogen Spot Market Simulation (H2SMS) Project

HyXchange, TNO and Berenschot

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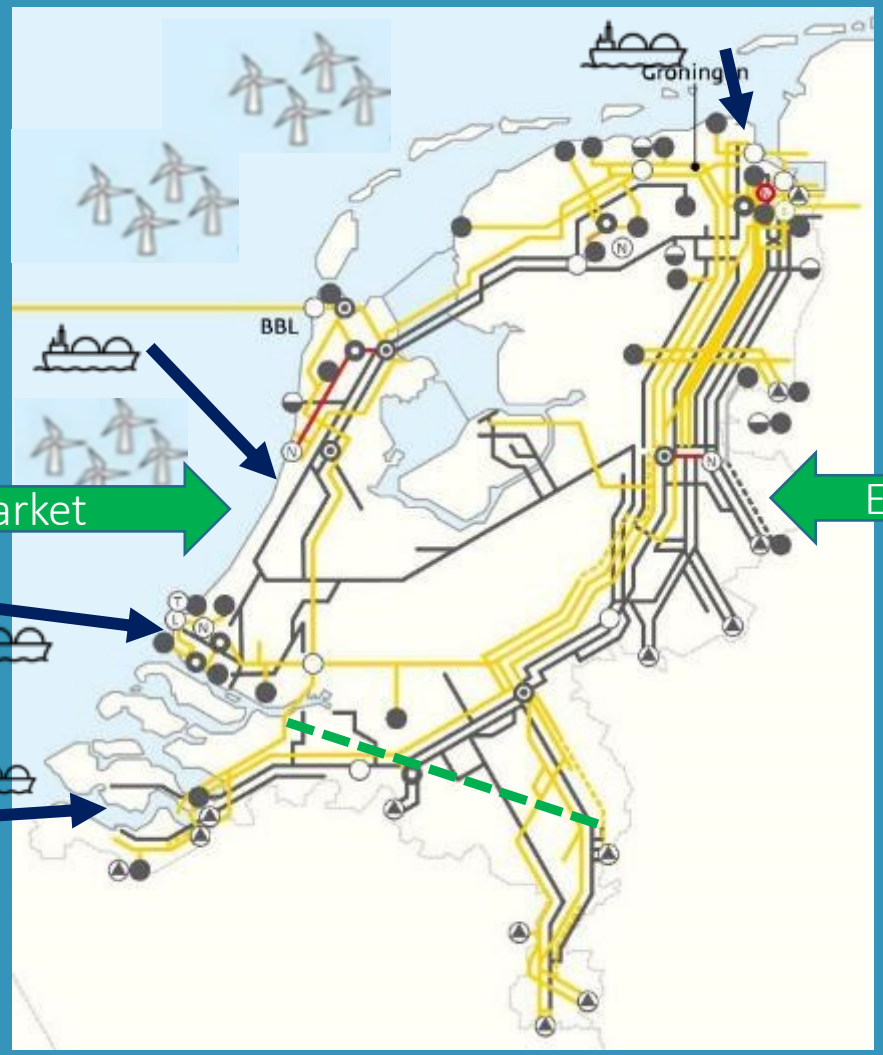
The final policy and technical report are available at: https://hyxchange.nl/document-library/

HyXchange initiative : steps towards realization

Funded by Gasunie and four sea ports

Reference group of over 150 representatives from 70 Market Parties

Global H2 market



EU Gateway im/exports

Development plan HyXchange

1. Certificate pilot (2022): certificate system a wish of many market parties. Developed by doing a pilot, awaiting the hydrogen infrastructure.

2. **Spot market simulation (2022/23) including balancing:** Spot market needed, due to intermittent output of electrolyzers. Simulate the market dynamics, grid balancing and storage.

3. **Index (2023):** this provides a value to the hydrogen and/or certificate, including derivatives. Puts a reference price to hydrogen. Precursor for futures.

Made possible by:

TKI NIEUW GAS
Topsector Energie

gasunie
crossing borders in energy

Port of Amsterdam

North Sea Port

provincie Zuid-Holland

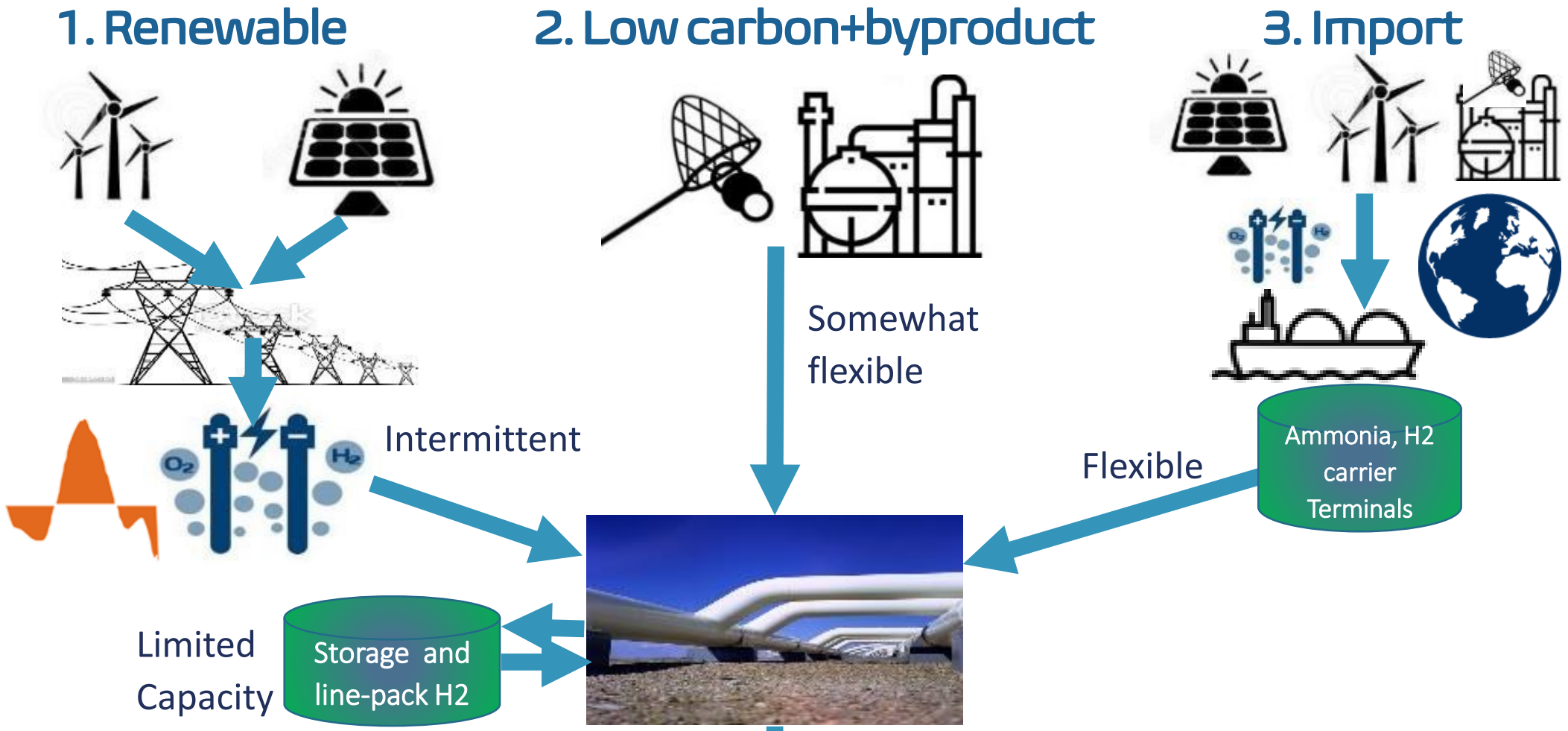
Port of Rotterdam

GRONINGEN SEAPORTS

Provincie Zeeland

With content input contributions from many market parties in live simulation sessions

HyXchange spot market simulation: find out about H2 market dynamics, balancing, security of supply, pricing

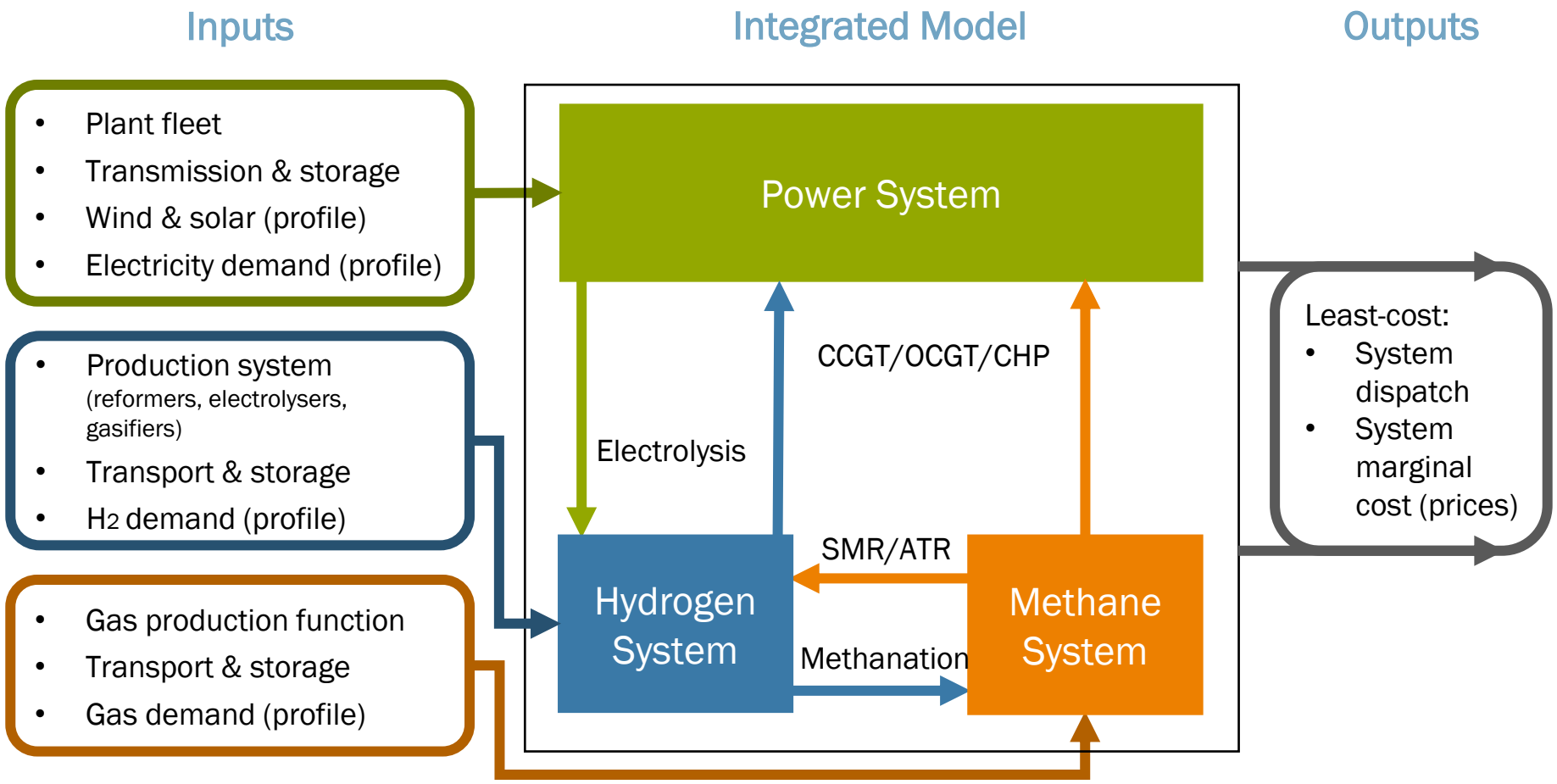


System Simulation on marginal costs

TNO model (I-ELGAS): optimization on marginal cost
Three spot markets with interactions

