

LEADING ENERGY TRANSITION THROUGH GREEN H₂ USING TOPSOE SOEC



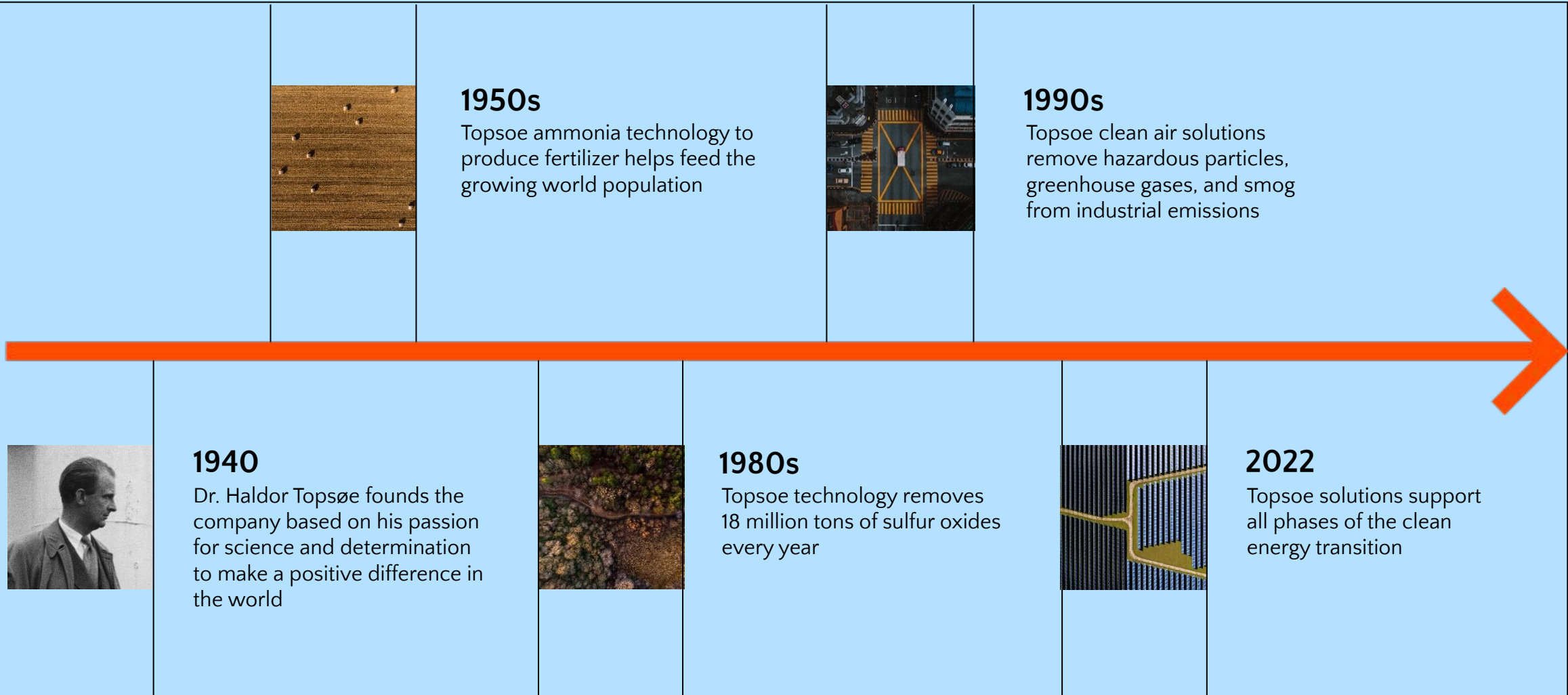
TOPSOE

INTERNATIONAL CONFERENCE ON GREEN HYDROGEN, 2023

Jasvant Singh
Head of the Department, Development (R&D)
5th July 2023



A HISTORY OF TAKING ON SOME OF THE WORLD'S TOUGHEST CHALLENGES



A COMPANY BUILT ON APPLIED SCIENCE

Thanks to decades of exceptional R&D, Topsoe is in a **unique position** to accelerate the transition to sustainable technologies.

9%

R&D investments of annual revenue



+40

Scientific partnerships with universities and institutes

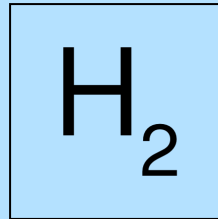
+500

Patent families

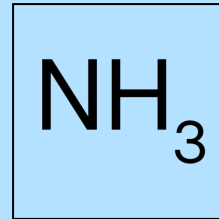
TOPSOE HAS THE NECESSARY BUILDING BLOCKS



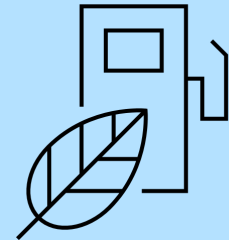
Hydrogen



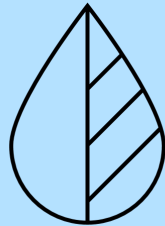
Ammonia



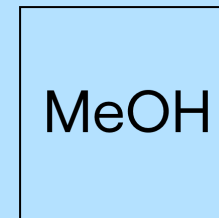
Electrofuels



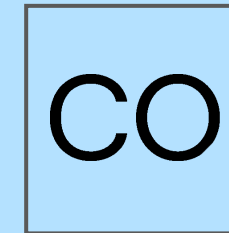
Renewable fuels



Methanol



Carbon monoxide



OUR VISION

TO BE RECOGNIZED
AS THE GLOBAL LEADER
IN CARBON EMISSION
REDUCTION TECHNOLOGIES
BY 2024





ENABLING THE TRANSITION

WE KNOW HOW TO TRANSFORM RENEWABLE ELECTRICITY



THE DEVELOPMENT PATH OF TOPSOE'S SOEC TECHNOLOGY

80's

Solid Oxide Fuel Cell (SOFC) developed

- SOFC cell and stack can also be used as SOEC
- Electrolysis of both water and CO₂

