



Green Ammonia

Key to Decarbonization of Industry,
Agriculture & Beyond

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June 25, 2022

IIT Delhi

TOPSOE

Agenda

1

TOPSOE

2

DECARBONIZATION

3

**LOW CARBON/
GREEN AMMONIA**

Topsoe: Perfecting chemistry for a better world

- A passion for chemistry
- A mission to make a positive difference to the world
- A vision to lead the global transition into the renewable future and reduce carbon emissions



15

Present in 15 countries across 5 continents

2200

Employees

40+

Scientific partnerships with universities

8%

R&D investments of annual revenue

Global leader in technologies, catalysts and services for producing essential chemicals and fuels



Process design, engineering and licensing



> 150 High-performance catalysts produced in-house



Proprietary equipment



Business and technical service

Innovative technologies

A company built on science

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



Today and for the future

A history of taking on some of the world's toughest challenges



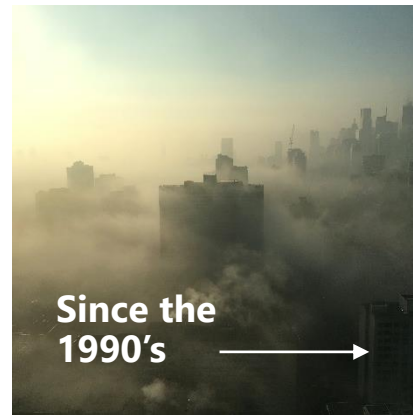
Dr. Haldor Topsøe founds the company based on his passion for science and determination to make a positive difference in the world



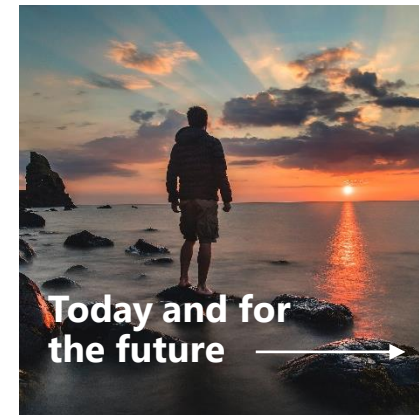
Topsoe ammonia technology to produce fertilizer helps feeding the growing world population



Topsoe technology removes 18 million tons of sulfur oxides every year

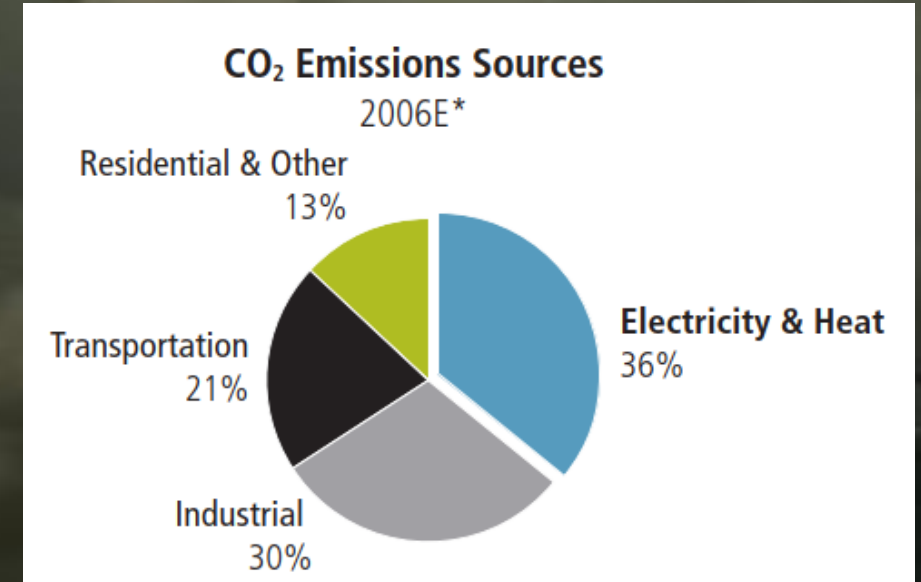
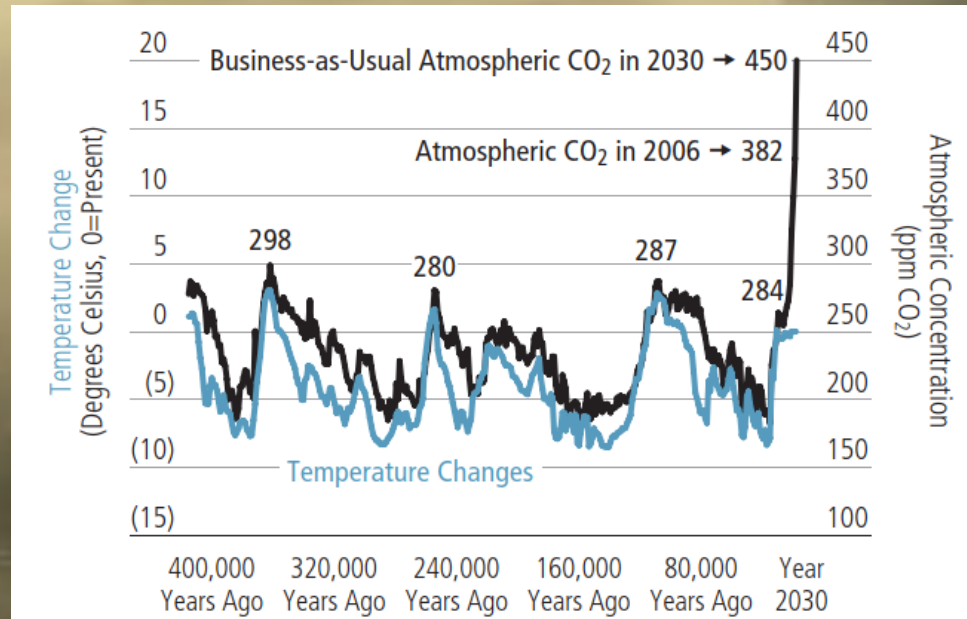


Topsoe clean air solutions remove hazardous particles, greenhouse gases, and smog from industrial emissions



Topsoe solutions support all phases of the clean energy transition

Decarbonization : Pressing Global Challenge of Our Times



Source: Arctic and Antarctic Research Institute, Laboratoire de Glaciologie et de Géophysique de l'Environnement and Laboratoire des Sciences du Climat et de l'Environnement and AllianceBernstein (from report 'Abating Climate Change')

Source: EIA, WRI & AllianceBernstein (from report 'Abating Climate Change')

Decarbonization via Power-to-X (PtX)

Sustainable E-fuels

Carbon-based (bio-sources / bio-CO₂)