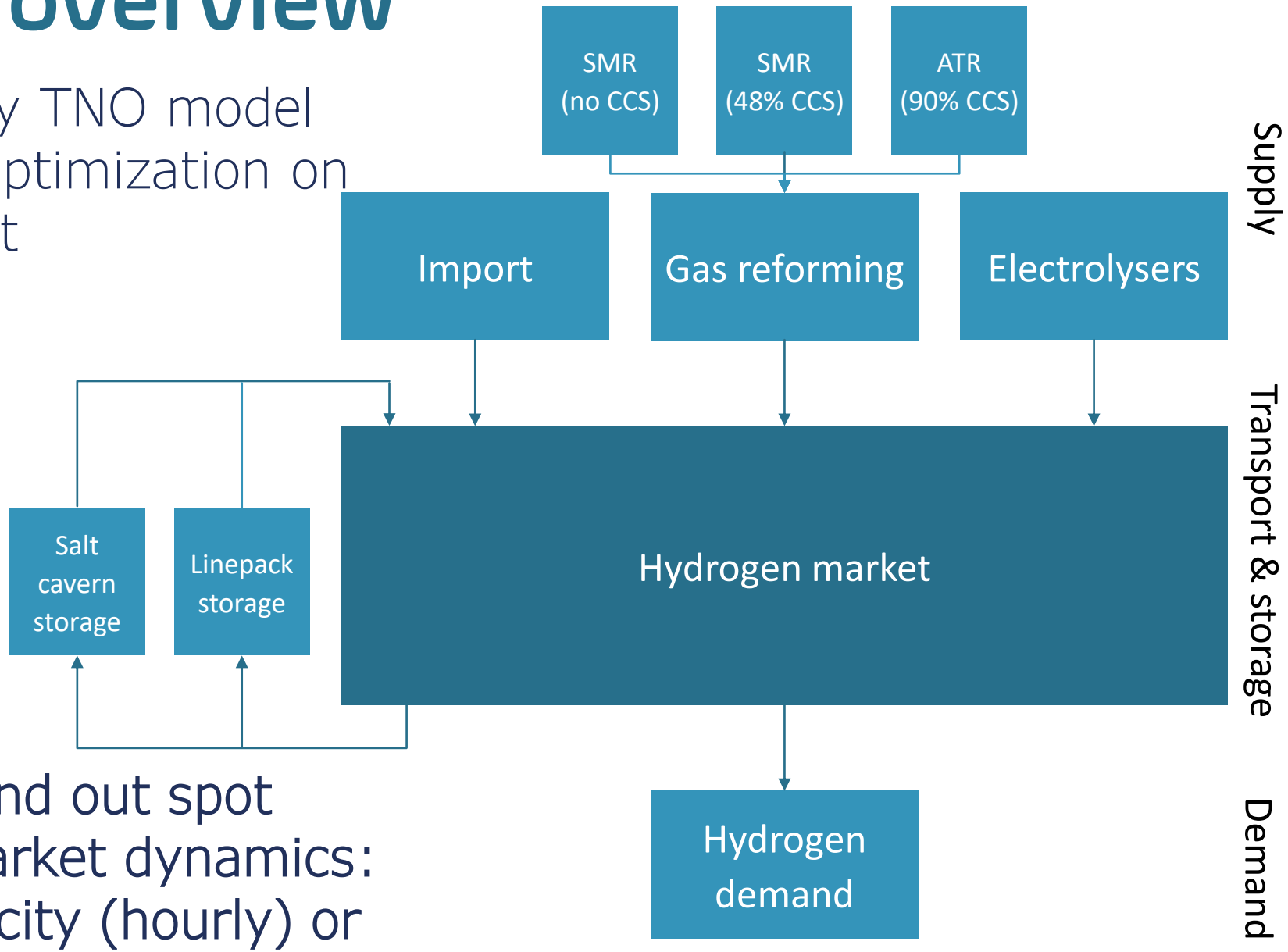
Main goal: find out hydrogen spot market dynamics:
- like electricity (hourly) or
- like gas (daily)?
- In between?

Not the purpose to predict prices!



System overview

Simulation by TNO model (I-ELGAS): optimization on marginal cost



Main goal: find out spot hydrogen market dynamics:

- like electricity (hourly) or
- like gas (daily)?

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H2 spot market/balancing simulation on a (inter) national hydrogen grid. Unique in the world

- Balancing varying electrolyzer H2 output with flexible H2 output of low-carbon SMR+CCS or import ammonia cracking
- H2 hourly electrolysis overproduction: store or utilize
- Storage: line-pack, salt caverns for balancing – is that enough?
- Import hydrogen carriers including storage, conversion and flexibility: →additional balancing opportunities.
- Modelled is import ammonia (blue, green) for practical reasons
- Connection to Germany, Belgium
- Consumers: in 2030 mainly industry and transportation sector

Main goal: find out hydrogen spot market dynamics:

- **like electricity (hourly) or like gas (daily)? In between?**

Not the purpose to predict prices!