2015

Focus shifts to SOEC

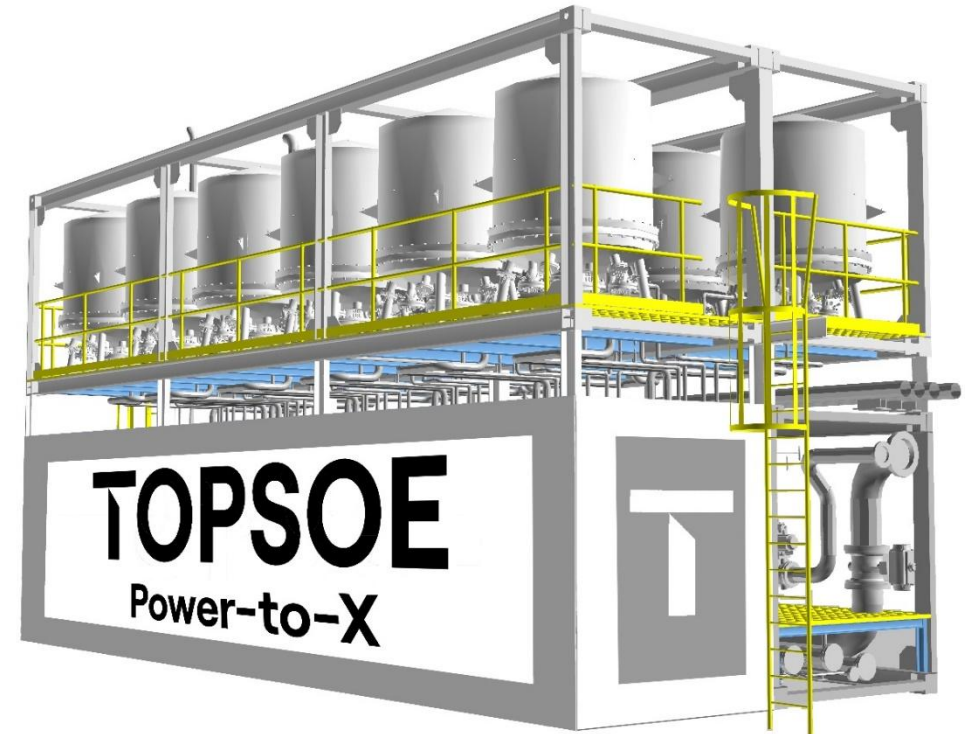
- Demonstration and industrial SOEC units since 2015
- Continuous optimization & innovation
- Market leading efficiencies



2022

Worlds biggest SOEC manufacturing facility

- Production begins 2025
- Initial 500 MW annual capacity
- Ability to expand annual capacity to 5 GW

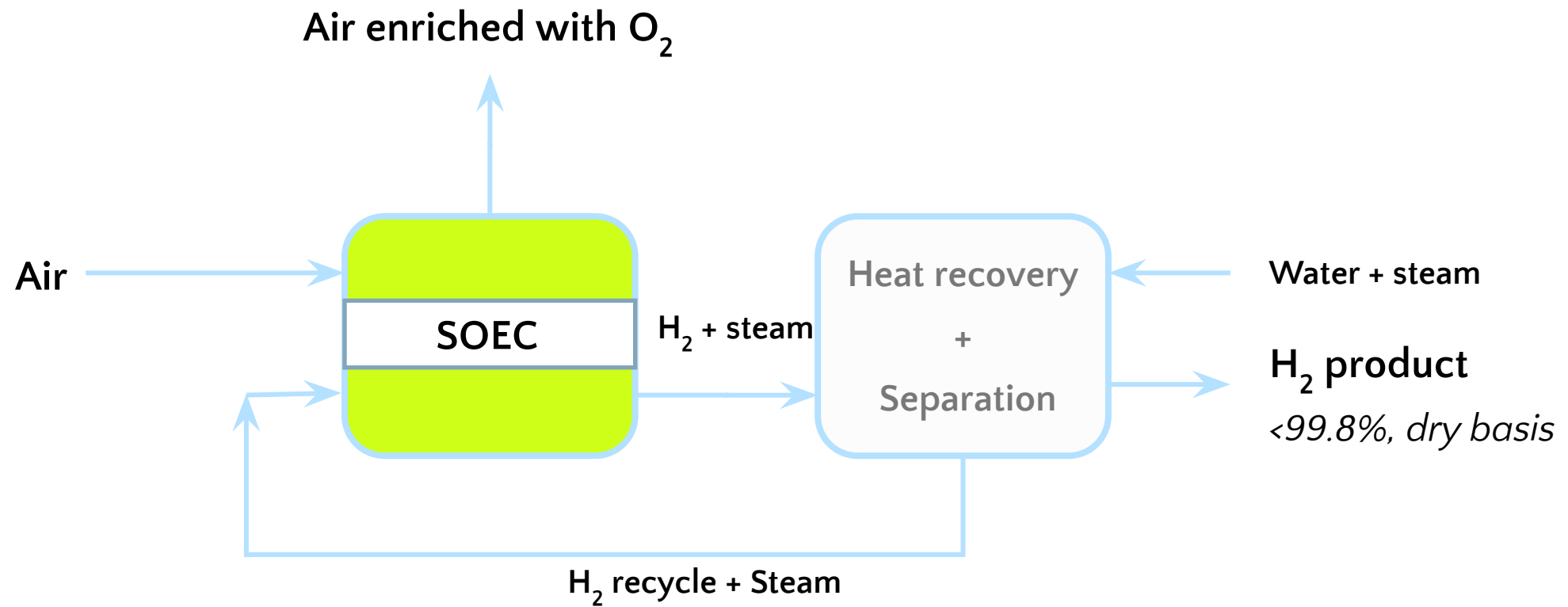


TOPSOE'S SOEC TECHNOLOGY: PRODUCTION PLANT

- First-of-its-kind
- FID reached to begin construction of the world's largest SOEC electrolyzer manufacturing plant
- Plant manufacturing capacity is 500 MW per year with an option to expand to 5 GW
- First offtake in-place for 500 MW and the option to expand to 5 GW
- SOEC consumes less electricity than alkaline and PEM technologies, since the process requires less power overall; with the integration of a steam feed, the SOEC process becomes even more efficient.