- Methane, CH₄
- Methanol, CH₃OH
- Gasoline
- DME
- Diesel
- Jet fuel

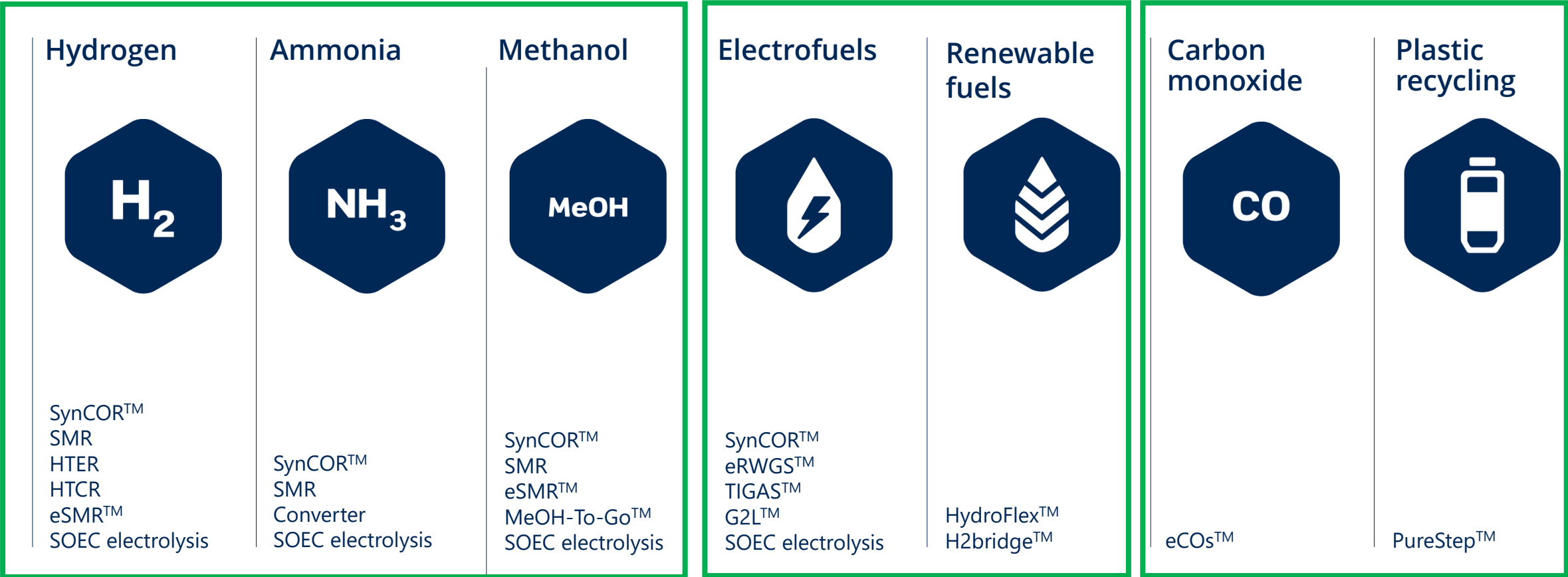


Non-carbon-based (abundantly available)

- Hydrogen, H₂
- Ammonia, NH₃

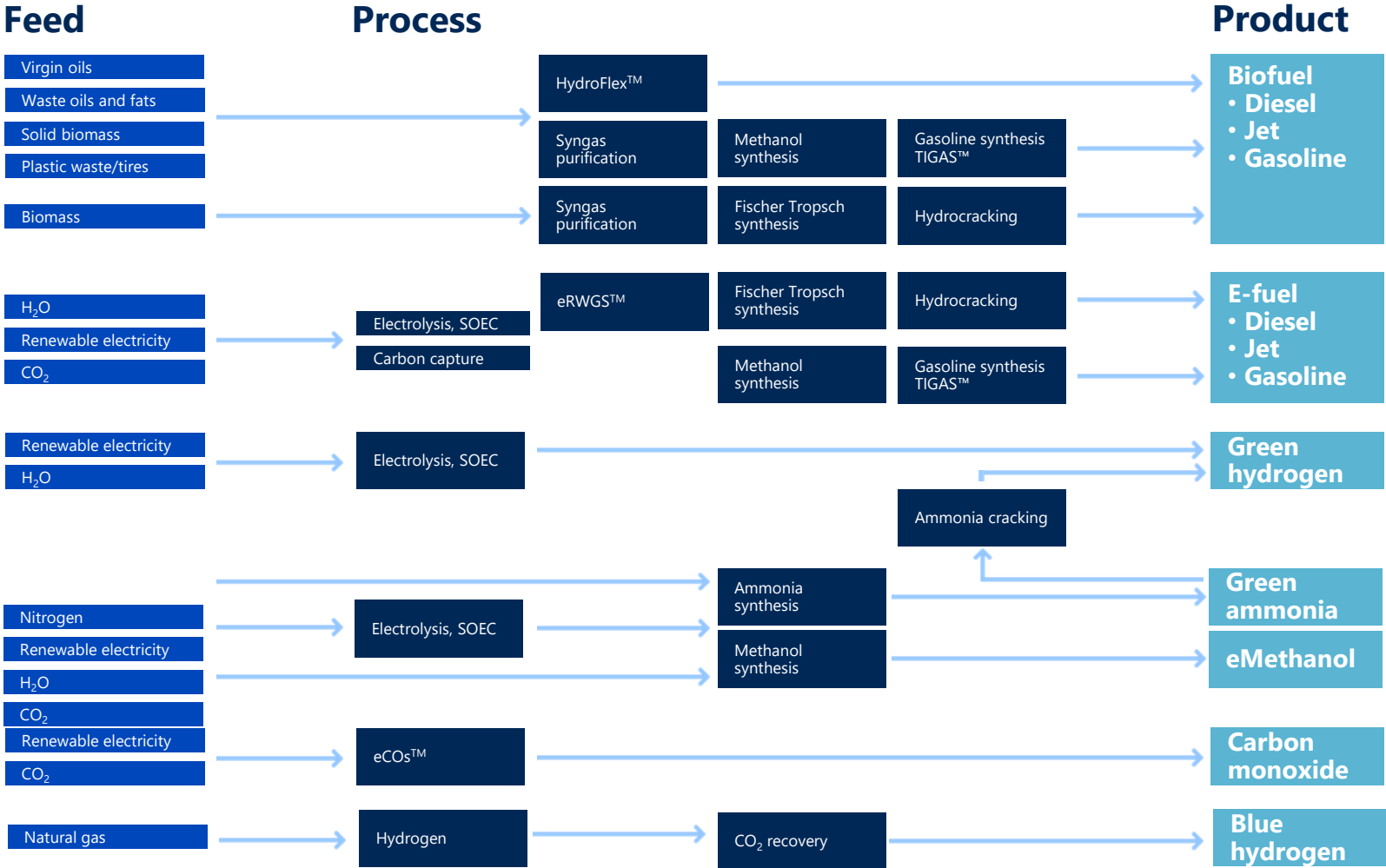


Topsoe product lines: Building blocks of a Decarbonized energy system



Market leadership in process technologies and catalysts – Global & in India

Decarbonization journey involves stitching together productive combinations of multiple (Topsoe) technologies



We help industries navigate the challenges involved in turning to production of low carbon emission products by combining traditional and well proven technologies with new and groundbreaking innovations.

Green Ammonia



Meet changing market demands
with green ammonia

TOPSOE

Topsoe: Market leadership in Green, Blue & Renewable Fuels Projects



نيوم NEOM

Green ammonia

4000 TPD capacity green ammonia plant in Saudi Arabia based on Topsoe's highly dynamic ammonia-synthesis technology.

Air Products will be the exclusive off-taker of the green ammonia produced.