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Supply, transp. & storage, demand 2030

Main assumptions

Supply	14 GW
Seaborne ammonia import & cracker • Blue ammonia (Henry Hub) • Green ammonia (MENA)	7.7
Gas reforming • SMR • SMR/CCS • ATR/CCS	6.4 3.5 1.6 1.3
Electrolysers (PEM)	4

Storage	10 GW
4 caverns & line pack	9.5

Market & policy	
Green hydrogen obligation	42%
PEM full load hours (subsidy)	>4200 hours/y**
Market clearing	hourly

H2 Demand *	72 TWh / 8 GW
Netherlands	59 / 6.7
Belgium /Gent	0.5 / 0.1
Germany/NRW	12 / 1.4

** Assumed that half of current ammonia demand is imported directly in 2030, so not produced in NL from H2: H2 demand decrease. Assumed increase H2 demand from others including steel industry*

*** Assumed as a base case: the operation time of electrolyzers is 4200 hours (subsidy criterion 2022)*
As a variant we have also simulated fully free (market-based) dispatch

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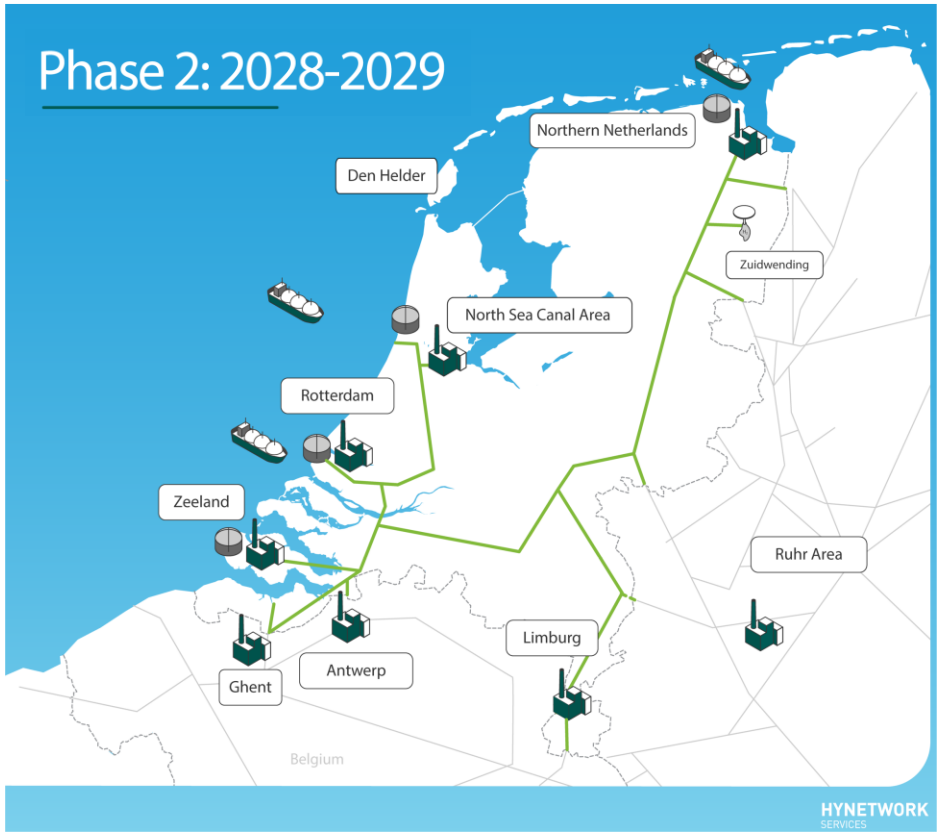
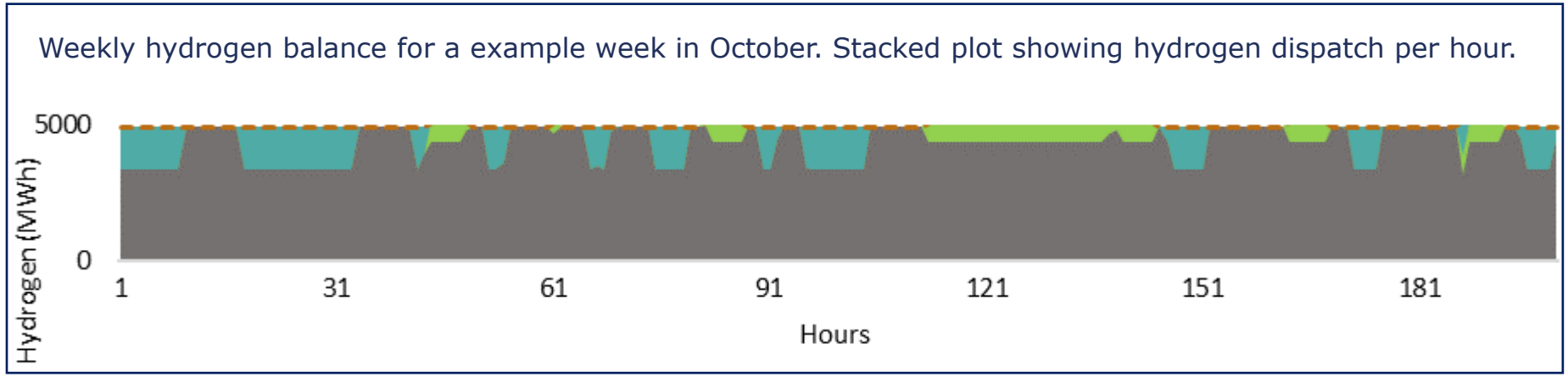
The revised H2 infrastructure planning: start in regions

(presented by HNS on 29-6-2023)

