SOE FOR HARD-TO-ABATE SECTORS: EXPERIENCE FROM THE INDUSTRY

TOPSOE

AMPS Workshop
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TOPSOE AT A GLANCE: OVER 80 YEARS OF INNOVATION AND LEADERSHIP

We are a leading global provider of technology and solutions for the energy transition. We combat climate change by helping our customers and partners achieve their decarbonization and emission reduction goals.

Based on decades of scientific research and innovation, we offer world-leading solutions for transforming renewable resources into fuels and chemicals for a sustainable world, and for efficient and low carbon fuel production and clean air.

We were founded in 1940 and are headquartered in Denmark.

1/3

of the current renewable diesel and SAF operating capacity is based on Topsoe technology

>2800

employees

1.3G€

in revenue

100M€

invested in R&D in 2023

>600

patent families

WE HAVE THE KNOWLEDGE, AND ALL OF THE BUILDING BLOCKS TO DECARBONIZE HARD-TO-ABATE SECTORS

Renewable fuels
#1 in the market

Hydrogen
#1 in the market

H_2

Ammonia
#1 in the market

NH_3

Methanol
#3 in the market

MeOH

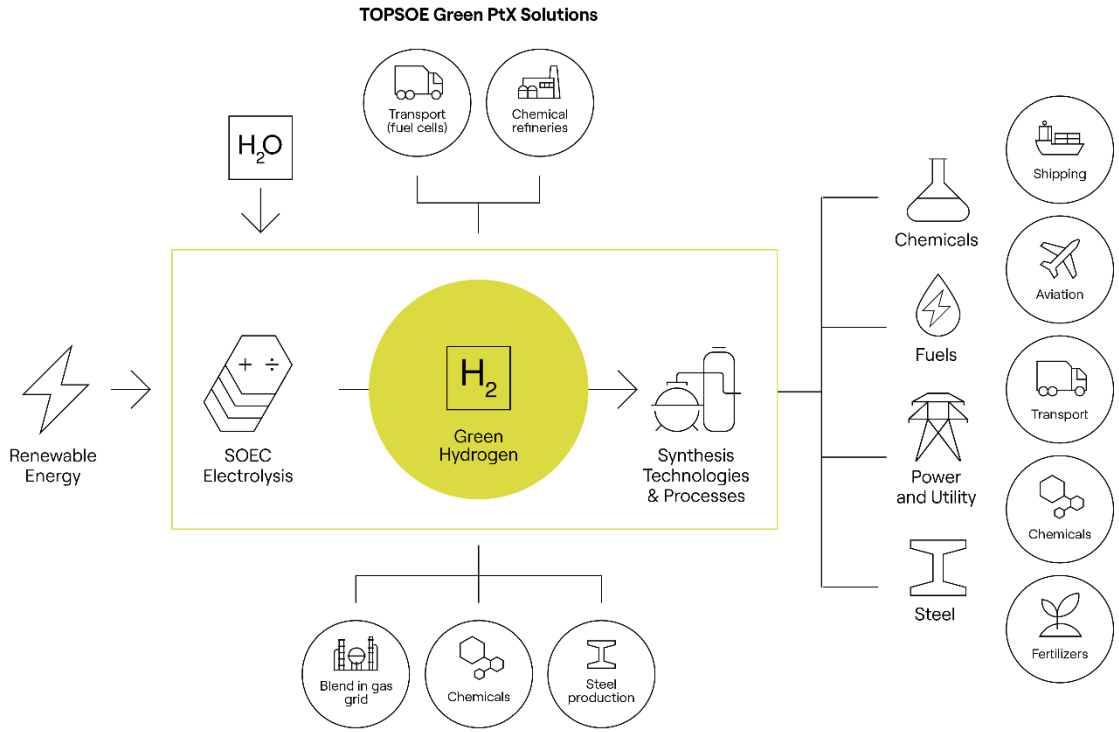
Carbon monoxide

CO

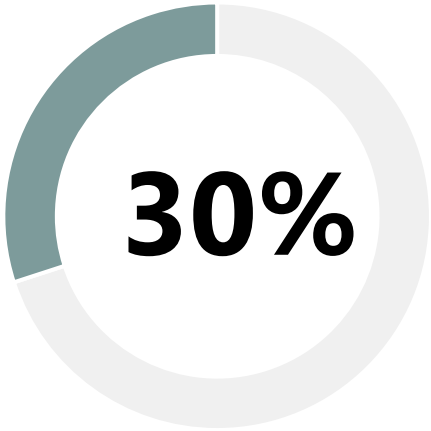
Electrofuels

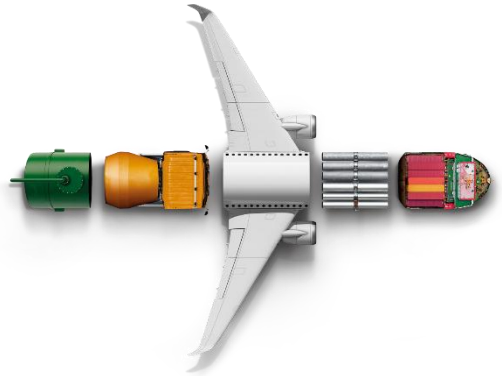
TOPSOE

POWER-TO-X IS THE BRIDGE
ENABLING US TO DECARBONIZE SECTORS ARE UNEVENLY EXPOSED IN THE NET-ZERO TRANSITION

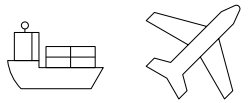


Sectors that cannot be easily electrified account for a significant portion of Global GHG emissions!