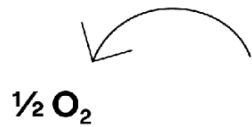
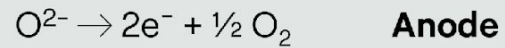
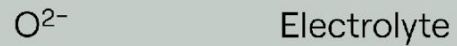
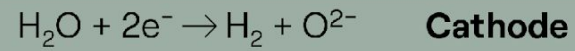
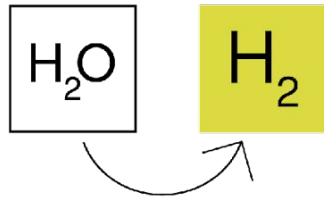
HYDROGEN PRODUCTION FROM WATER/STEAM AND RENEWABLE POWER



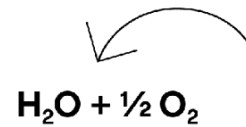
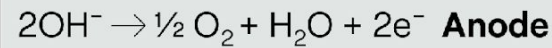
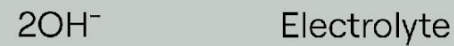
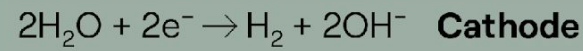
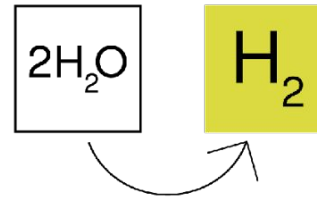
HOW SOEC ELECTROLYSIS WORK

CONCEPTUAL DIAGRAM OF SOEC, ALKALINE, AND PEM ELECTROLYSIS, INCLUDING HALF-CELL REACTIONS (THE OXIDIZING AND REDUCTION REACTIONS)

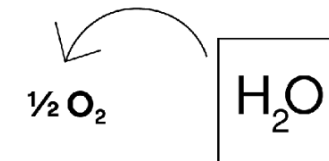
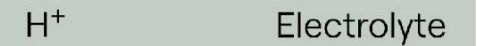
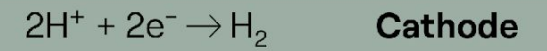
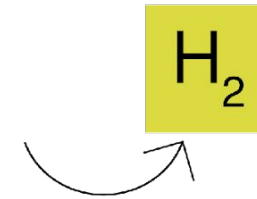
SOEC