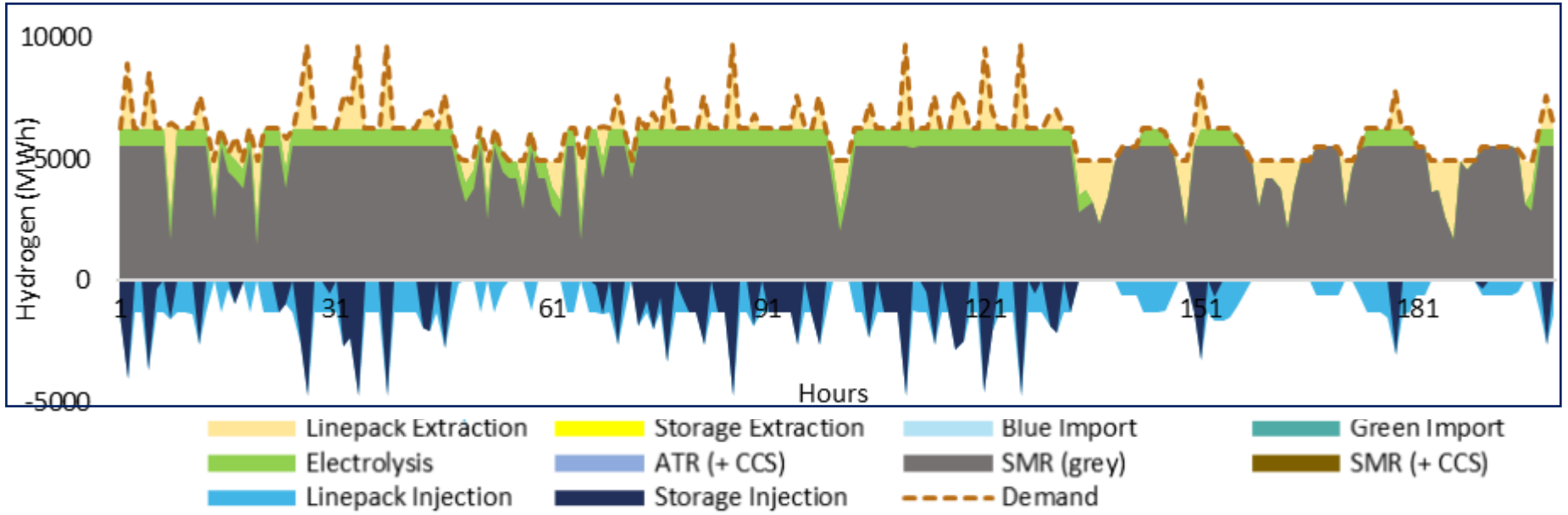


This implies: the market will start up in each of the harbour regions separately (Groningen, Rotterdam, Zeeland, Amsterdam) in 2025-2027, to be integrated nationally (including connect to the Hystock storage) in 2028

Start H2-system in 2027: connected or disconnected



Regional markets, disconnected, no storage

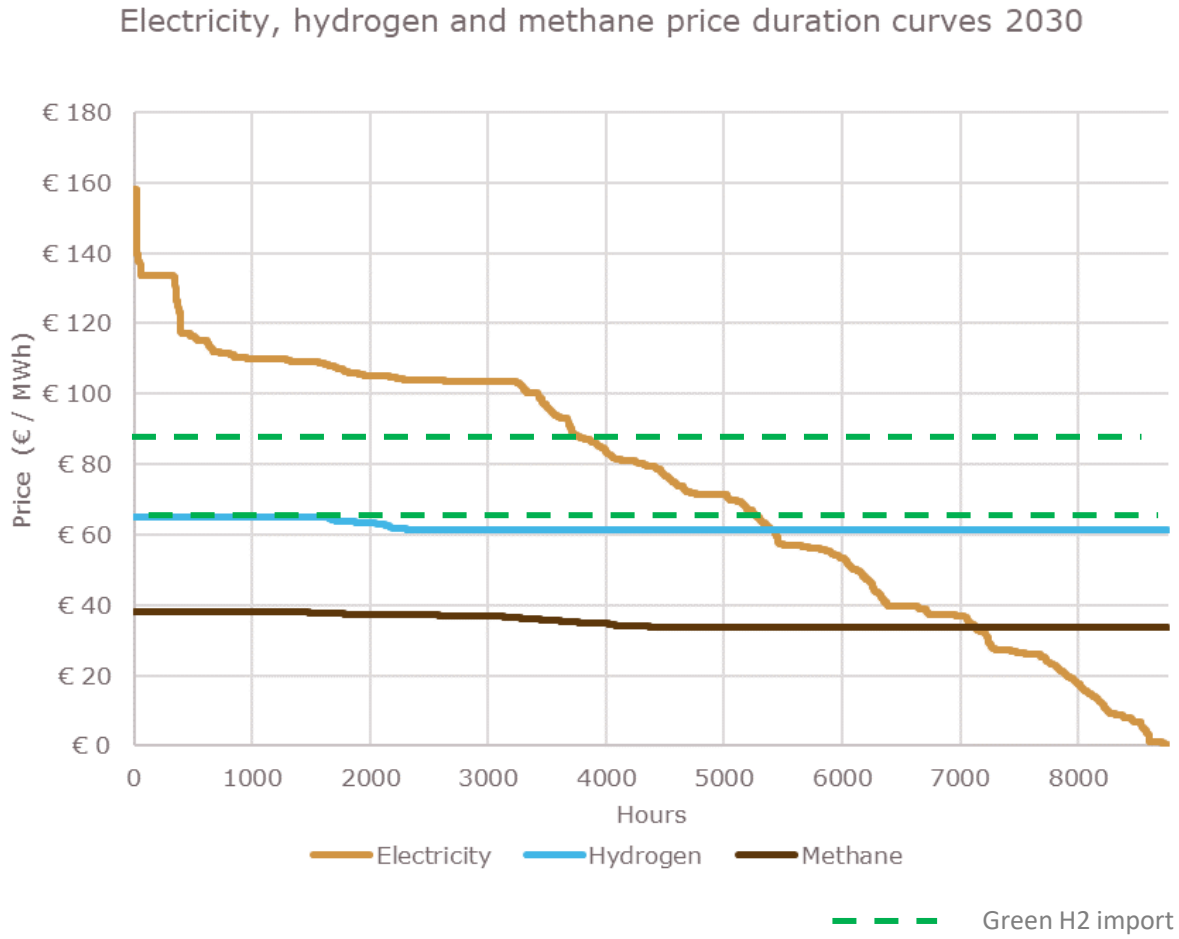


If there would be a national connection with storage.