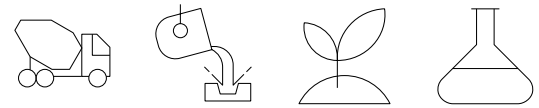




HEAVY TRANSPORT

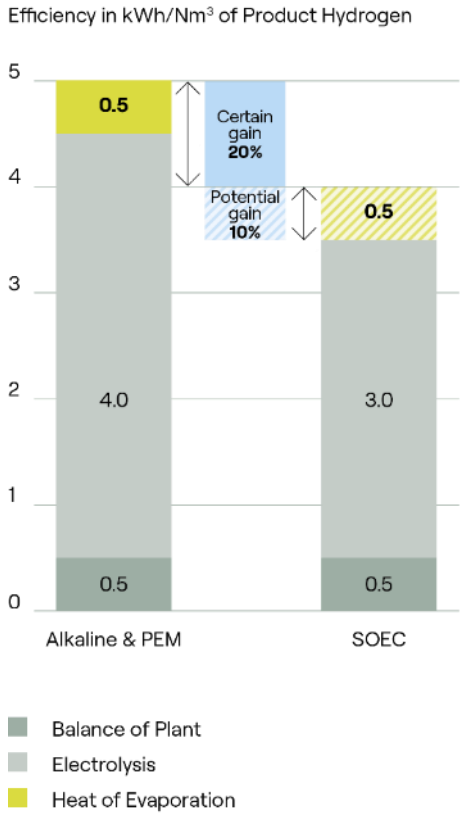


HEAVY INDUSTRY



THE CHEMISTRY BEHIND OUR SOEC ELECTROLYSIS PROCESS

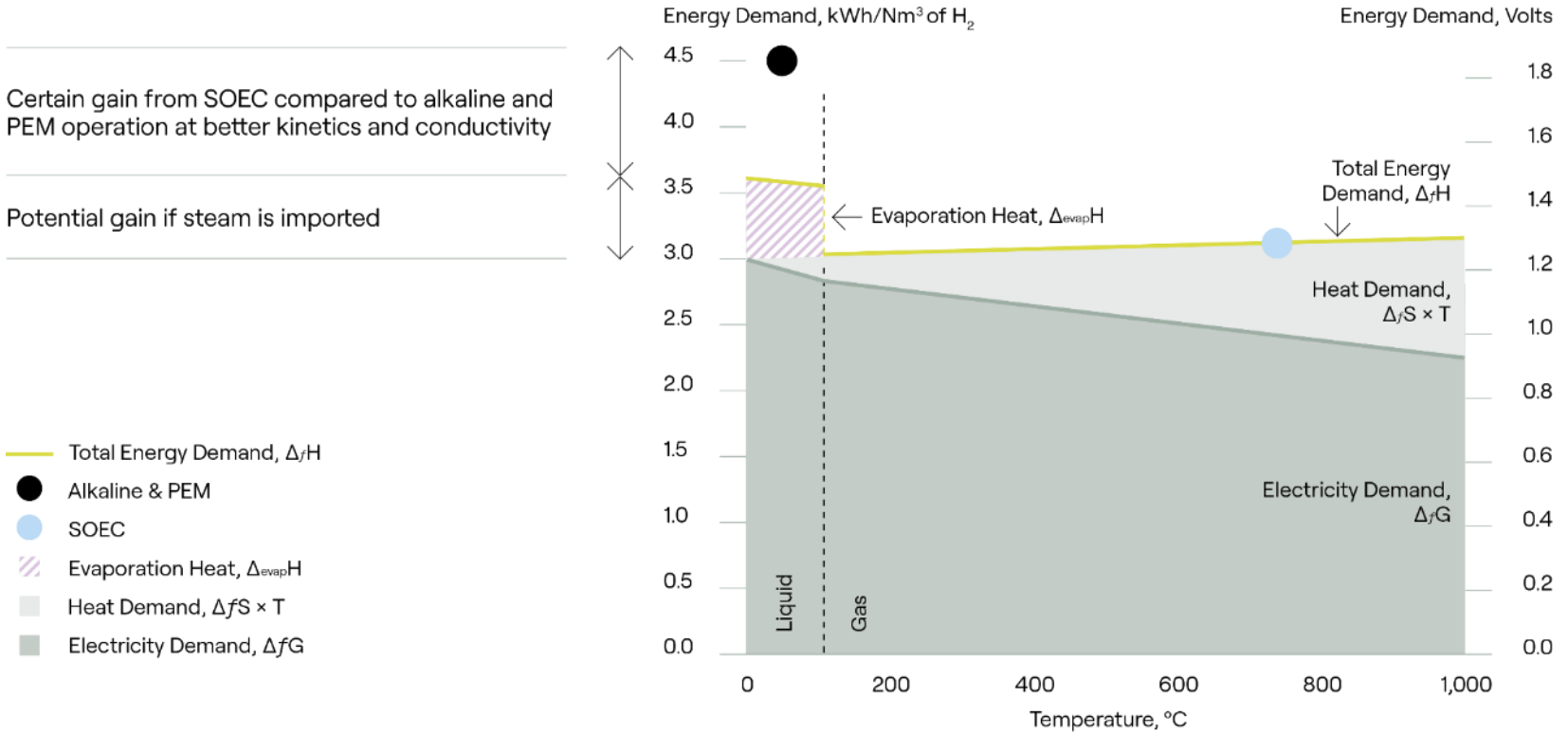
SOEC'S ADVANTAGE OVER ALKALINE AND PEM TECHNOLOGIES



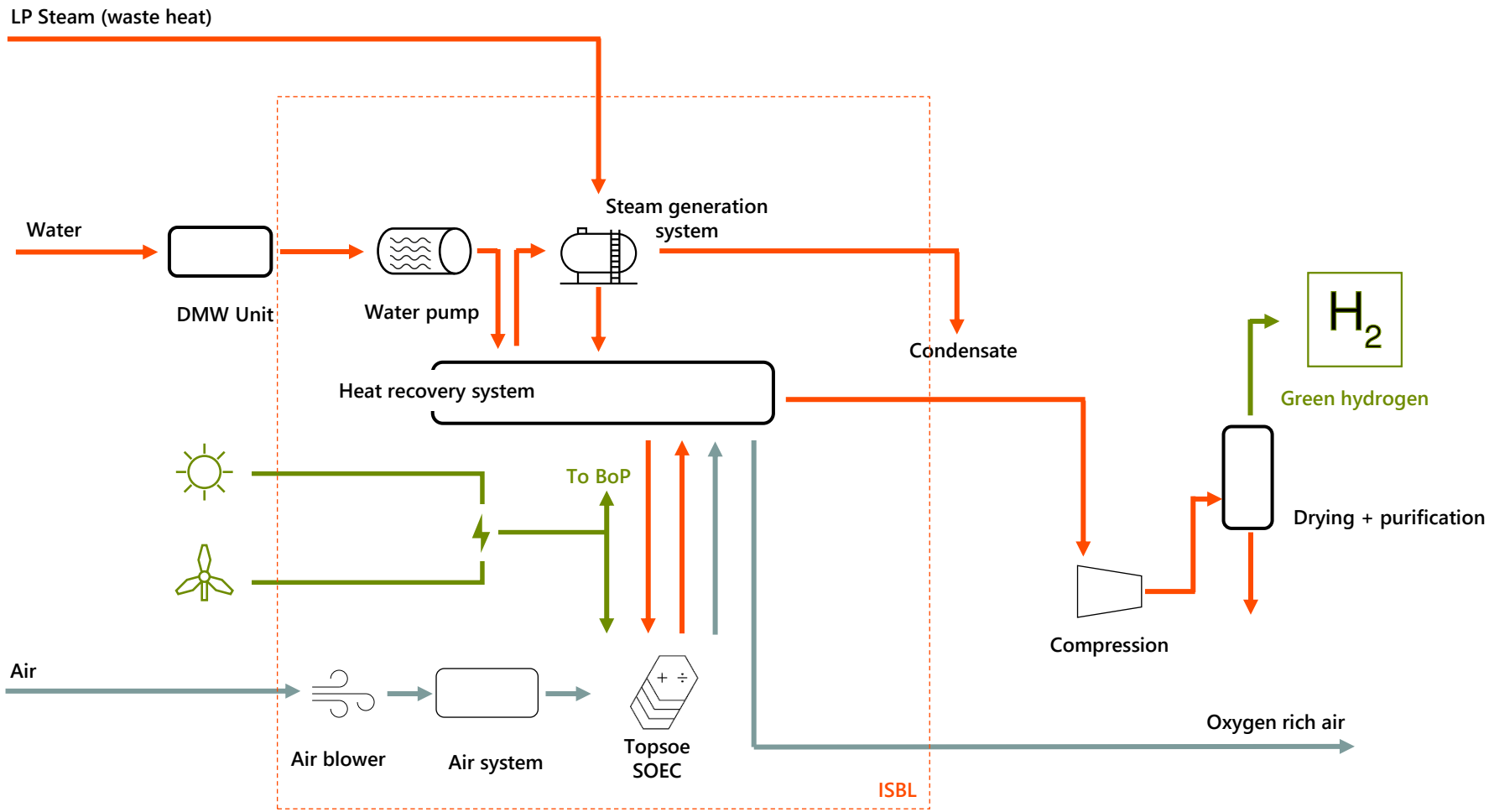
ENERGY DEMAND FOR WATER ELECTROLYSIS

Certain gain from SOEC compared to alkaline and PEM operation at better kinetics and conductivity