Green Ammonia

Aquamarine Investment Partners have announced a plan to build a facility that produces green hydrogen from renewable electricity via Topsoe SOEC & RE power.

This hydrogen will be further processed using our technology, producing green ammonia for use as marine fuel or fertilizer



Blue Ammonia

The Barents Blue project is the first large-scale greenfield blue-ammonia plant in Europe, and will include planned CO₂ storage offshore

The Barents Blue plant will produce more than 1 million tons of clean ammonia once it becomes operational in 2025.



eMethanol

Liquid Wind plans to produce methanol from captured CO₂, and hydrogen from water electrolysis – all based on our eMethanol™ technology.

The project will provide local industries and other Swedish institutions with the energy they need to pursue a sustainable future.



Biofuels

Preem, Sweden's largest fuel company, chose Topsoe's HydroFlex technology to produce up to 1 million cubic meters of clean renewable diesel and jet fuel per year.

This corresponds to about 25% of Sweden's estimated consumption of renewable fuels in 2030.



Recycled carbon fuels

Phase 1: The planned facility will process up to 300 tons of shredded tires each day to produce low-carbon, low-sulfur drop-in fuels that can be blended into diesel and gasoline.

Phase 2: A second hydrotreatment unit will have the capacity to produce sustainable aviation fuel (SAF).



TIGAS™ | blue gasoline

Nacero Inc. plans to build a lower-carbon gasoline manufacturing facility at a site in Penwell, Texas.

Phase one will produce 70,000 barrels per day of gasoline component, ready for blending. Phase two will increase capacity to 100,000 barrels per day.

The gasoline produced at the facility will contain no sulfur and have half the lifecycle carbon footprint of traditional gasoline.



Blue hydrogen

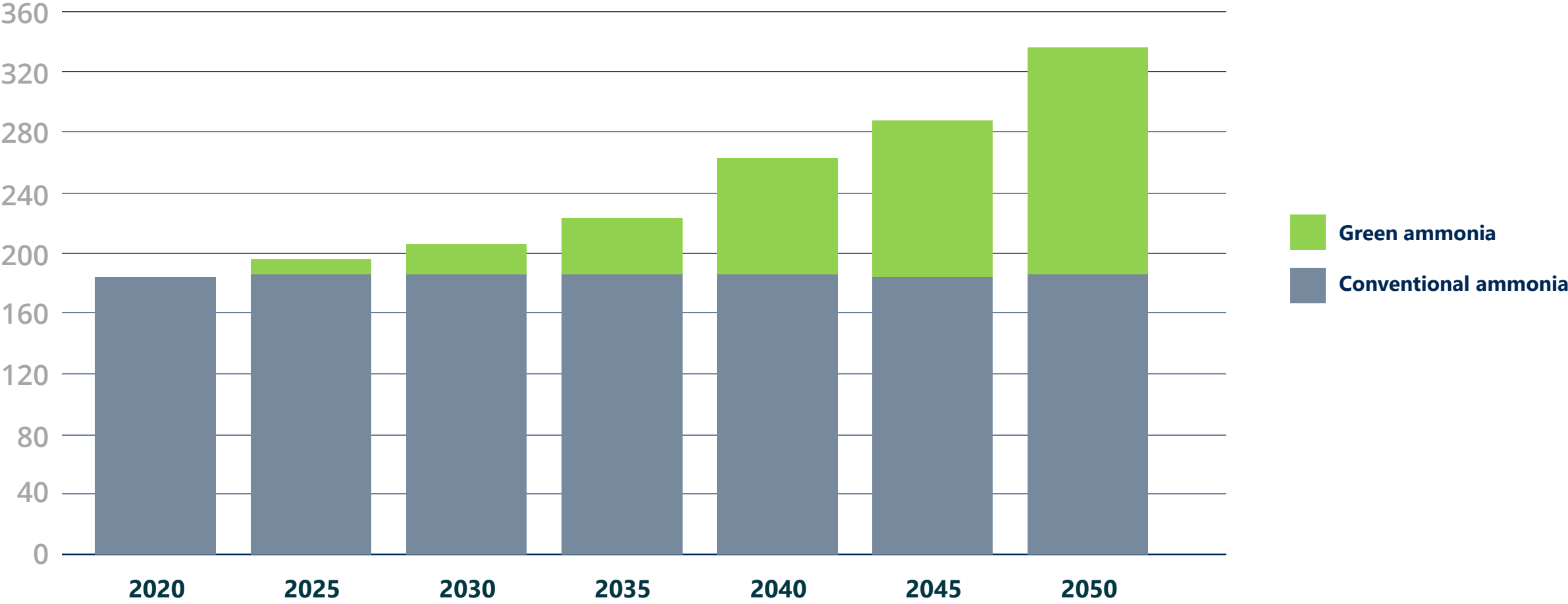
KNPC, the largest single-country hydrogen producer, chose Topsoe's SMR and HTER technologies to aid in producing 618,000 normal cubic meters of blue hydrogen per hour.