ALKALINE



PEM



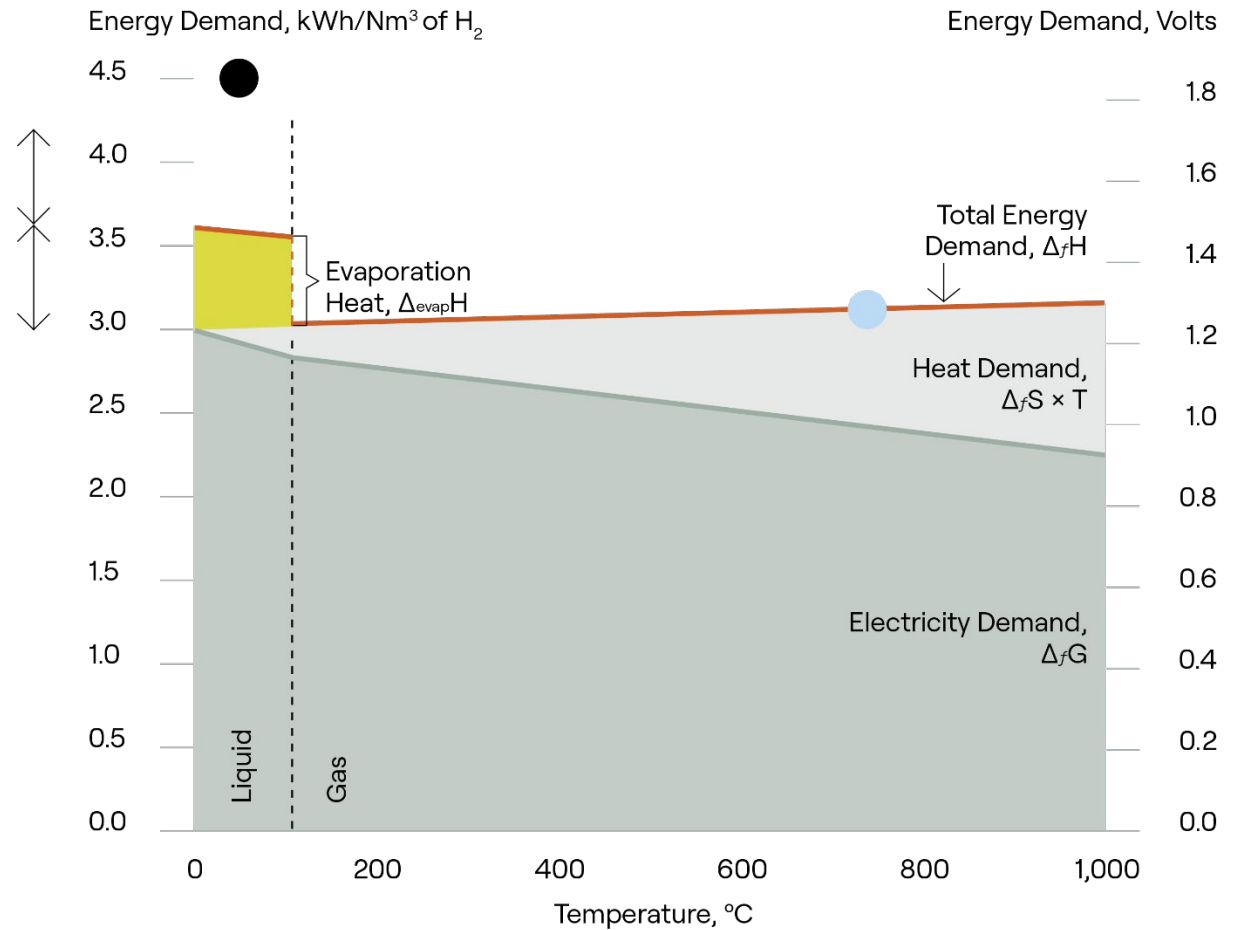
TEMPERATURE INFLUENCE ON ELECTROLYSIS

ENERGY DEMAND FOR THE ELECTROLYSIS OF WATER EXCLUDING BALANCE OF PLANT

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

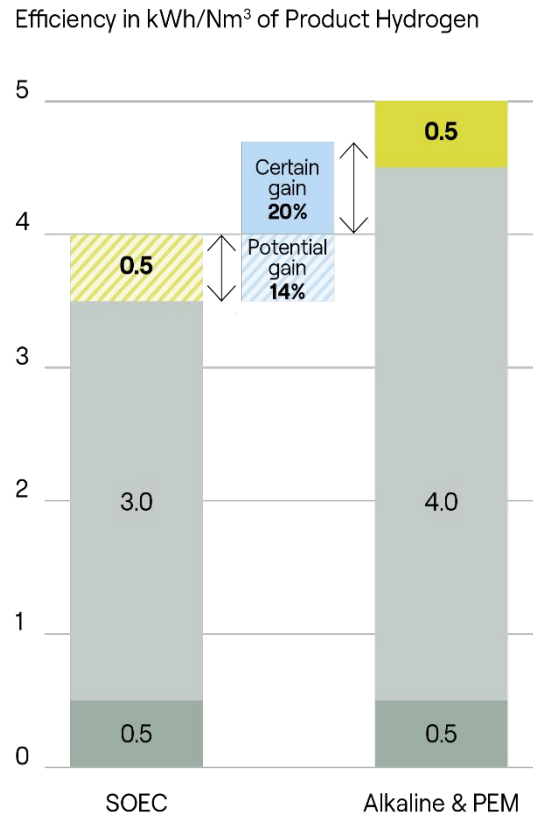
Potential gain if steam is imported

- Total Energy Demand, $\Delta_f H$
- Alkaline & PEM
- SOEC



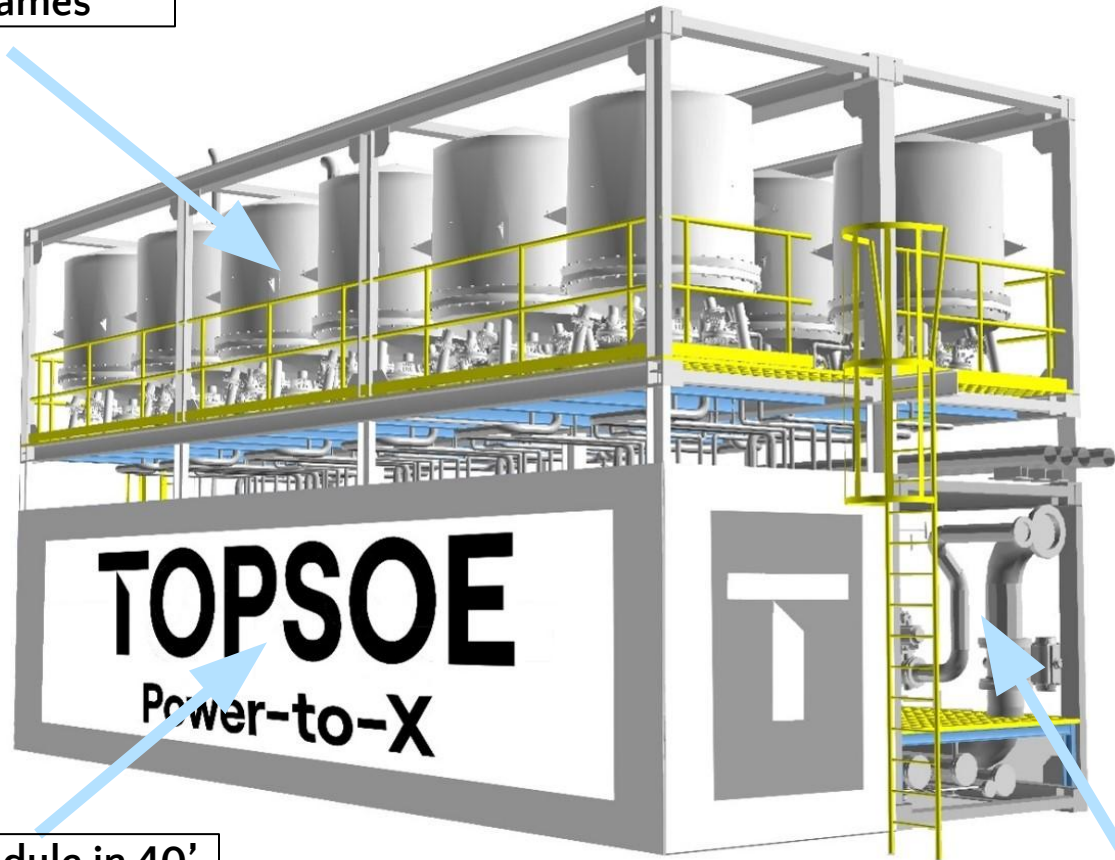
SOEC IS UP TO 35% MORE EFFICIENT THAN LOW TEMPERATURE ELECTROLYSIS

- Balance of Plant
- Electrolysis
- Heat of Evaporation



SOEC FROM CELL TO 5 MW MODULE