Potential gain if steam is imported

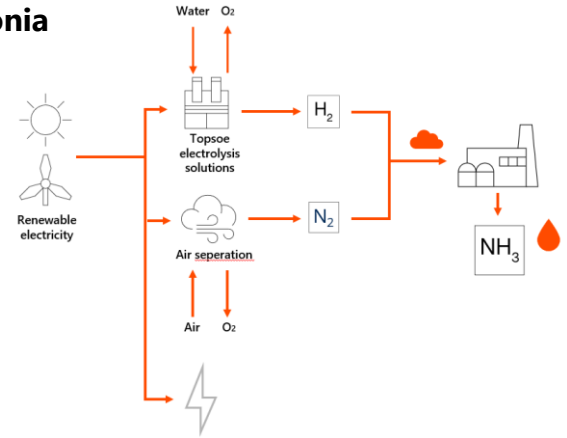


GREEN HYDROGEN BY SOEC

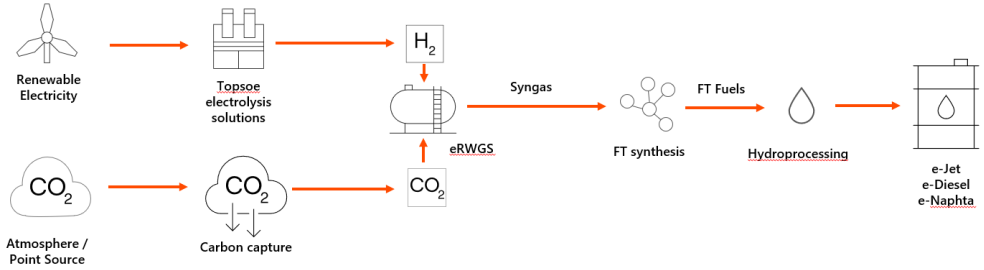


POWER TO X BY SOEC

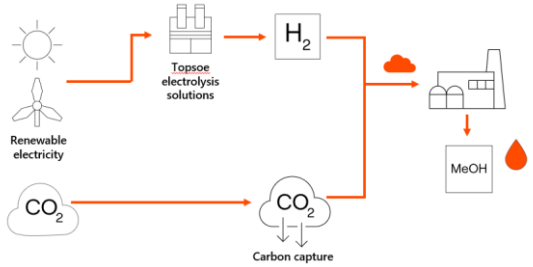
Green Ammonia



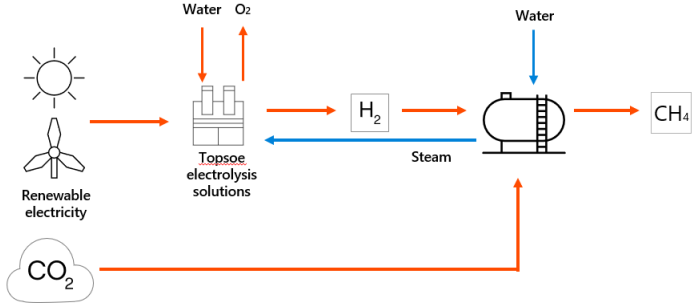
Green e-fuels



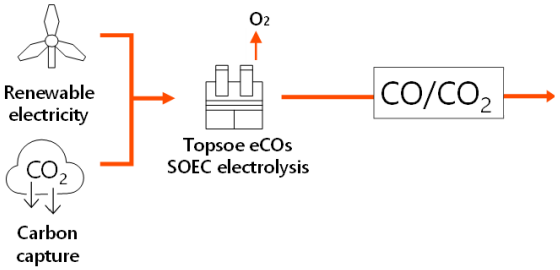
Green methanol



Green renewable methane

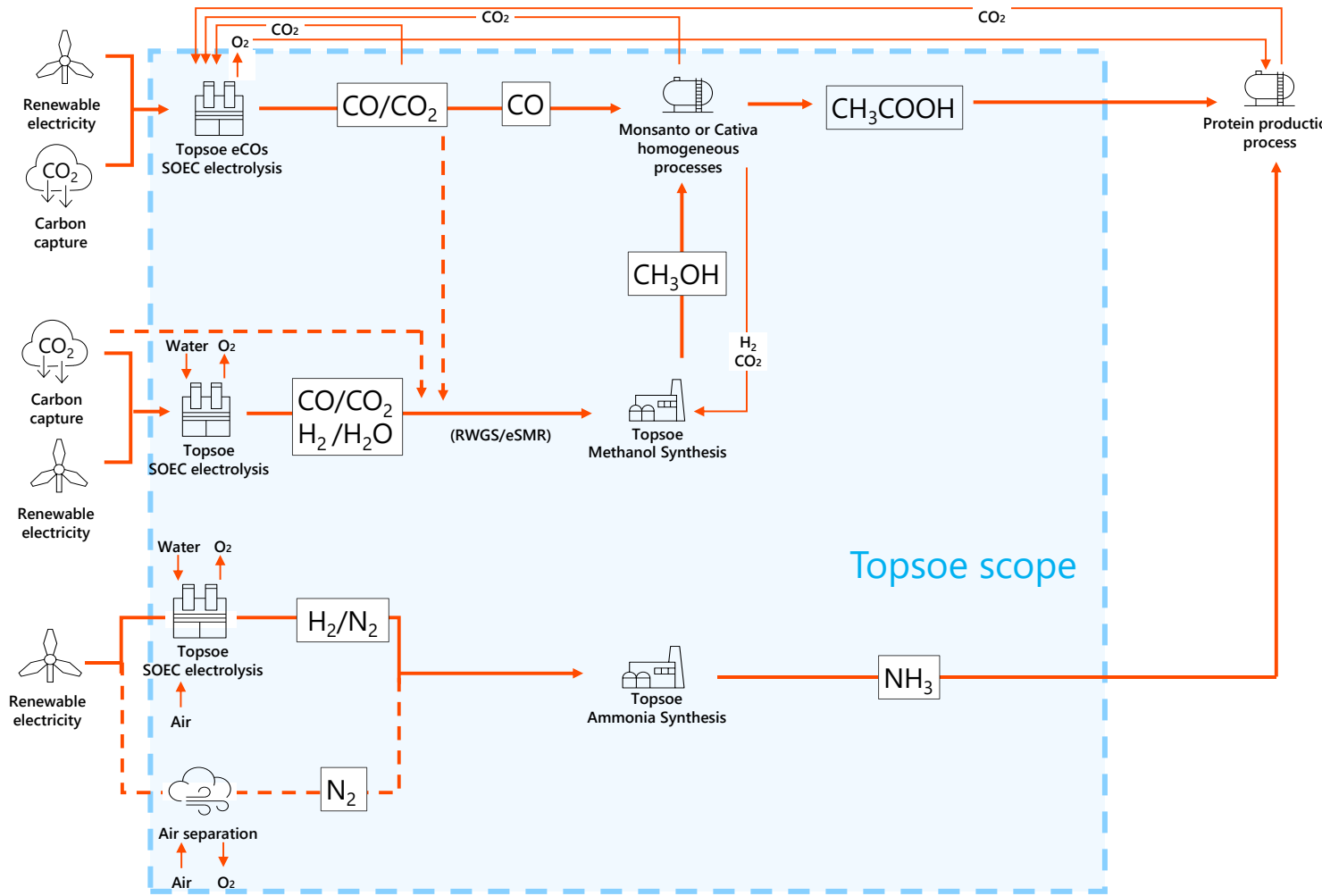


Green CO



CO_2 TO FOOD – TOPSOE SCOPE

SUPPORT FROM THE *BILL & MELINDA GATES FOUNDATION* AND THE *NOVO NORDISK FOUNDATION*

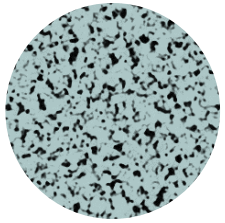
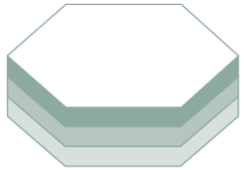
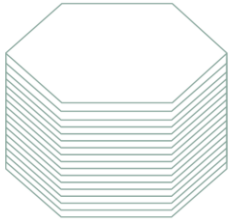


"A sustainable, safe and stable food source of proteins for human food derived from CO_2"

- H_2O-, CO_2 and Co-electrolysis in comparison
- What is the most efficient option to produce e-MeOH, e-AcOH etc.
- Combination with up- and downstream processes

CO2 as a sustainable raw material in our future food production - Novo Nordisk Fonden

FROM NANO TO MEGA
SOEC ELECTROLYSIS AT ALL SCALES

SOEC **electrode**	SOEC **cell**	SOEC **stack**	SOEC **core**	SOEC **section**
				

100 MW SOEC **plant example**

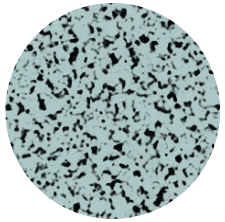
Topsoe and First Ammonia signed a 5GW launch company agreement for the reservation of first-of-a-kind, industrial-scale, solid oxide electrolyzer cells (SOEC) to produce green ammonia, a fuel for transportation, power storage and generation, and fertilizer

First Ammonia's 1st commercial-scale green ammonia plant is located at Port Victoria, Texas, United States.