.... and many others

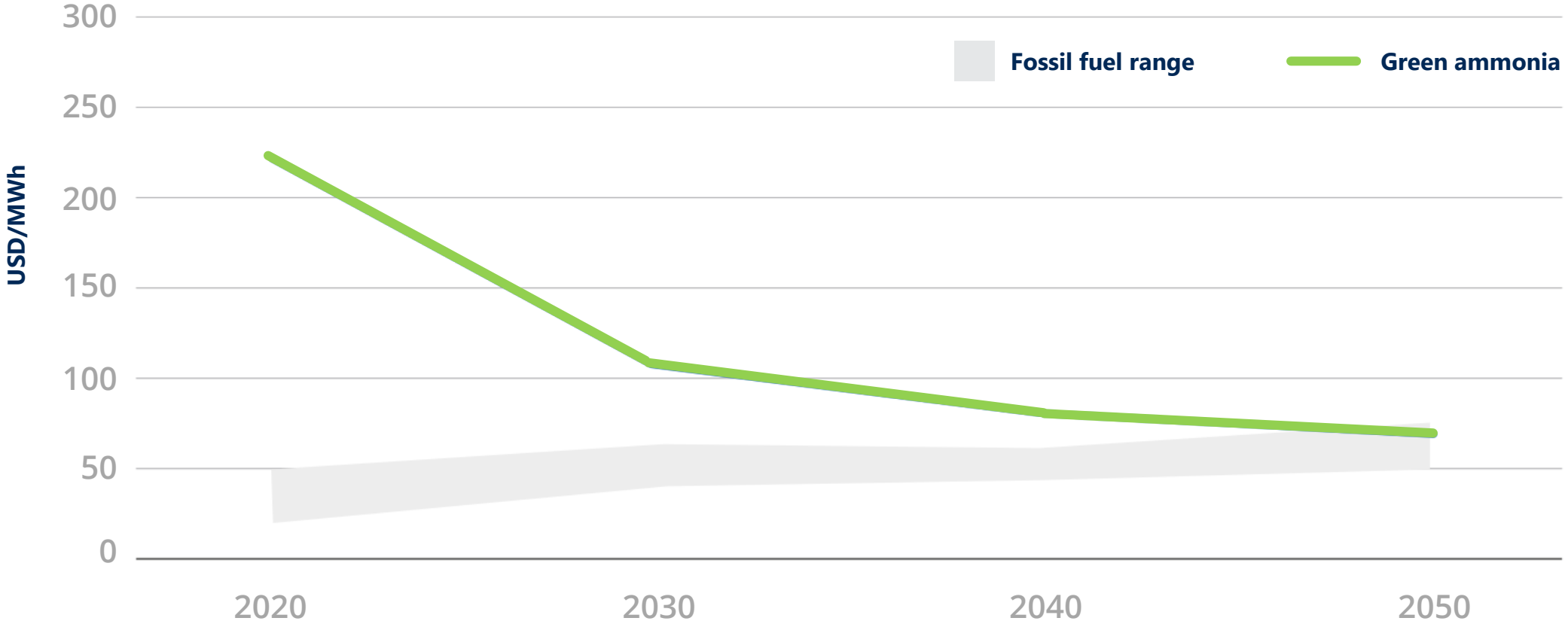
TOPSOE

Projected annual ammonia production (million tons)