Scenario Variants 2030
Marginal costs import case 2030 (*Prices in HHV)*

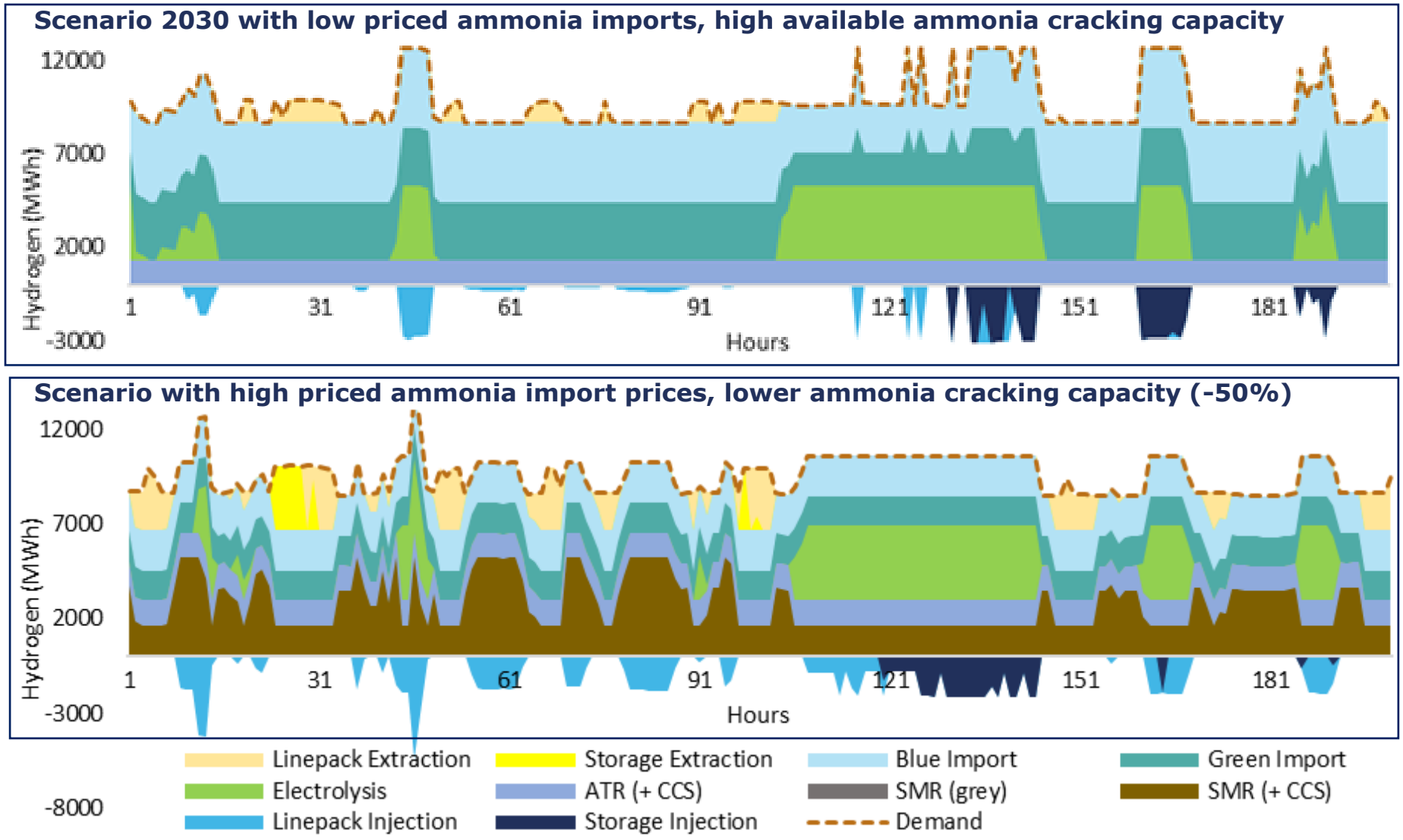
- H2 marginal costs mostly set by two main plateaus:
  - green ammonia import+cracking
    - low price €66 /MWh H2
    - high price €88 /MWh H2
  - blue ammonia import+cracking €62/MWh

Additional scenario variants are run, key is also % availability of ammonia cracker



H2 market simulation 2030 example : October week

Weekly hydrogen balance for a example week in October. Stacked plot showing hydrogen dispatch per hour.



Dynamic (hourly) variation pattern by domestic renewable + electrolysis.

Demand is mostly baseload. The gaps in renewable are mostly filled by ammonia imports + cracking and/or gas reforming, depending om price levels of import ammonia and gas.

This also influences H2 storage and line-pack.