Learn more

FROM NANO TO MEGA
SOEC ELECTROLYSIS AT ALL SCALES

SOEC **electrode**



SOEC **cell**

SOEC **stack**

SOEC **core**

SOEC **section**

100 MW SOEC **plant example**

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Learn more

PLUG & PLAY CONFIGURATION
EASE OF DEPLOYMENT AND OPTIMIZED FOR SCALABILITY AND MAINTENANCE

Above image shows two SOEC sections - **each containing 8 cores**.

Key benefits of Tospoe's Modular SOEC Plant

- **Plug-and-play** configuration
- Section count to required H_2 volume
- From a single 8 core SOEC section…to a **multi-MW** system

TOPSOE SOEC STACK MANUFACTURING FACILITY

HALDOR TOPSOE'S VEJ 2, 7400 HERNING, DENMARK

Funded by the European Union
Emissions Trading System
Innovation Fund

Topsoe awarded EUR 94 million for the construction of electrolyzer manufacturing facility in Herning, Denmark.

Initial capacity: 500 MW/year, expandable to 5GW

Production plant size 23,000 m^2

Total land area 72,000 m^2

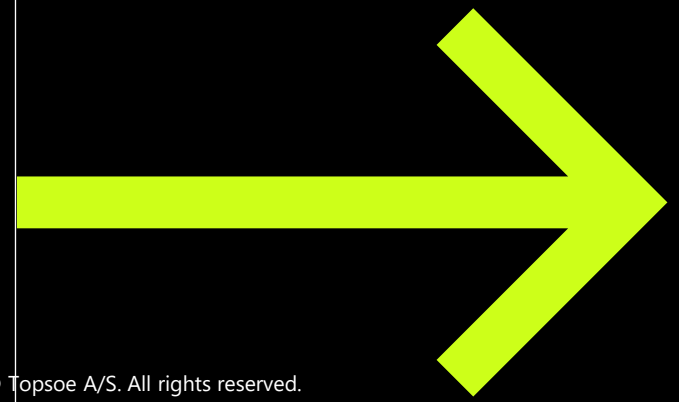
150 employees, on-site, when production begins in 2024.

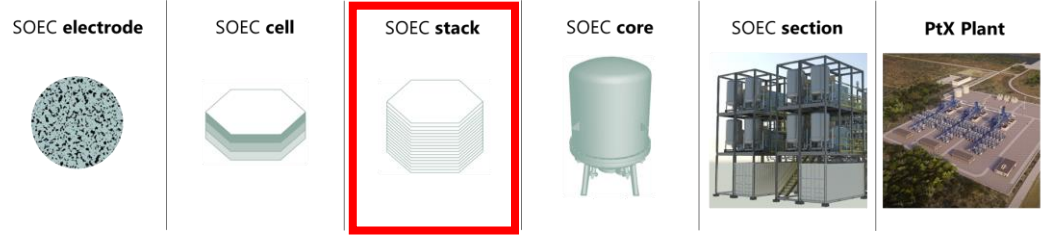
UPDATE May 2025
Full production starting this year

About the Innovation Fund
The Innovation Fund is the EU fund for climate policy, with a focus on energy and industry. It aims to bring to the market solutions to decarbonize European industry and support its transition to climate neutrality while fostering its competitiveness. The Innovation Fund is financed through the EU Emissions Trading System (EU ETC).