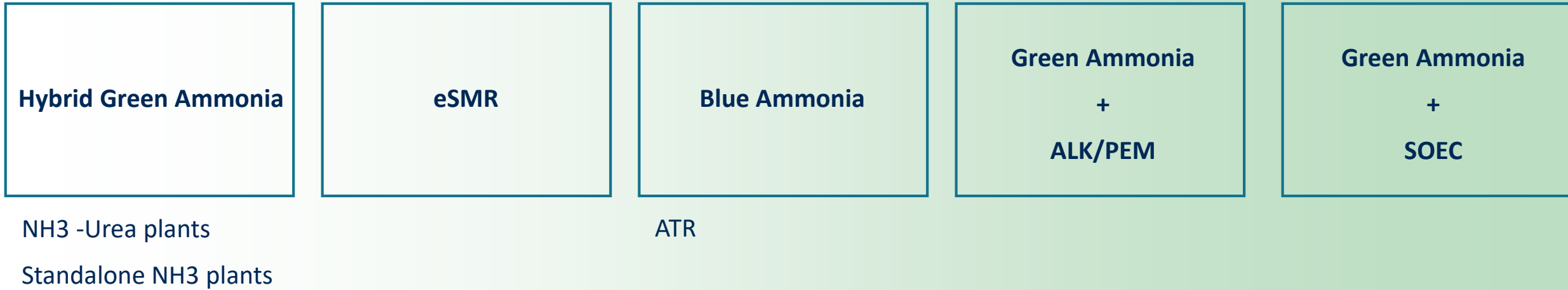
Conventional and green



Green ammonia product cost projections



Low-Carbon Ammonia Production → Spectrum of Process Technologies

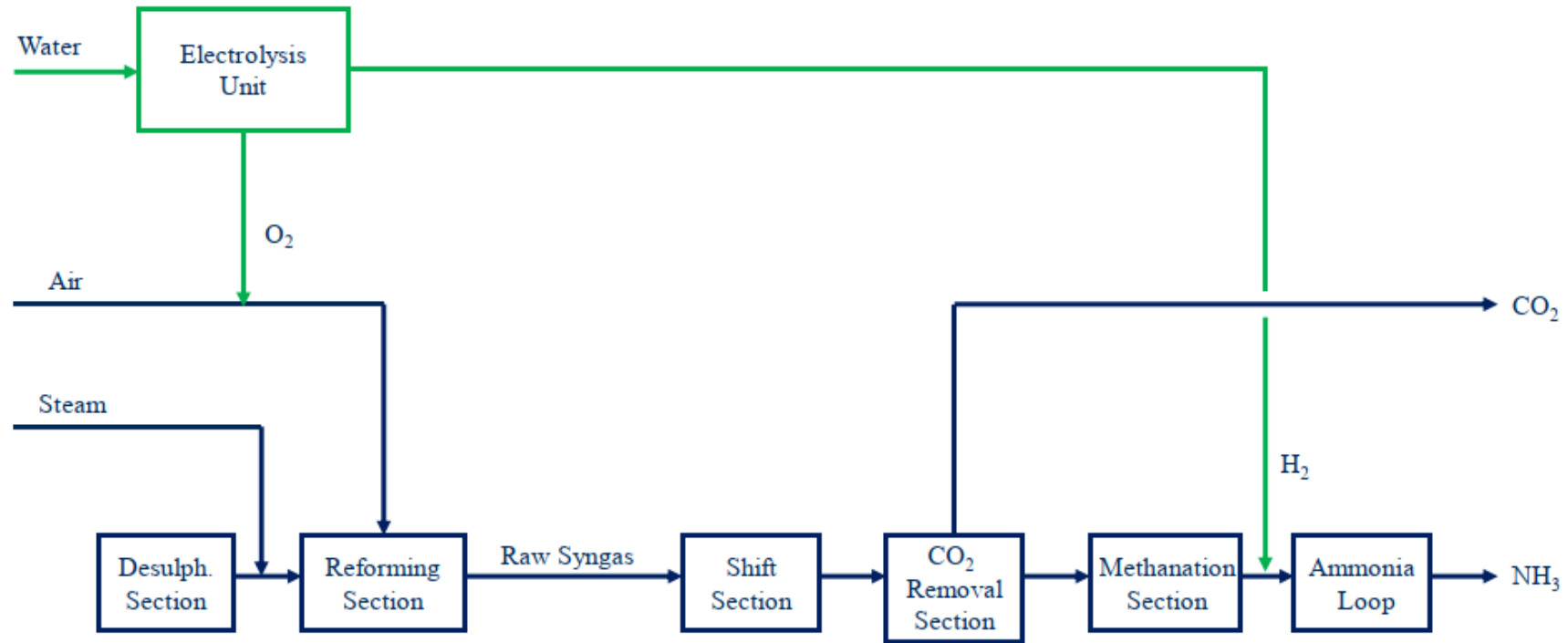


Hybrid Green Ammonia Solution

For Existing & New Ammonia Plants

Process Description

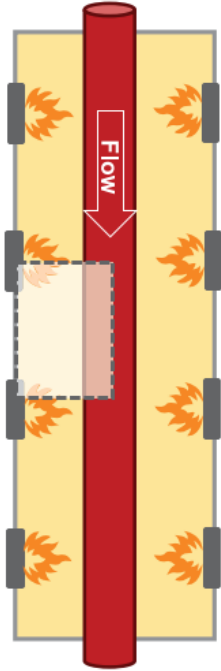
Main Process Train



**Potential for Low Cost Green/Low Carbon Ammonia Production from Existing Plants;
High RoCE**

Conventional SMR Has Scope For “Step Improvement” In Design

CONVENTIONAL SMR



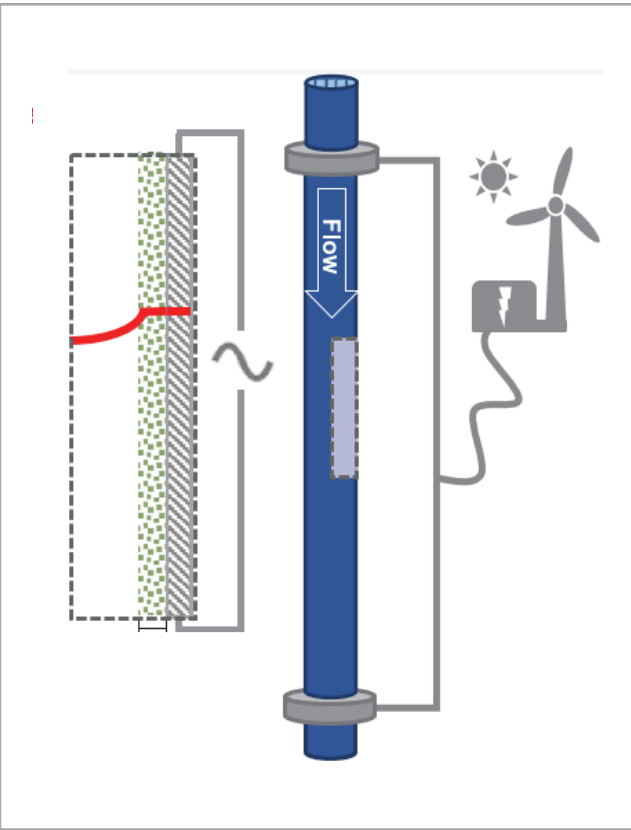
SCOPE FOR IMPROVEMENT

- 1 Oversized**
 - < 2% of furnace volume contains catalyst (productive volume where the reaction occurs)
 - > Fired Section adding to unnecessary volume and associated capex
- 2 Wasted Heat**
 - Flue Gases + Reactor Wall + Catalyst: Low thermal conductivity
 - Hence combustion must occur at higher temperature to generate necessary heat flux...thus increasing the opex
- 3 Partially Monitored**
 - Monitoring of reformer’s furnace side is done intermittently and is laden with errors. Resulting ambiguity often leads operators to run the reformer lower than design temperature (opex loss) or leading to tube ruptures (capex loss)
- 4 Inefficient / Unsafe**
 - Low Thermal Conductivity of Reactor Wall + Catalyst...combined with strongly endothermic reaction leads to
 - Temperature gradient across the catalyst → Insufficient catalyst utilization
 - Detrimental side reactions e.g. carbon formation
 - Thermal Stress: Tube creep & eventual bending or rupture
- 3 Long Startup Times**
 - Long start-up times needed to heat up the entire reactor

eSMR : Highly Efficient State-of-the-Art SMR Technology

e-SMR

(Direct Contact Ohmic Heating)



SOURCES OF VALUE

- 1 Furnace Section Eliminated**
 - Reactor Volume reduced substantially to a **minor fraction**
 - Fuel NG Eliminated
 - CO₂ Emissions reduced
- 2 Little/No Wasted Heat**
 - Intimate contact between electrical heat source and tube wall
 - No furnace section needed → Little/No wasted heat
- 3 Little/No Tube Wall Gradient**
 - No thermal stress in tube wall → Tubes last longer
- 4 Efficient Catalyst Performance**
 - Constant Heat Flux → Reaction kept close to equilibrium across catalyst volume
 - Much higher catalyst utilization/performance
 - Less detrimental side reactions e.g. carbon formation
- 5 Further Plant Efficiencies Possible**
 - Possible to improve plant efficiency further. Possibilities include:
 - Reduced S/C ratio
 - Increased Methane Conversion (typically limited by carbon deposition etc)
- 6 Fast PR startup**
 - PR start-up within minutes

Green Ammonia Plant

1

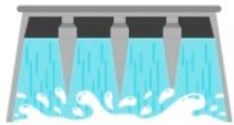
Renewable Energy



Wind Energy



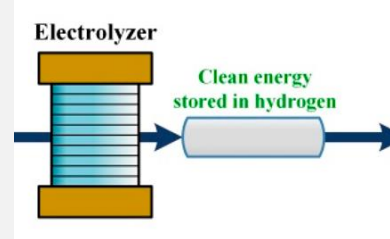
Solar Energy



Hydro Energy

2

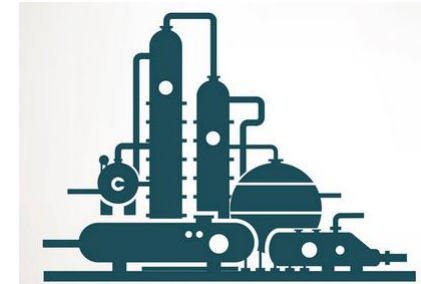
Green Hydrogen



- Hydrogen Storage
 - Salt, Rock, Tanks etc

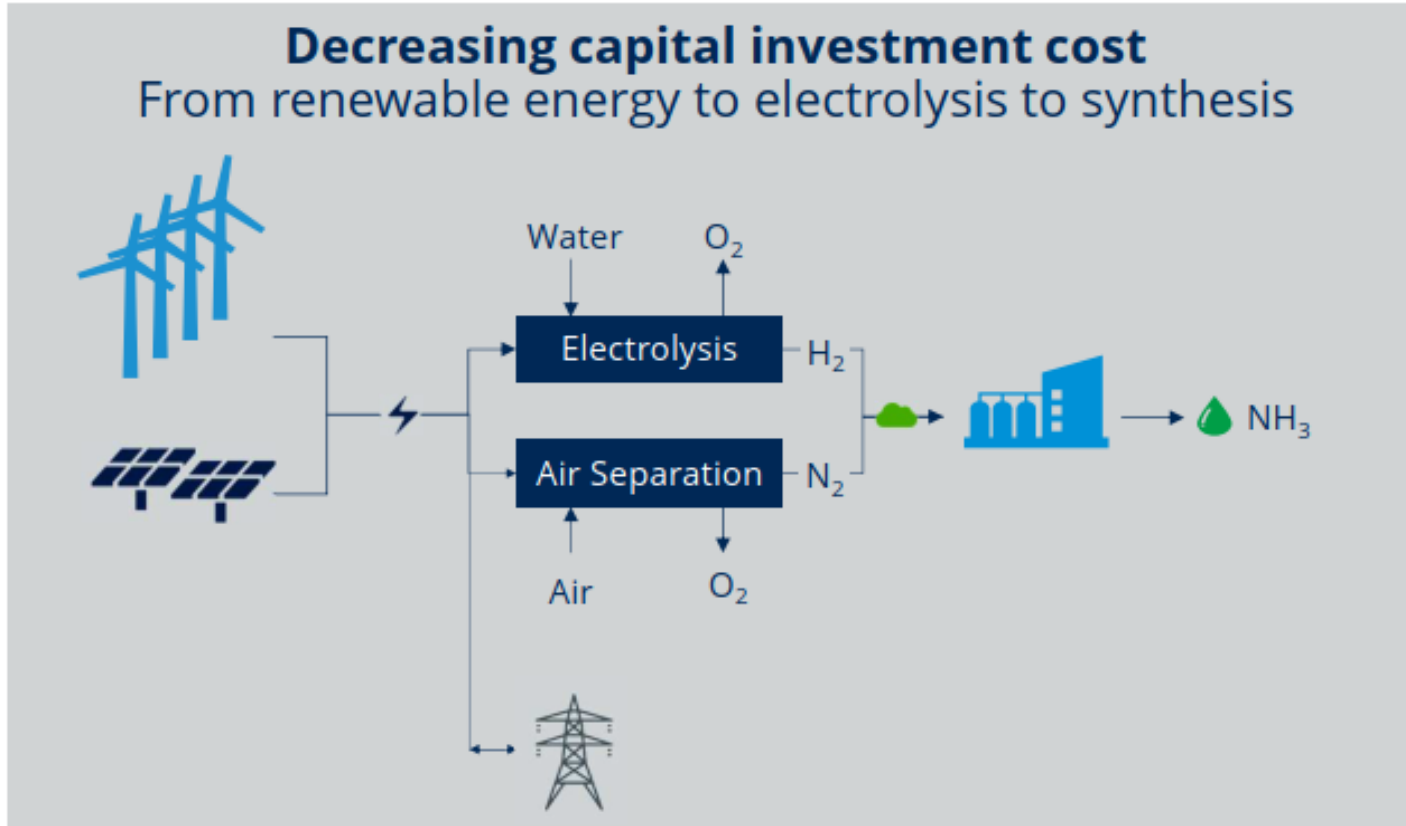
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Green Ammonia