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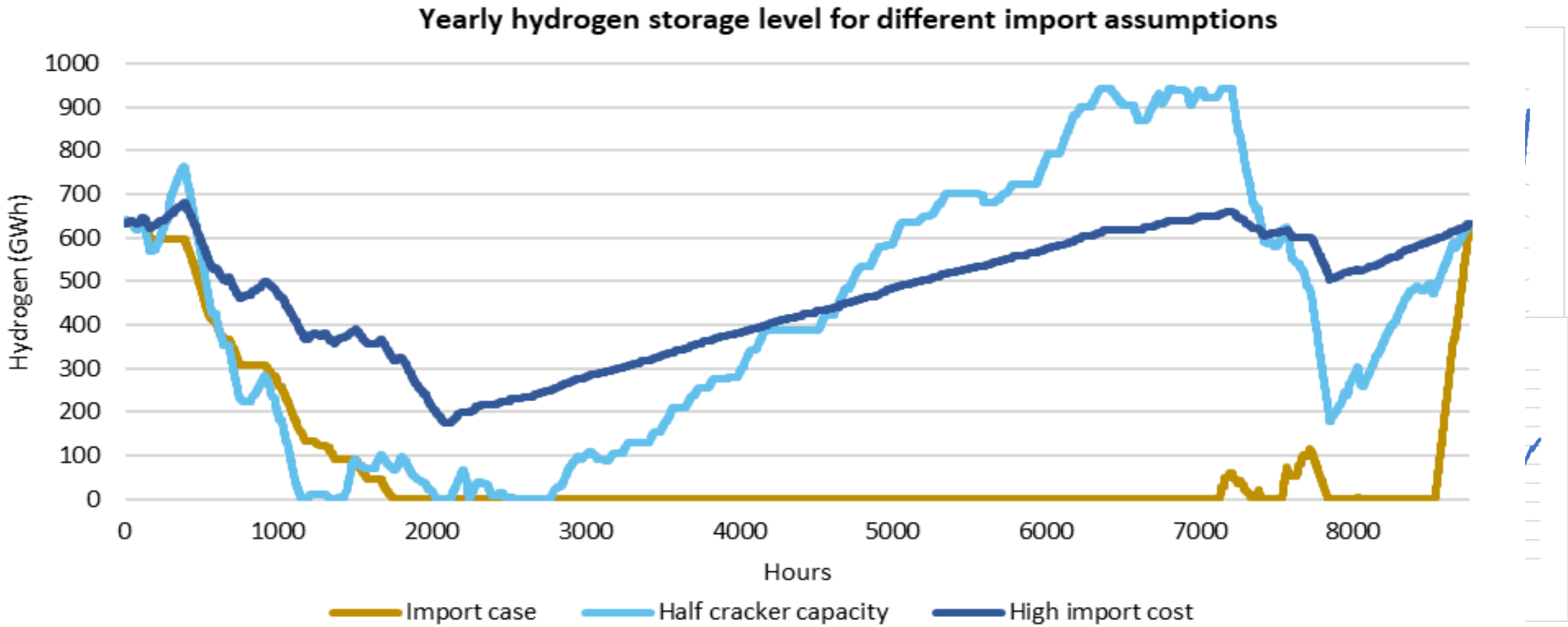
Hydrogen storage in 4 Salt Caverns in 2030: import case 100% and 50% cracker capacity

Note: the simulations were run with the original assumption of 4 caverns in 2030
Current planning is 1 cavern in 2030, +3 in 2032



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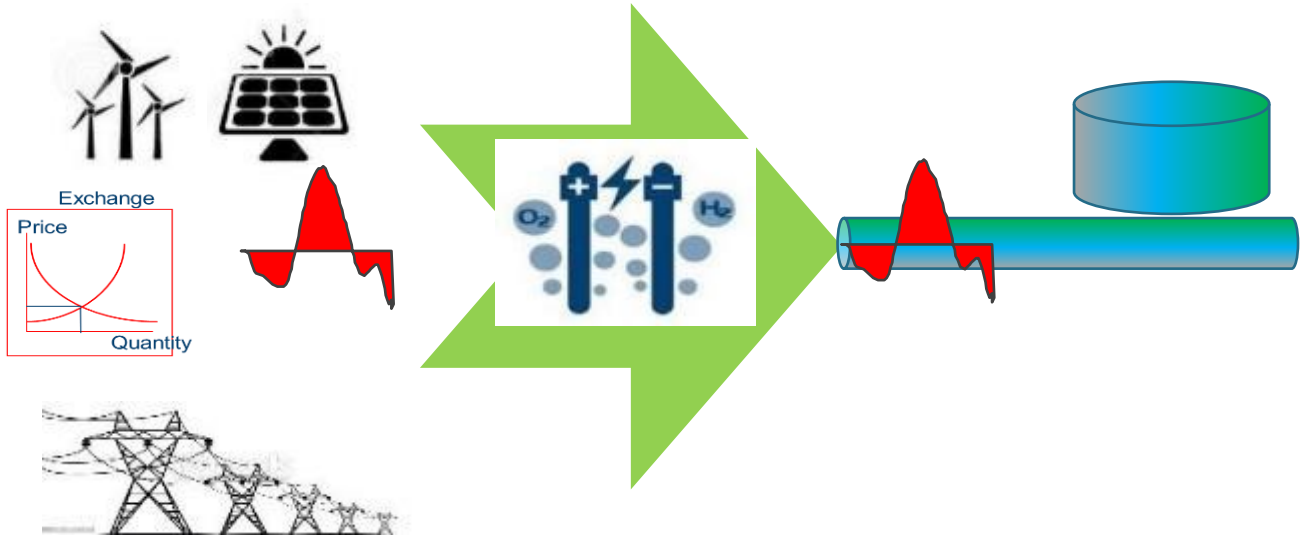
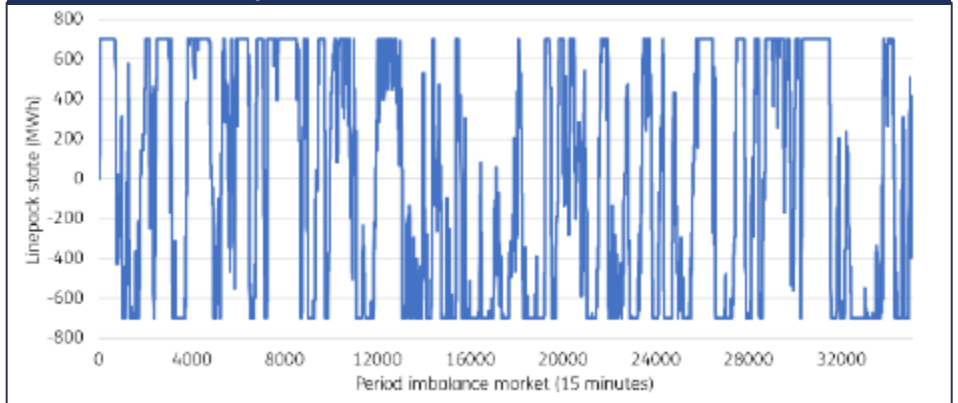
Electrolysers as E-flexibility providers