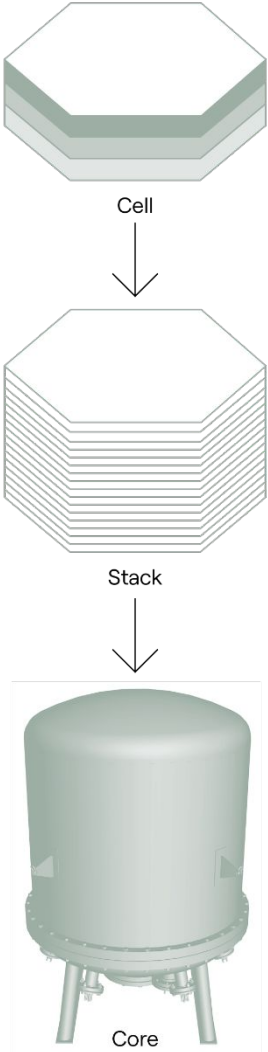
12 SOEC Cores in two 40' frames



PSU module in 40' frame

Piping & Instrumentation module in 40' frame

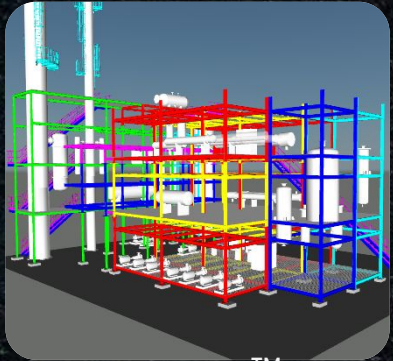
SOEC CELL, STACK AND CORE



15 MW SOEC HYDROGEN PLANT



Topsoe ModuLite™ solution



ModuLite™
Design



ModuLite™
workshop fab



ModuLite™
E&I + insulation



ModuLite™
Shop assembly

TOPSOE



ModuLite™
Packing & shipment



ModuLite™
Easy site assembly



Plant in operation



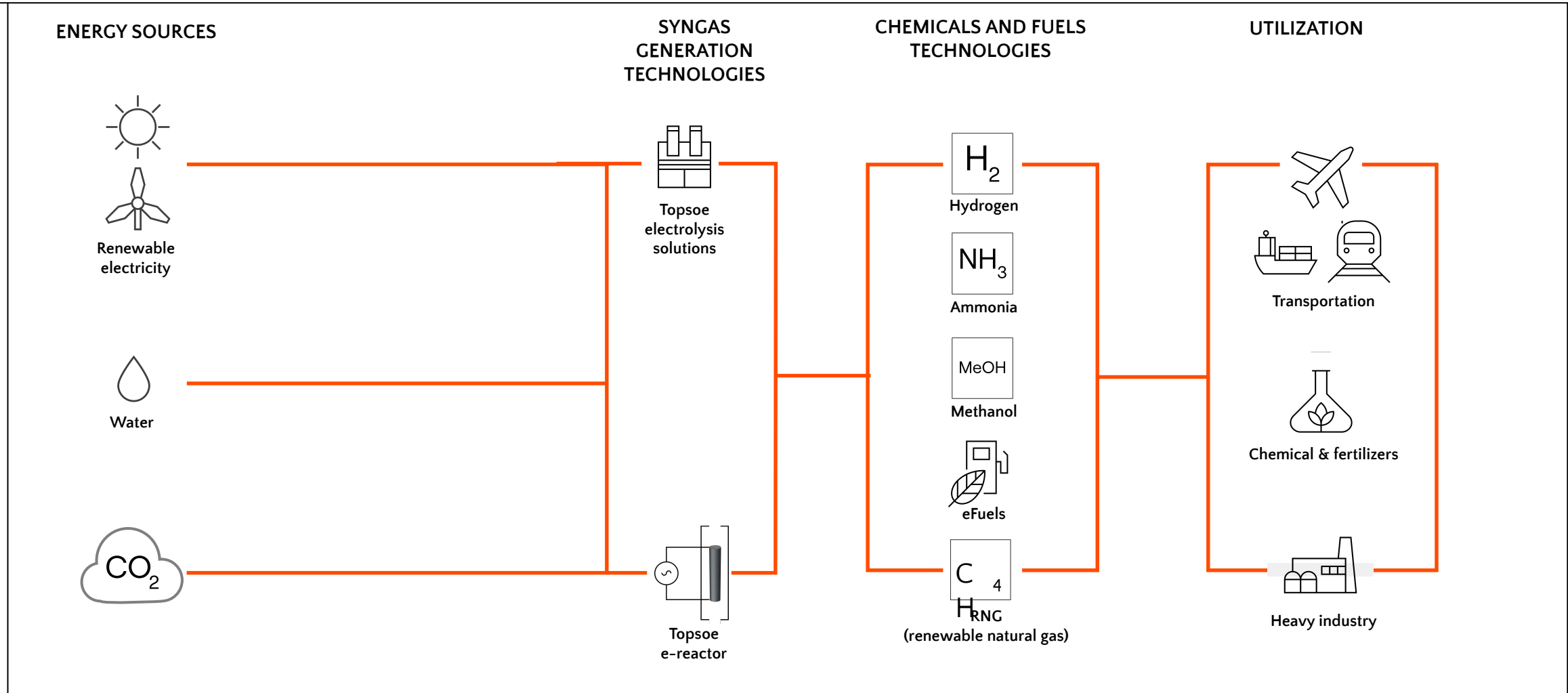
REFERENCE: MODULAR 30.000 NM³/HR H₂ UNDER CONSTRUCTION FROM DESIGN TO CONSTRUCTION