- **Dynamic / Flexible Technology**

Green Ammonia Solution by Topsoe

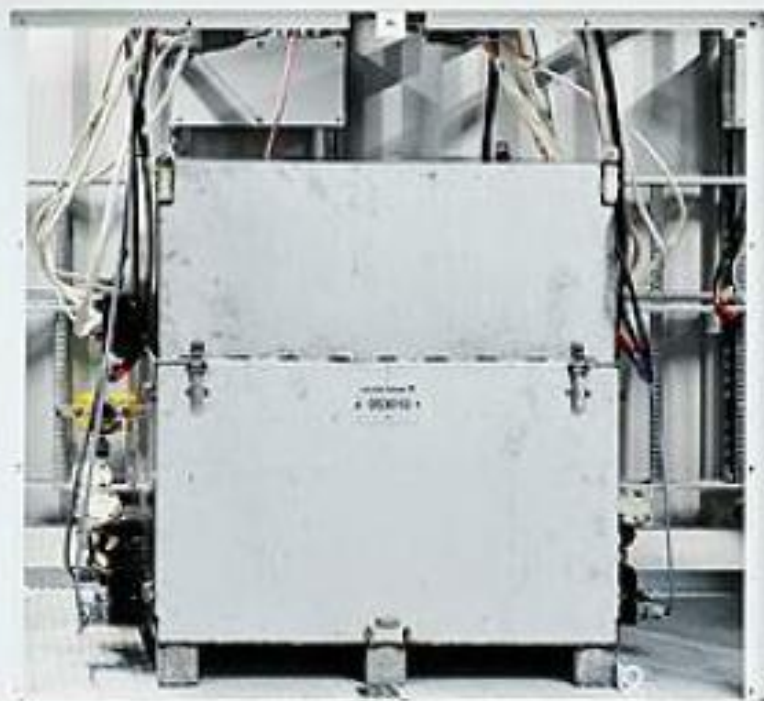
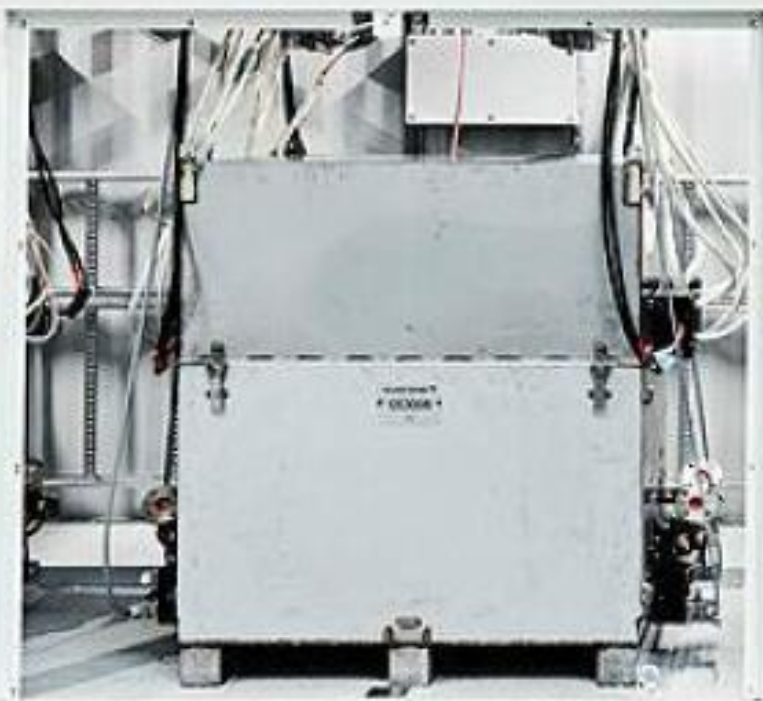


Advantages

- Fully flexible operation
- Reduced/No Hydrogen storage needed
- Store energy as NH₃
- Grid balancing