RECENT RESULTS

TOPSOE



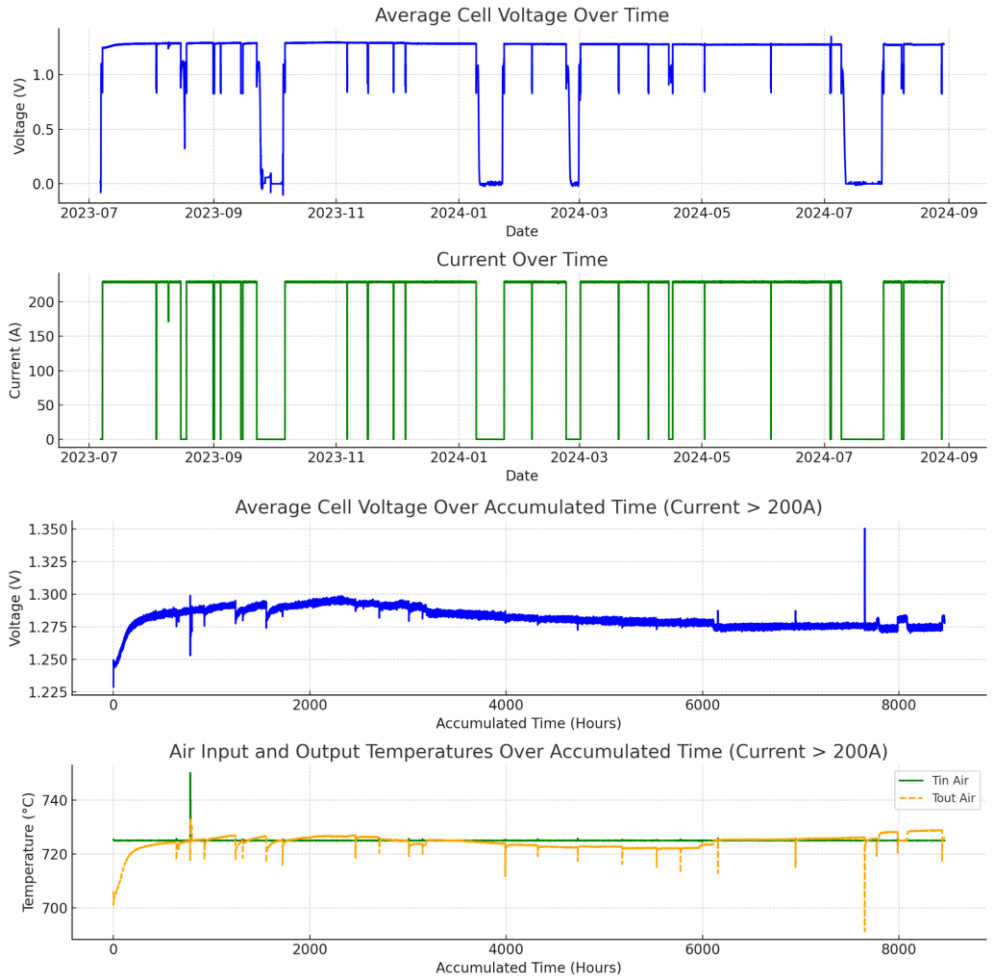


TOPSOE STACK PLATFORM 2 (TSP-2)
DURABILITY OF STACKS IN STEAM ELECTROLYSIS

- 4 x TSP-2 sub-stacks – total 96 cells.
  (3 stacks of 25 cells + 1 stack with 21 cells)
- Constant current of 229A
- Thermoneutral operation (H_2O SOEC)
- Operated at 3.5 bara
- **>10 000 hours of operation**
- **>100.000 Nm^3 produced**

✓ Extrapolated lifetime ~ several years

✓ **Durability of TSP-2 stack is promising**



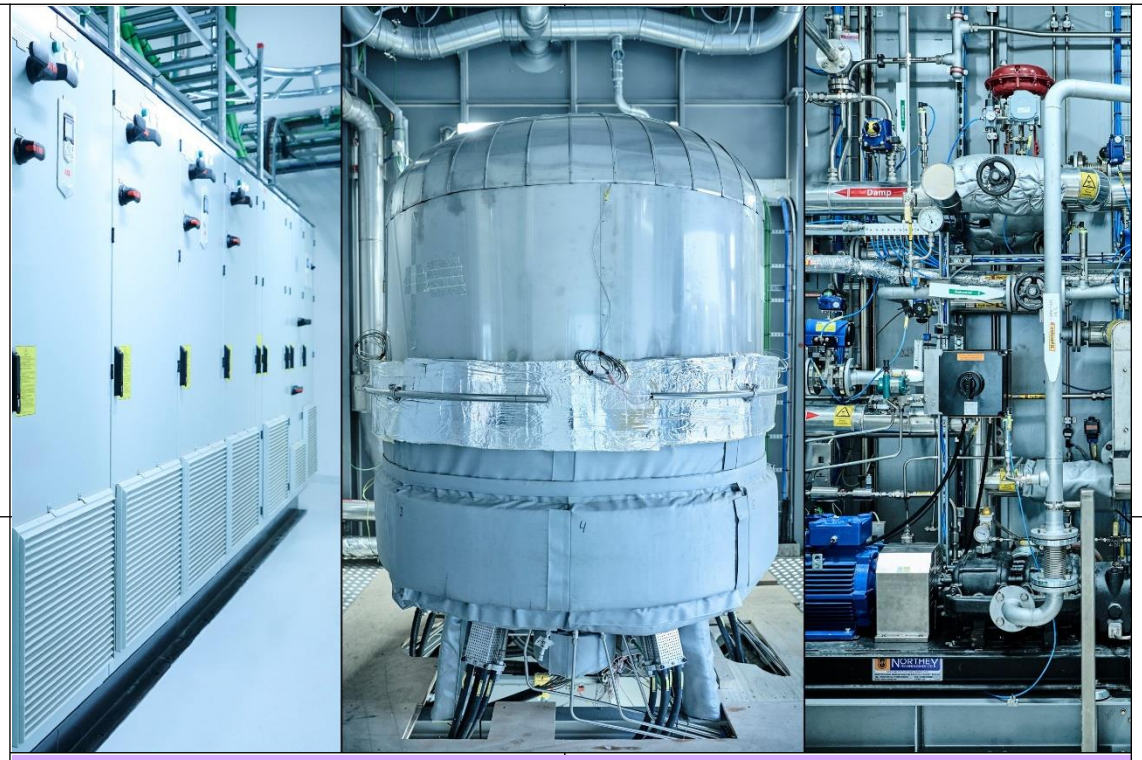
INDUSTRIAL SCALE DEMONSTRATION PLANT
KEY OBJECTIVES

1. Demonstrate complete hydrogen plant

2. Validate performance of SOEC core

3. Test industrially relevant design of system

12 Stacks, total 1200 cells, 350 kW_{el} (PSU), 115 Nm^3 H_2/h



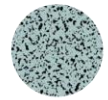
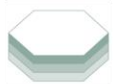
Industrial SOEC Core

THE EUROPEAN UNION
The European Regional Development Fund

Funded as part of the Union's response to the COVID-19 pandemic

Investing in your future

This work has received financial support from the project "SOEC Upscale", funded by European Regional Development Fund via the grant REACTRF-22-0076.