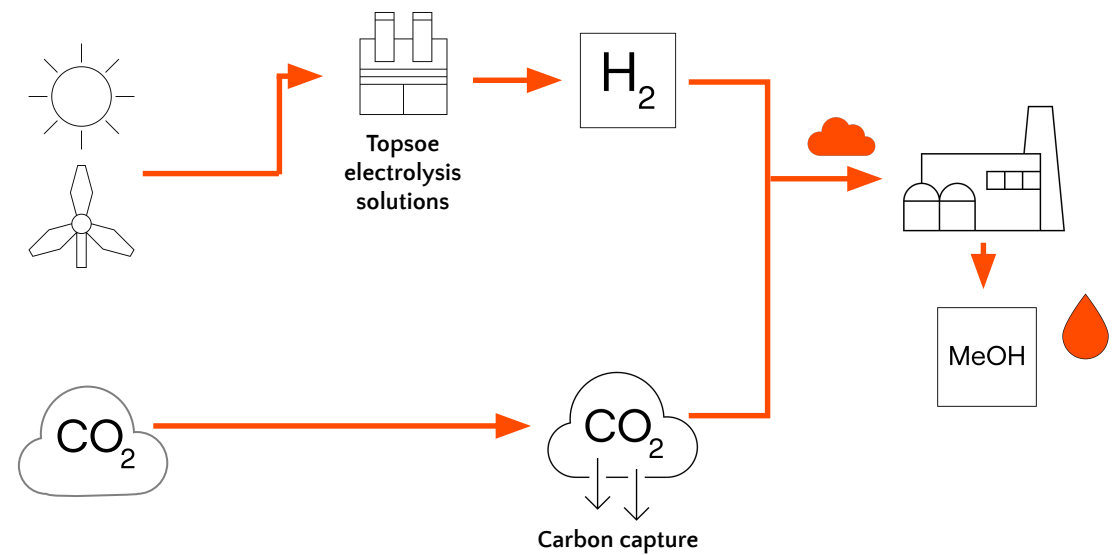
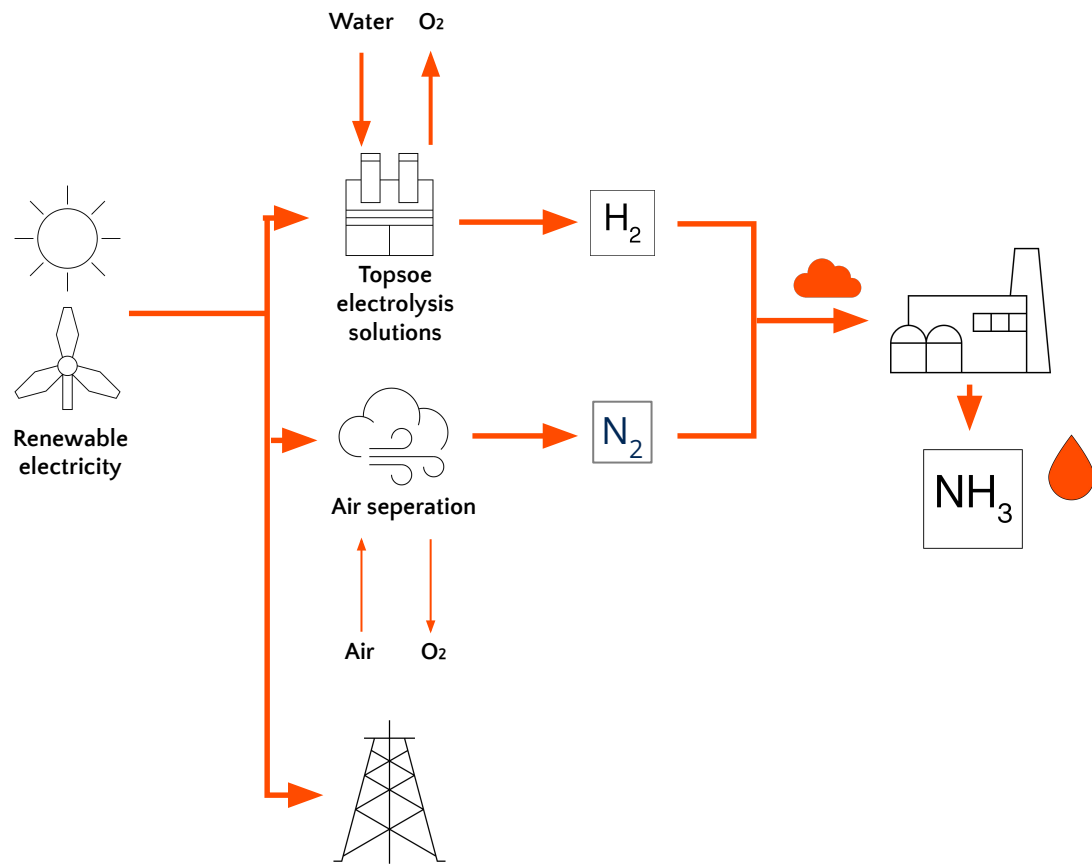
PACKING AND SHIPMENT OF MODULES