Process flexibility leads to lower cost of ammonia production

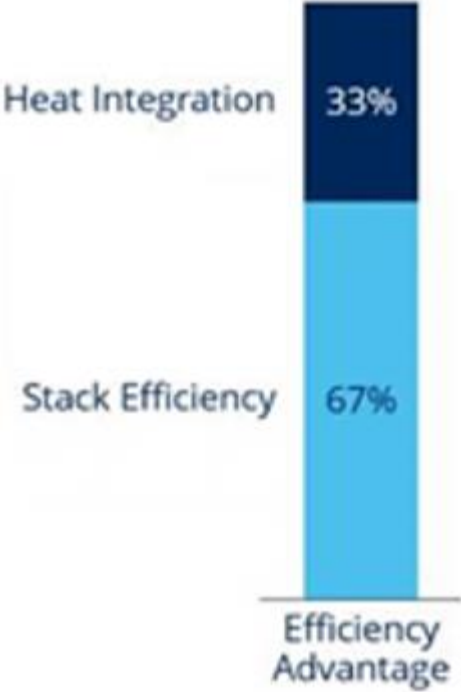
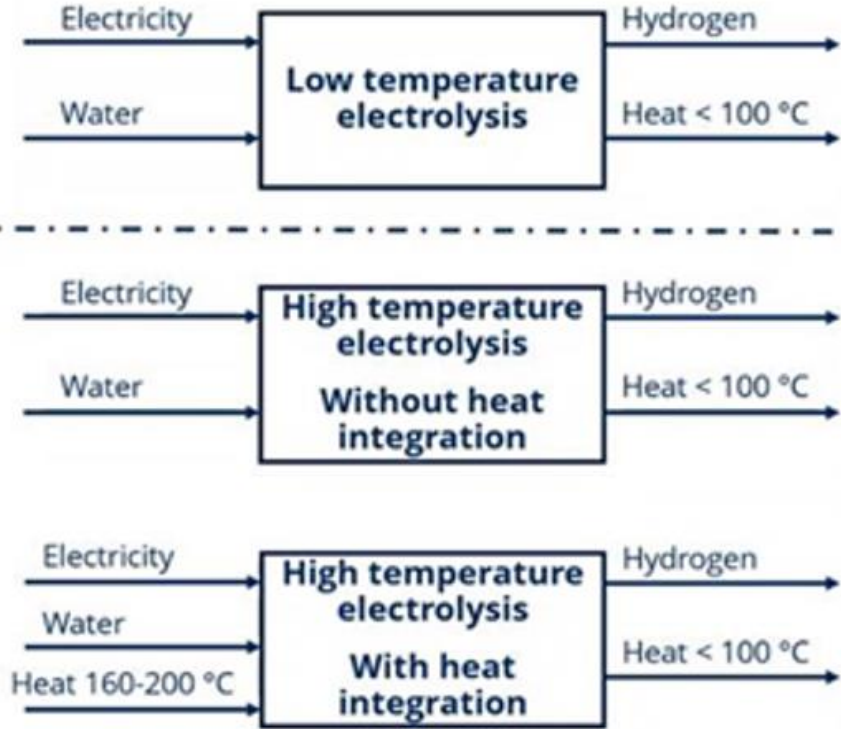
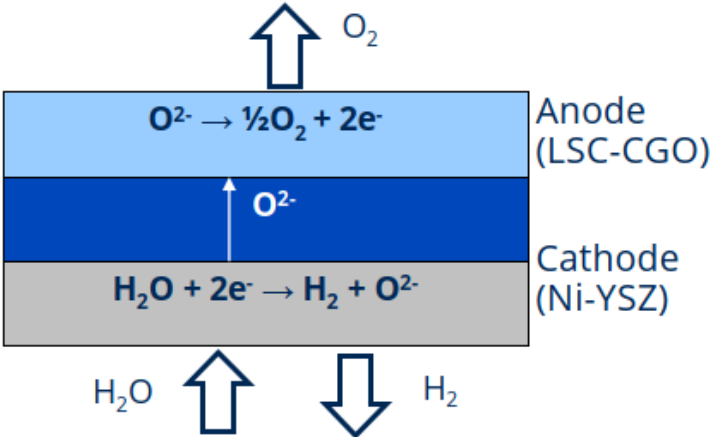
HALDOR TOPSØE 





SOEC Electrolysis

SOEC electrolysis



SOEC & Ammonia Synthesis

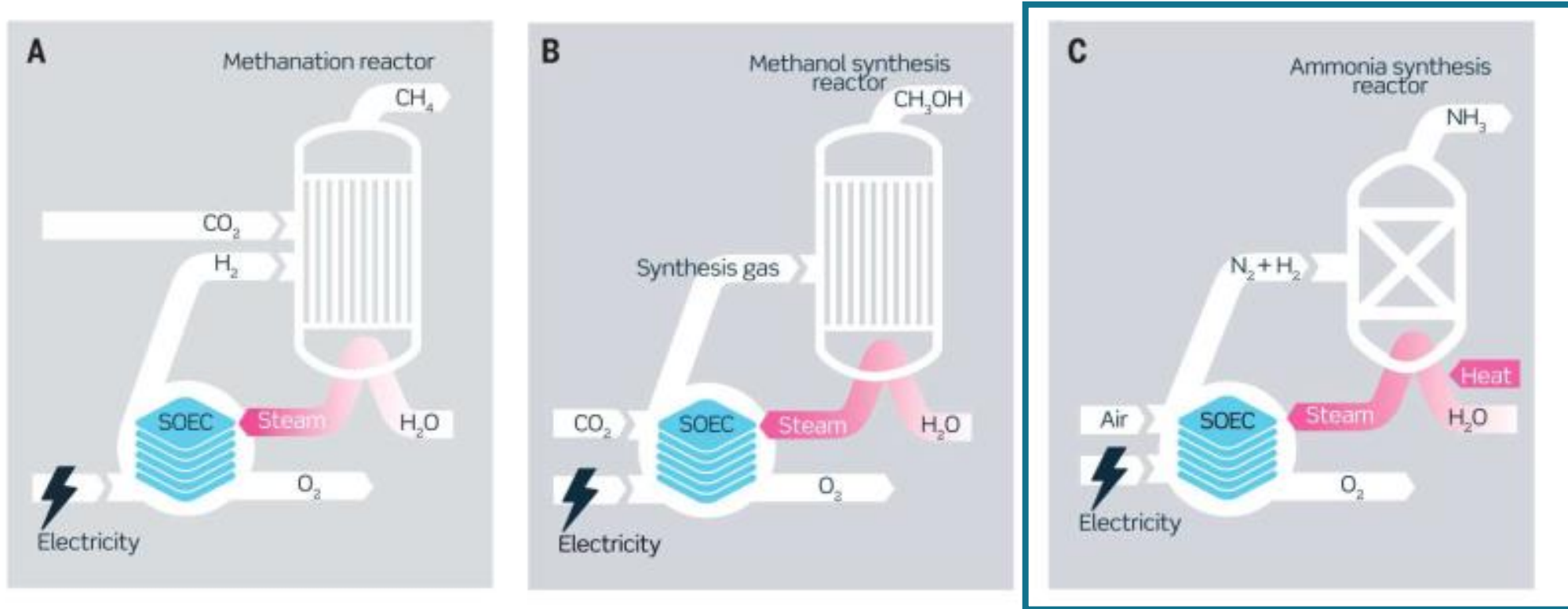
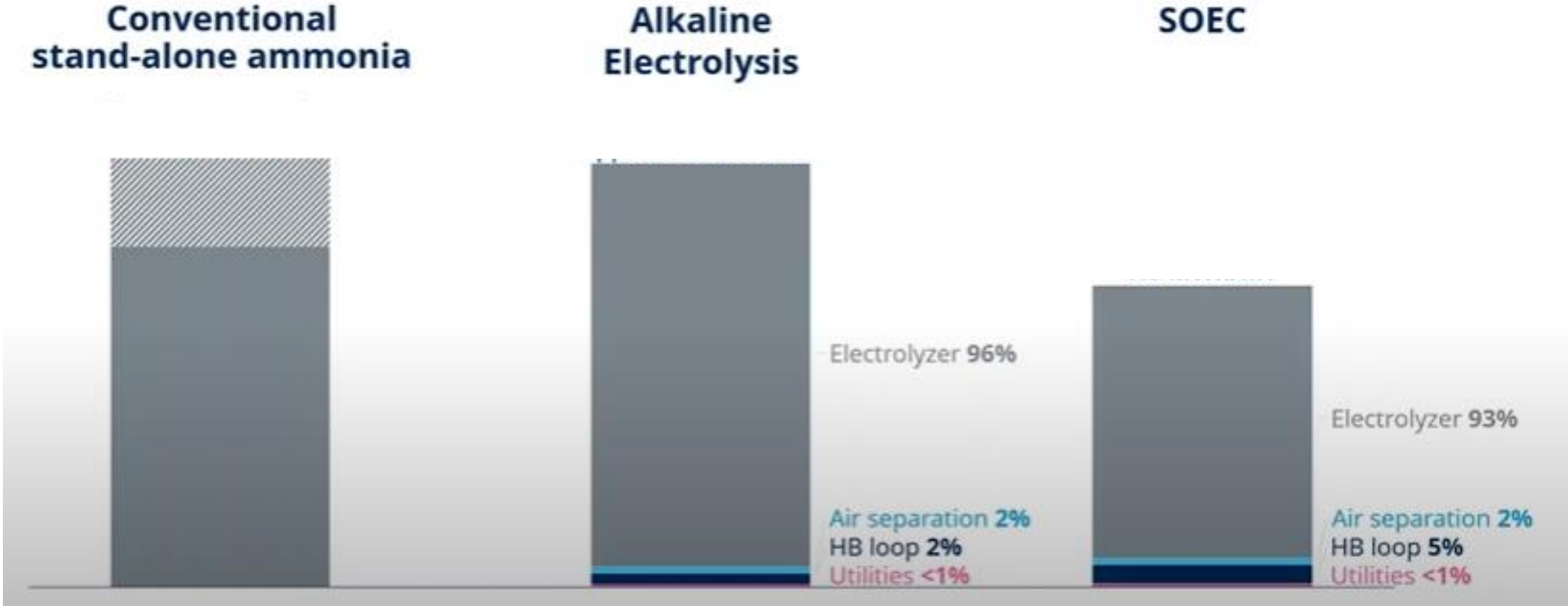