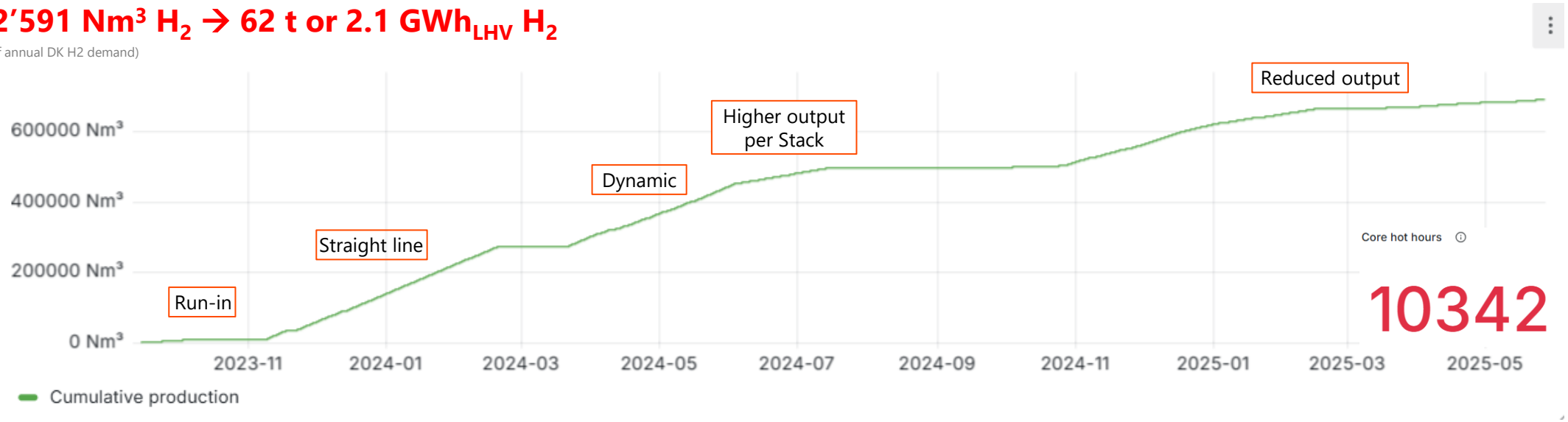





CUMULATED PRODUCTION & STACK OPERATION HOURS

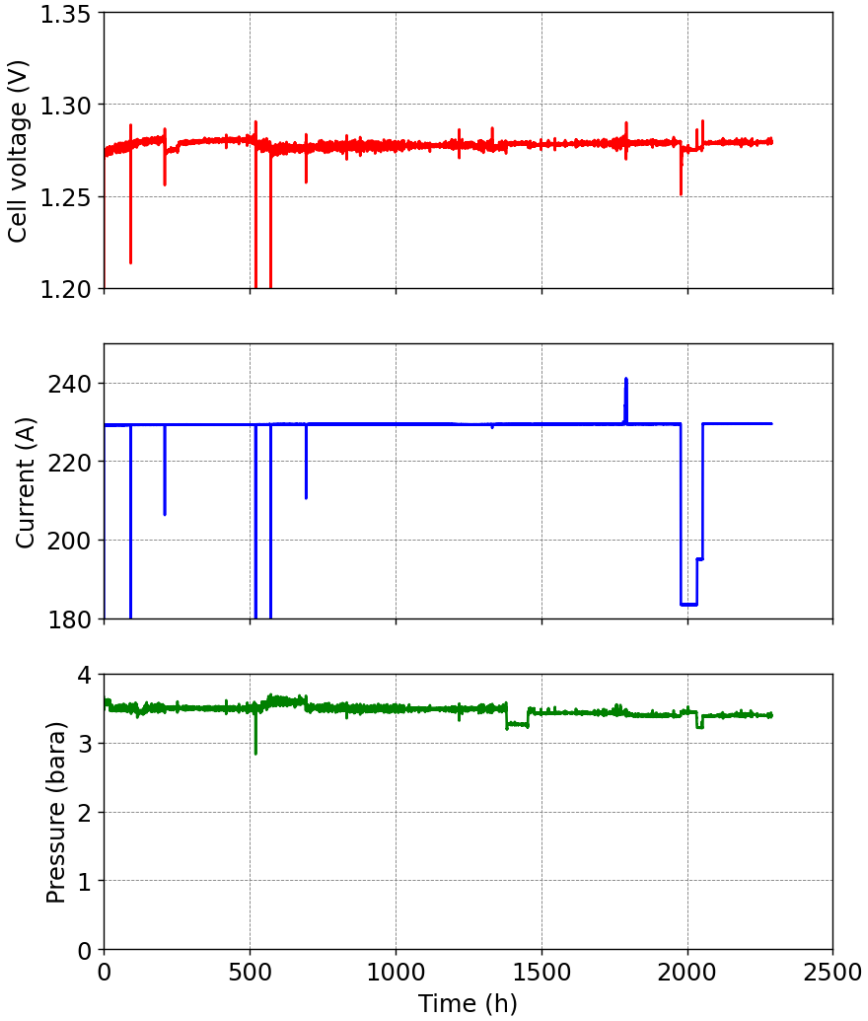
692’591 Nm^3 H_2 → 62 t or 2.1 GWh_{LHV} H_2

(2 ‰ of annual DK H2 demand)

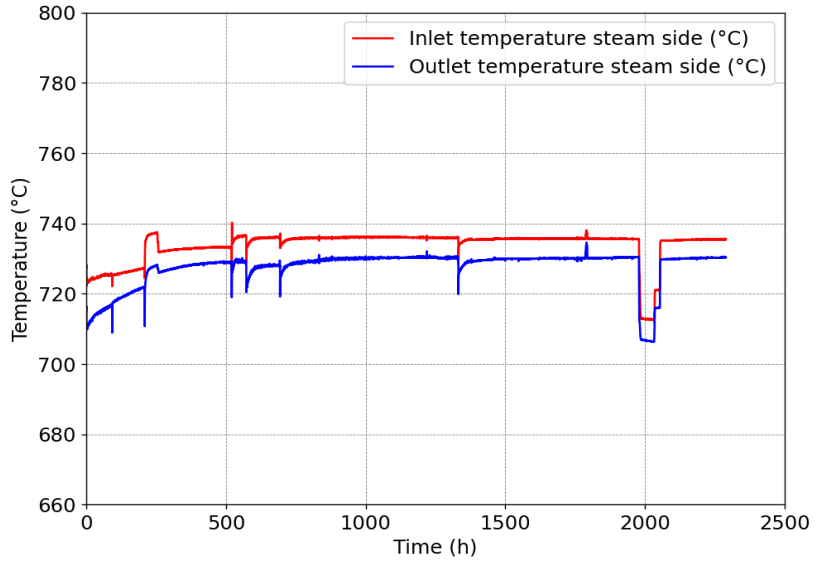


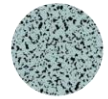
- Total ca. 10’000 h in operation, 62 t of hydrogen produced
- Operation phases:
  1. Run in
  2. 2000 h straight operation
  3. Dynamic operation / standby cycles
  4. Higher output per Stack
  5. Reduced output, while waiting for series manufactured stacks

OPERATION OF FULL-SIZE CORE: MODULE WITH 12 TSP-2 STACKS = 1200 CELLS



- 352 kW_{el} (PSU) ≈ **30 kW_{el} / stack**
- Pressurized **3.5 bara**
- **115 Nm^3 H_2/h** (→ 345 kW_{LHV} H_2)
- Very stable, low degradation,
  5 cycles (1 current on-off, 3 Hot-standby, 1 Thermocycle)