TOPSOE'S POWER-TO-X SOLUTIONS ACCELERATE THE ENERGY TRANSITION



GREEN AMMONIA AND METHANOL BY SOEC



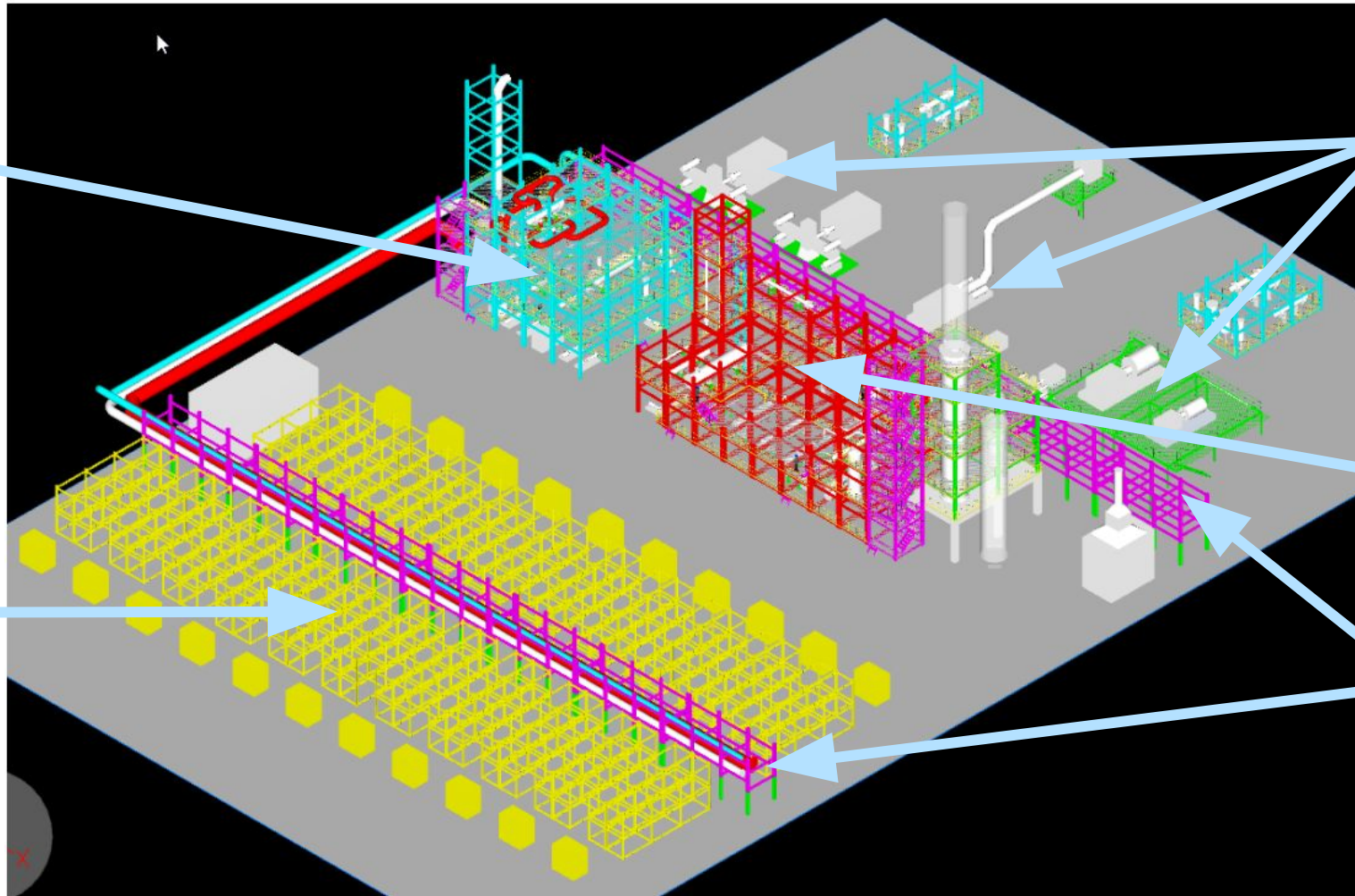
FIRST AMMONIA – 100 MW SOEC GREEN AMMONIA PLANT (300 MTPD) – MODULAR DESIGN

Balance of Plant
(BOP)