Fig. 5. Integration of solid oxide electrolysis systems with chemical syntheses. When SOECs are combined with a synthesis process, such as (A) methanation, (B) methanol synthesis, or (C) ammonia synthesis, reaction heat can be used to generate steam for SOECs. In (C), SOEC also functions as an oxygen-separation membrane, obviating the need for cryogenic air separation (67).

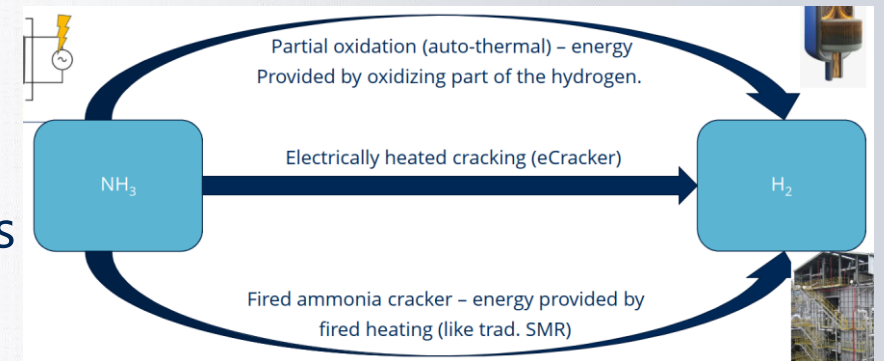
Green Ammonia Integration with Topsoe SOEC Electrolyzer

High Energy Efficiency



Ammonia Cracking

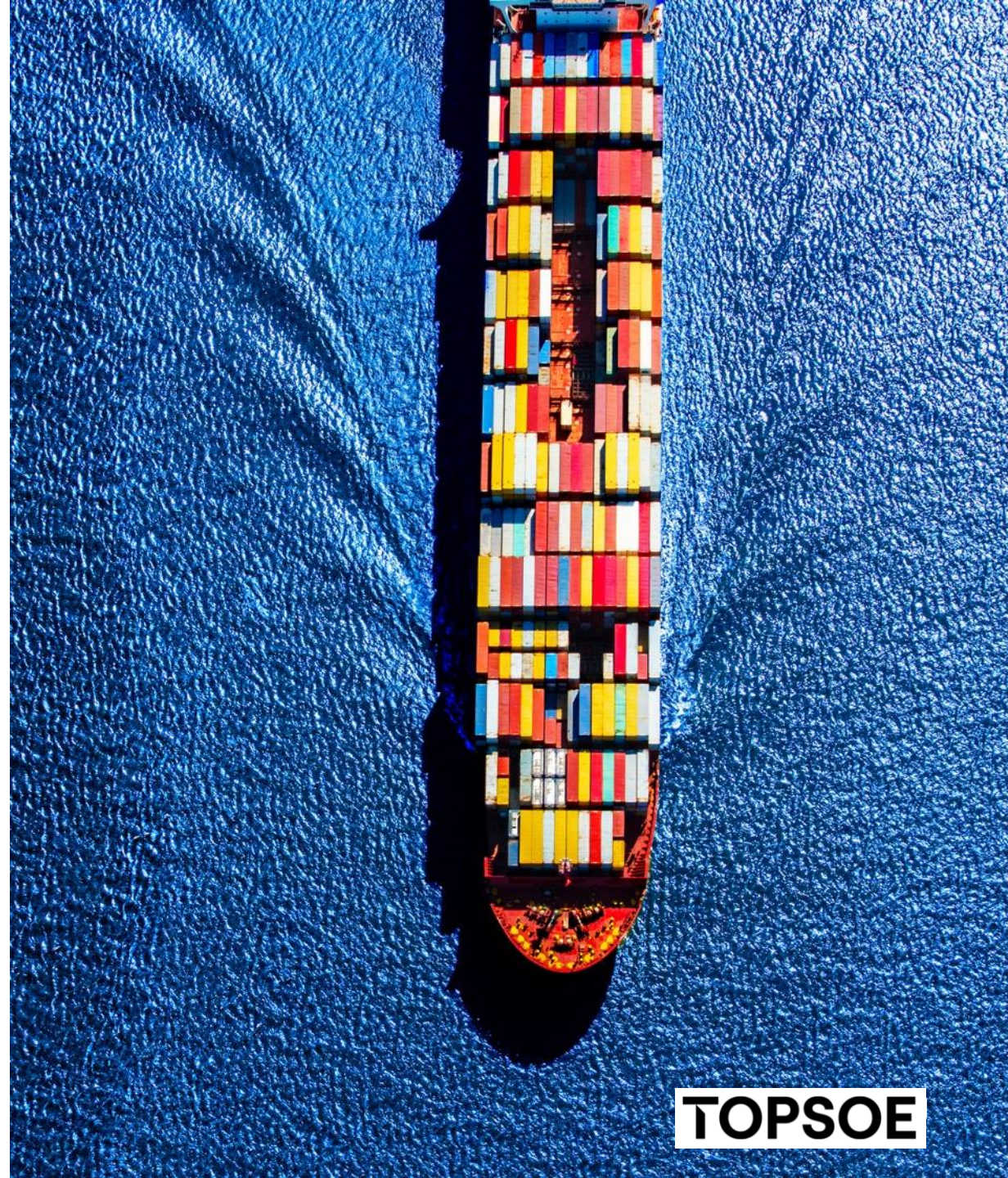
- Topsoe Ammonia Crackers in operation for 30+ years
- Existing design for 100-2400 MTPD ammonia feed
- Catalysts + Process Technology
- Catalysts (DNK series) in the same family as Ammonia Synthesis
- Fired cracker / eCracker etc



BRING ON THE POST-CARBON WORLD

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TOPSOE