CORE ELECTRICAL POWER CONSUMPTION

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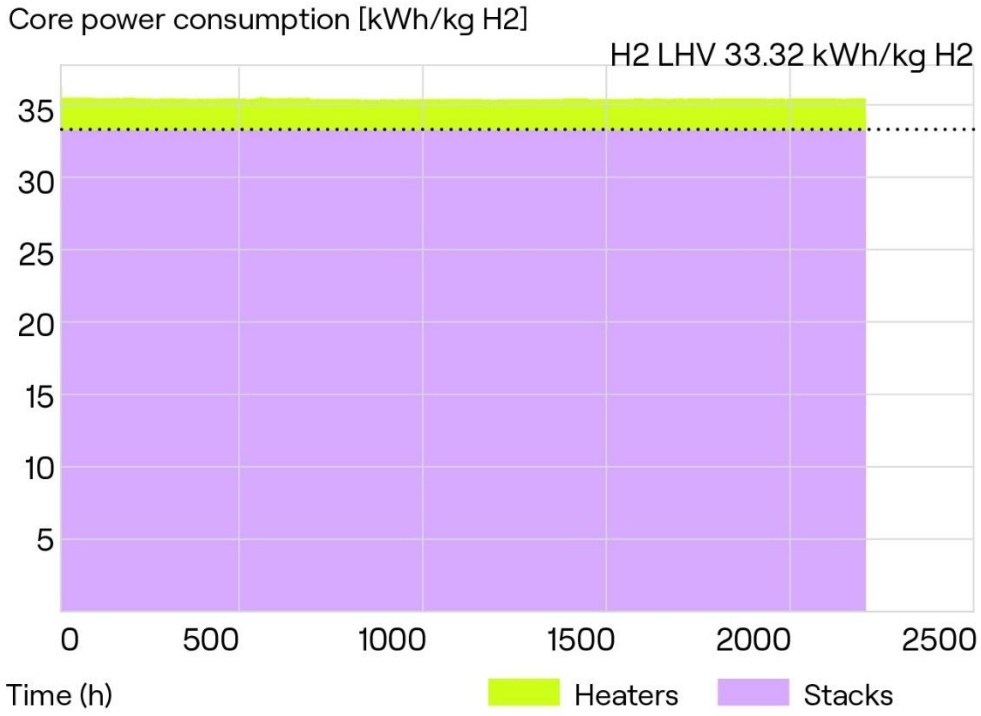
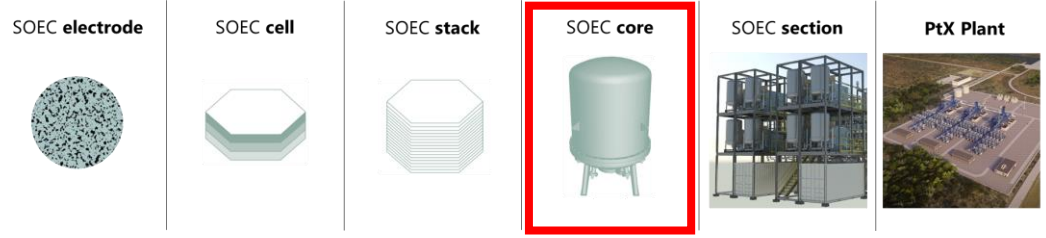
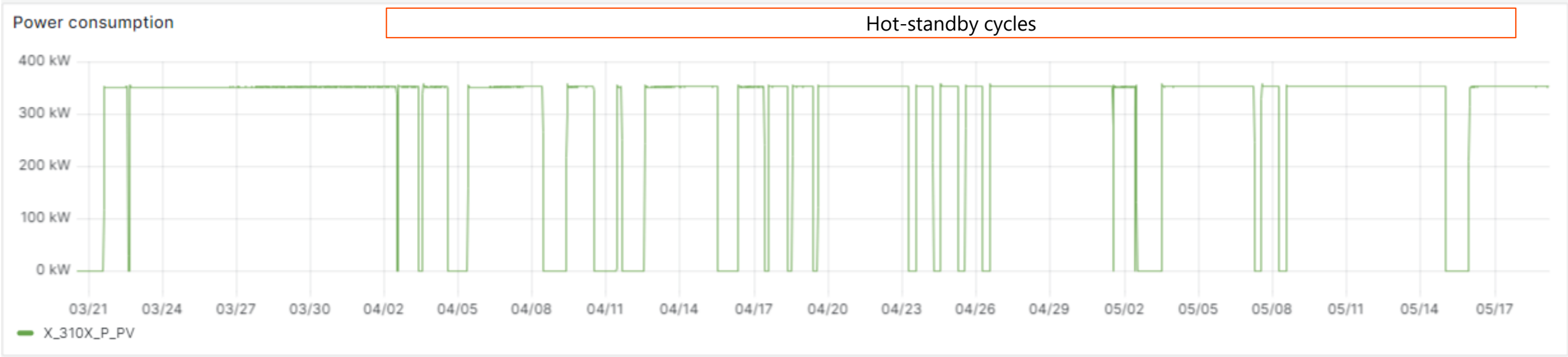


- → Power consumption of core stable at 36 kWh/kg H_2
- → Stack efficiency stable at ≈ 100%, thermoneutral operation
- → Electrical heater consumes ≈ 7% of power
  Total electrical efficiency of core ≈ 93%
- → ≈ 1/3 of 7% loss recovered for steam generation
  overall electrical efficiency 95% of core