20 Modules

21 SOEC Units

Total Plant area
90*140 m



5 Compressors

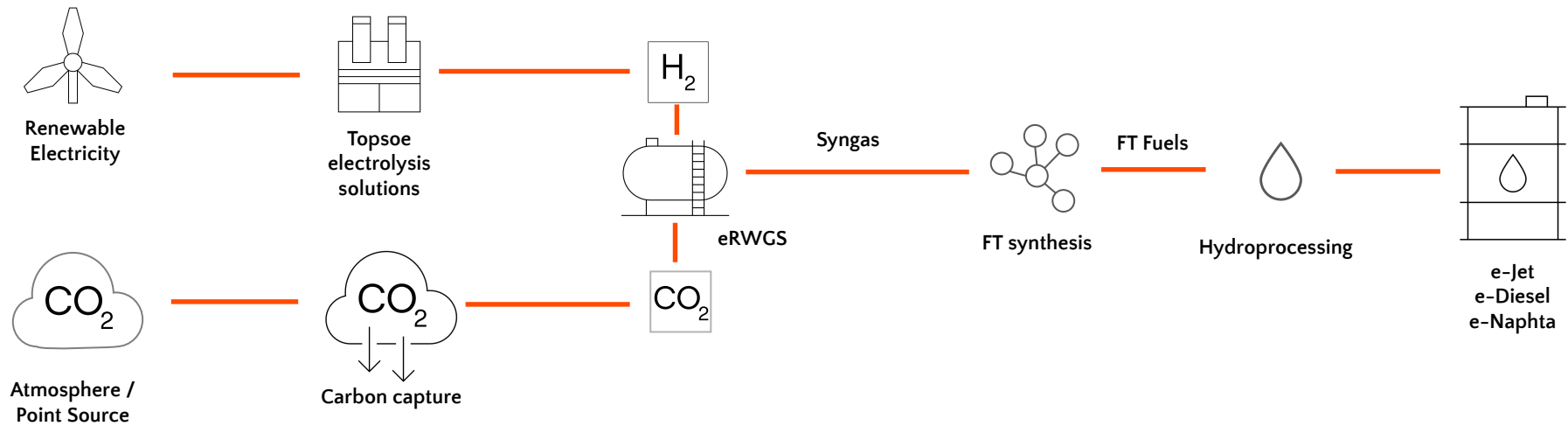
Ammonia Loop

26 Modules

Pipe Racks

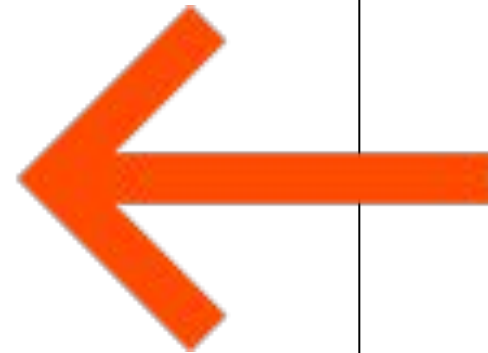
14 Modules

GREEN E-FUELS BY SOEC

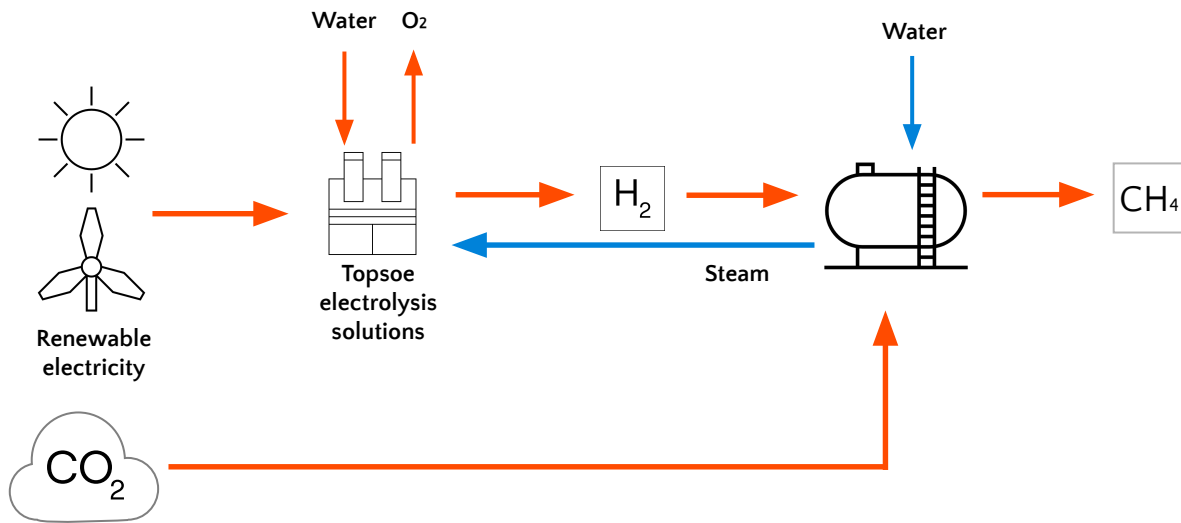


AN END-TO-END SOLUTION

- Fully integrated design
- Integrated guarantees
- Reliable production
- Bankable

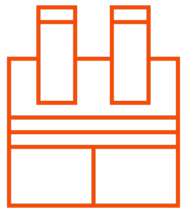


GREEN RENEWABLE NATURAL GAS BY SOEC



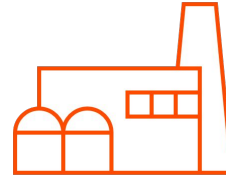
TOPSOES SOEC SOLUTION OFFERS A WIDE RANGE OF ADVANTAGES

EFFICIENCY



- SOEC is up to 30% more efficient than other electrolyzers, amounting to a power-use reduction of 1.5 kWh/Nm³ H₂
- In addition to the electrolysis of steam, SOEC can electrolyse CO₂ and thereby generate CO
- CO₂ electrolysis enables carbon capture & utilization from a point source and provides advantages for making eFuels such as eJet, eDiesel and methanol

SUSTAINABILITY



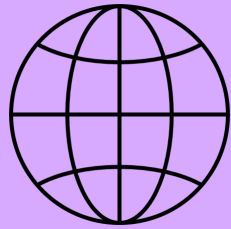
- SOEC is constructed from materials abundant in nature, and can easily be scaled up without material-availability constraints.
- The use of non noble materials will benefit cost as the raw materials will not become more expensive due to scarcity

LONG TERM SERVICE AGREEMENT



- Long-term service agreements giving certainty on energy consumption and production costs.

GLOBAL PROJECTS



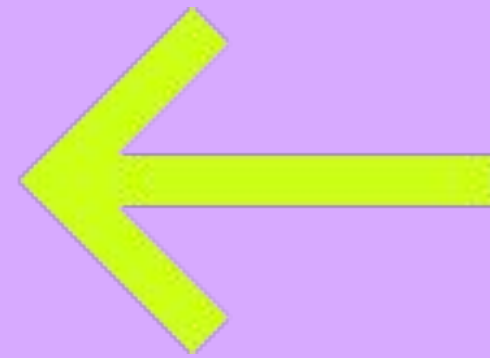
Topsoe provides technology for the world's biggest **green ammonia plant in Saudi Arabia**

Part of the "**Green Fuels for Denmark**" IPCEI project to convert green hydrogen and captured carbon into clean methanol and jet fuel

100 MW green ammonia project in Germany with US-based **Aquamarine** using Topsoe's SOEC electrolysis and dynamic ammonia technologies

Part of the **Liquid Wind consortium** in Sweden to produce clean methanol from green hydrogen and carbon from bio waste

Cooperation with **Skovgaard and Vestas** to develop, build and operate a fully dynamic 10MW green ammonia demonstration plant directly coupled to wind and solar power



KEY TAKE AWAYS

- Topsoe has required knowledge, catalysts, and technology to develop plants for the production of green hydrogen and subsequently providing solution for power to X.
- Topsoe has cutting edge , high efficient SOEC technology to ensure transition in to greenn chemicals
- Topsoe SOEC can produce hydrogen but can also generate CO from CO₂ thus provides Synthesis gas for various chemical production
- Topsoe moduLite™ provides one stop solution for small scale plants
- Topsoe provides end to end solutions starting from SOEC to end chemicals. E. g ammonia , Methanol



THANK YOU. ANY QUESTIONS?

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TOPSOE