Effect on the H2 balancing market: need for salt cavern storage

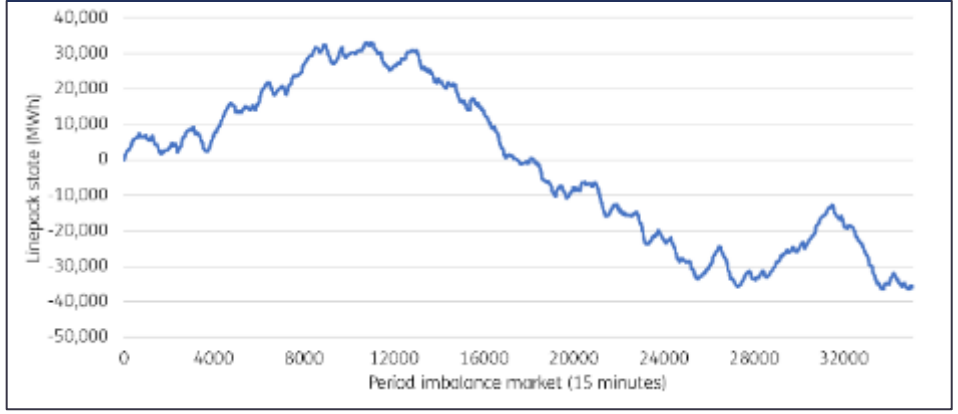
- Electrolyzers can provide flexible response to Electricity market volatility (spot, intra-day, balancing)
- Electrolysers cannot balance the complete E-market with only line pack: salt cavern storage capacity needed



Line pack state with constraint



Linepack state without constraint



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Key findings of project

As learned from market simulation and market parties input in Sim sessions

- **Time unit of the spot, intra-day market: to be hourly**
  - Hourly volume volatility for individual units, driven by weather and storage
  - Price volatility much lower: “slower” sources tend to be price-setting (import ammonia cracking or SMR/ATR)
- **Variations and flexibility: multiple Hydrogen sources needed for 24/7 supply**
  - Varying renewable output of electrolyzers must be supplemented by other sources (import ammonia cracking, SMR/CCS) to secure constant 24/7 delivery.
  - Balancing role electrolyzers on electricity market: well possible. But variations exceed line-pack: cavern storage and other flex needed.

Key implications for HyXchange set-up

As learned from market simulation and market parties input in Sim sessions

Balancing and within-day market:

- Important for market parties AND the H2 grid operator
- Balancing, secure supply requires multiple origins H2 (green, low-carbon)
- Need to administrate and transfer green certificates on H2 grid(s) – also during multi-region startup of the market (temporary relaxation of mass balancing rules needed)

Other key findings during sessions regarding Hydrogen carrier imports (e.g. ammonia):

- Ammonia helpful or may be needed to fulfil 42% renewable H2 industry target
- Clear premium of green certificate (difference between blue/green ammonia)

Regional start-up of markets: if enough market parties on TPA H2 infrastructure, and if sufficient flex available from Ammonia terminal cracker and/or SMR and/or storage

Recommended further research

To be discussed with TKI and others

- **H2 simulation years 2035 and 2040 (**current report: start H2 market 2030). *Elements*:
  - Migration gas power plants to hydrogen expected between 2030 - 2035
  - Location of electrolysers, minimizing transportation and congestions Dutch electricity grid.
- **Include new technologies with synergy:** *reduce large CAPEX, improve OPEX electrolyser*
  - Batteries + Electrolysers (combinations or integrated like battolyser): *better OPEX?*
  - Reversible electrolysers/power plants (e.g. reversible SOFC, flow battery): *reduce CAPEX?*
- I**nclude more hydrogen storage concepts:** *solutions for H2 storage problem*
  - large scale storage: hydrogen in (offshore) old gas fields (when feasible?)
  - small-scale concepts e.g. containers (pressurized or chemical absorption)
- **Include wider range of hydrogen carriers.** Next to currently modelled ammonia 2030: for 2035/2040 also LOHC's, Liquid hydrogen, Methanol, DME (Dimethyl Ether).

Investigate the energy system advantages in the above

Also: Possibilities to apply simulation model more internationally (Germany, Belgium)

Project proposal: role of imported H2 carriers (incl. auctions) for balancing the grid and securing H2 delivery, conversion

Considerations (following from the HyXchange H2 spot market simulation)

- Balancing the H2 grid more difficult than expected (limited pure H2 storage)
- H2 carrier import terminals to provide additional storage – or even main storage
- Also as strategic reserve, partly replacing gas storage: need conversion facilities

Study the role of H2 carriers import, auctions and terminals to find out importance for:

- Balancing and strategic reserve in H2 (compared with other options)
- Role in energy policy, energy system reliability, government attention
- Early stage without H2 storage: harbour regions in Netherlands, Germany
- Enduring value for market as a whole (Netherlands + Germany)
- Consequences for system role H2 carrier conversion
- Trading periods , requirements, system for H2 carriers, conversion and H2 balancing

Multi-stakeholder study project: Gasunie, H2Gobal, HyXchange, Ministries (NL, Germany), BDEW, possibly others

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