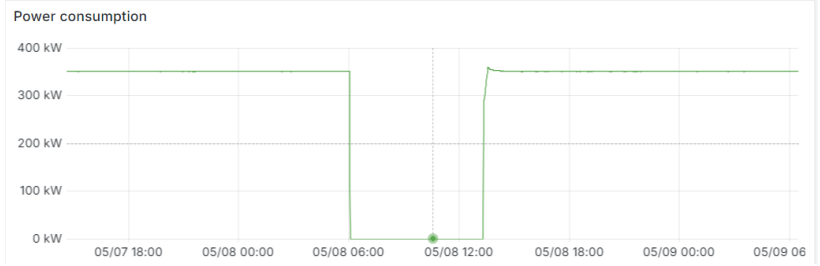
DYNAMIC OPERATION: HOT-STANDBY CYCLES

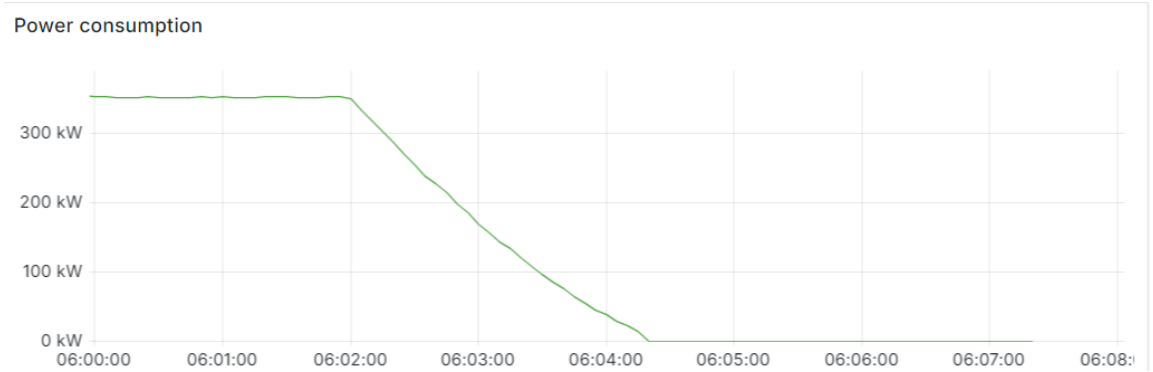


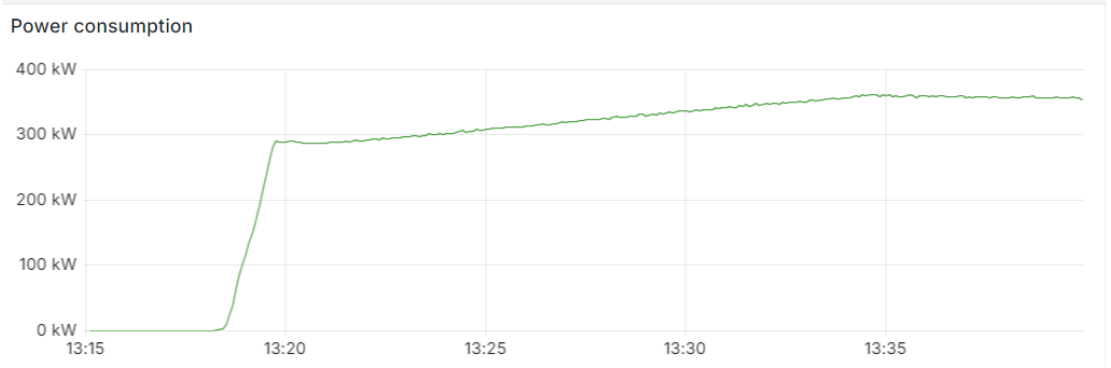


- 16 cycles, varying and optimizing conditions
- One 24h hot-standby

DETAILS: DYNAMIC OPERATION







- 3 min. from 100 % to 0% output
- 3 min. from 0 % to 80%, another 15 min. to 100%
- Hot-standby: electrical consumption core 11 kW (3%) vs. full load 372 kW (100%)
  (incl. internal heaters, excl. BoP: compressors, steam generation etc.)
- Well fitting to expected energy fluctuations and downstream processes

SUMMARY

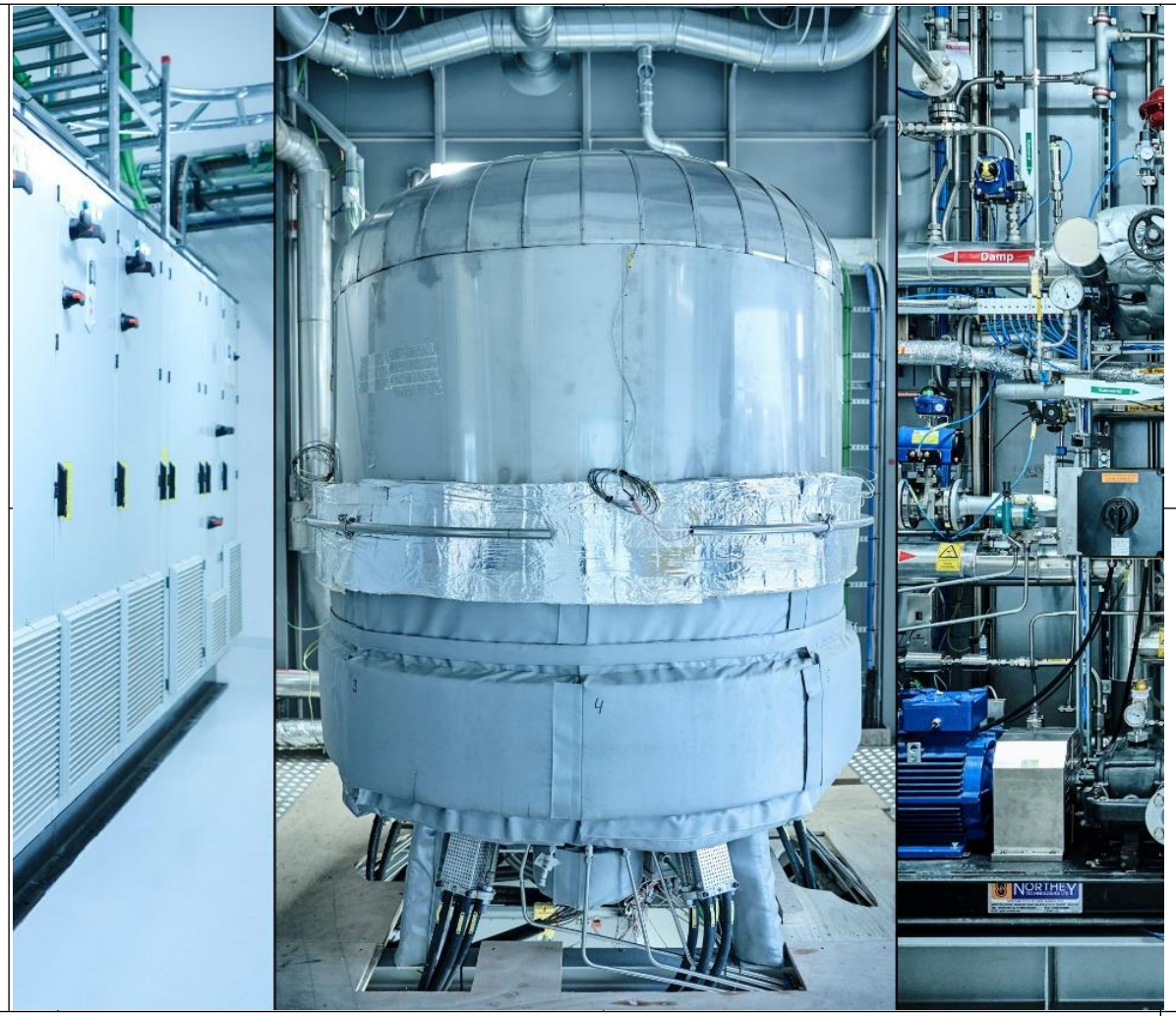
May 30, 2025

TOPSOE

Public

SUMMARY

- Topsoe possesses the knowledge and all the buildings blocks to deliver decarbonation solutions at scale to lead the fuel transition
- Topsoe are to provide the full solution combining SOE frontend and downstream processes like ammonia, methanol and SAF synthesis
- Demonstrated that SOEC Core as building block works with **high efficiency** (95 %, 36 kWh/kg H_2)
- Broad and fast modulation, low stand-by consumption → **also SOE is dynamic**
- 2025 Topsoe is to demonstrate the SOE section and produce SOE stacks and solutions at commercial scale



THANK YOU. QUESTIONS?

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Acknowledgements

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