Topsoes Ammonia cracking technology – Delivering green Hydrogen

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HALDOR TOPSOE

Fully dynamic green ammonia plant initiated and in operation Q2 2023

24MTPD green ammonia directly coupled to wind and solar power

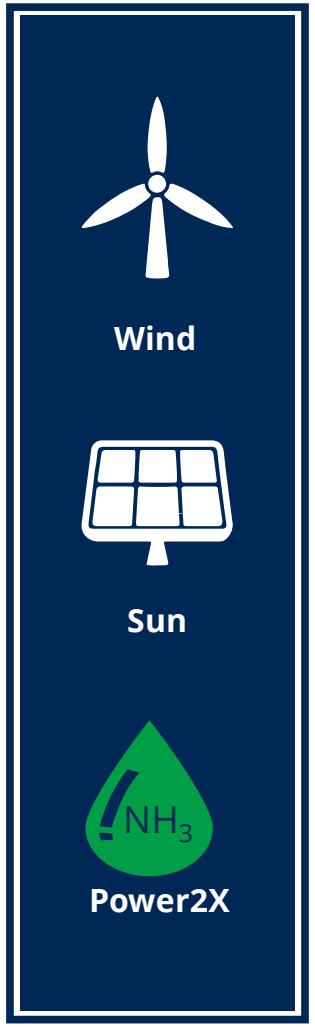
Skovgaard Invest aps

HALDOR TOPSØE

Vestas

EUDP

The Energy Technology Development and Demonstration Programme



12 MW

Wind turbines
6 x 2 MW Vestas V90

50 MW

PV power
91 hectar with bi-facial tracker PV panels

10 MW

Power-to-Ammonia
Worlds first green ammonia plant in dynamic mode

Topsoe

Power-to-Ammonia

- Fully flexible operation 10-100% plant load
- No hydrogen storage
- Store energy as NH_3
- Grid balancing
- Available for AE/PEM/SOEC electrolyzer technology

Topsoe Ammonia Catalysts

Knowledge platform for cracking catalysts

- Leading ammonia synthesis catalysts supplier
  - Strong knowledge base within field
  - Topsøe key competence
- Catalyst for ammonia cracking in same family
  - Necessary to understand differences
  - We co-develop catalyst and technology
- Topsøe ammonia cracking catalyst
  - A range of commercial available catalysts
  - Fine tuned for Topsøe technologies

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Why the optimal ammonia synthesis catalyst is not the optimal ammonia decomposition catalyst

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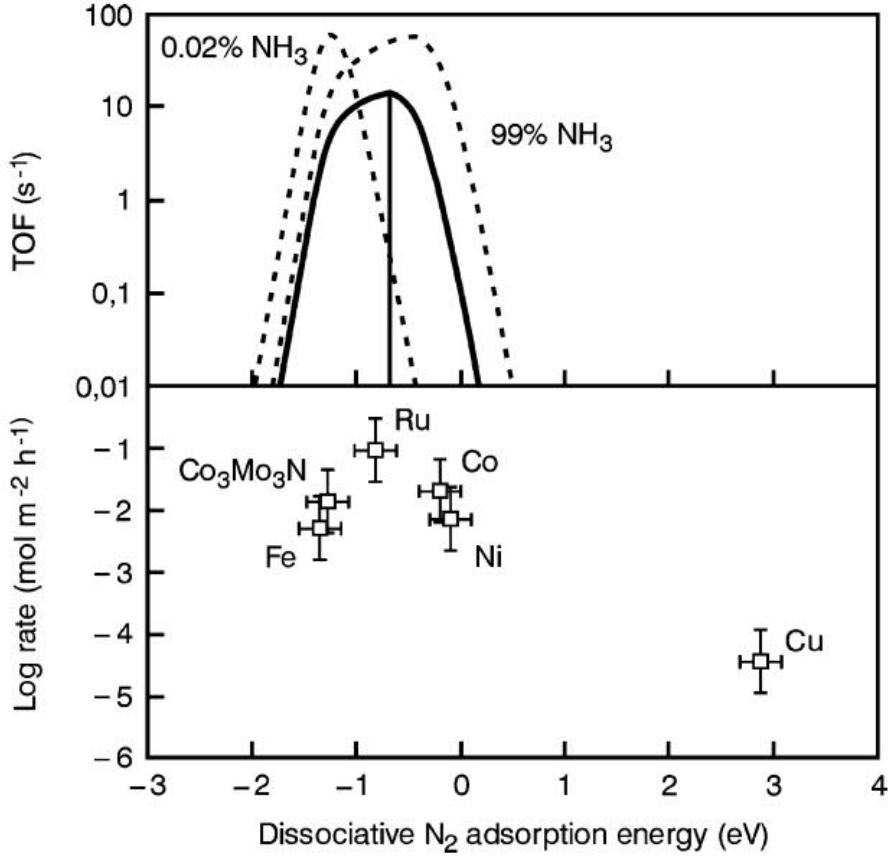


The Topsøe Ammonia Cracking Catalysts
DNK series

- DNK-2R – Medium Temp
  - Co-Fe based
  - A workhorse in existing plants
  - High durability
- DNK-5R – Medium Temp
  - Fe based
  - Proven performance at lowe
- DNK-10 Low Temp
  - Ru based
  - Very high activity catalyst
- DNK-X High temp
  - Ni based catalyst
  - Strong Topsøe experience – need to fit process development

How do we choose the right catalyst?

Combining catalyst and process technology understanding enable a very strong overall solution

Topsoe ammonia cracking technology

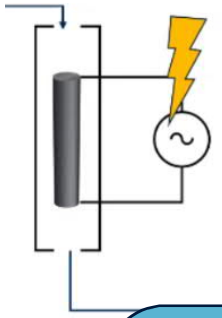
Building upon a strong technology core

- Topsoe Ammonia Crackers in operation for + 30 years
- Existing design for 100-2400 MTPD ammonia feed
- New and optimized design

- Scope of supply:
  - License
  - Basic Engineering Design Package
  - Proprietary Hardware
  - Catalysts
  - Training & Technical Services

Catalytic decomposition of ammonia

Endothermic – need energy to run



Partial oxidation (auto-thermal) – energy Provided by oxidizing part of the hydrogen.

NH_3

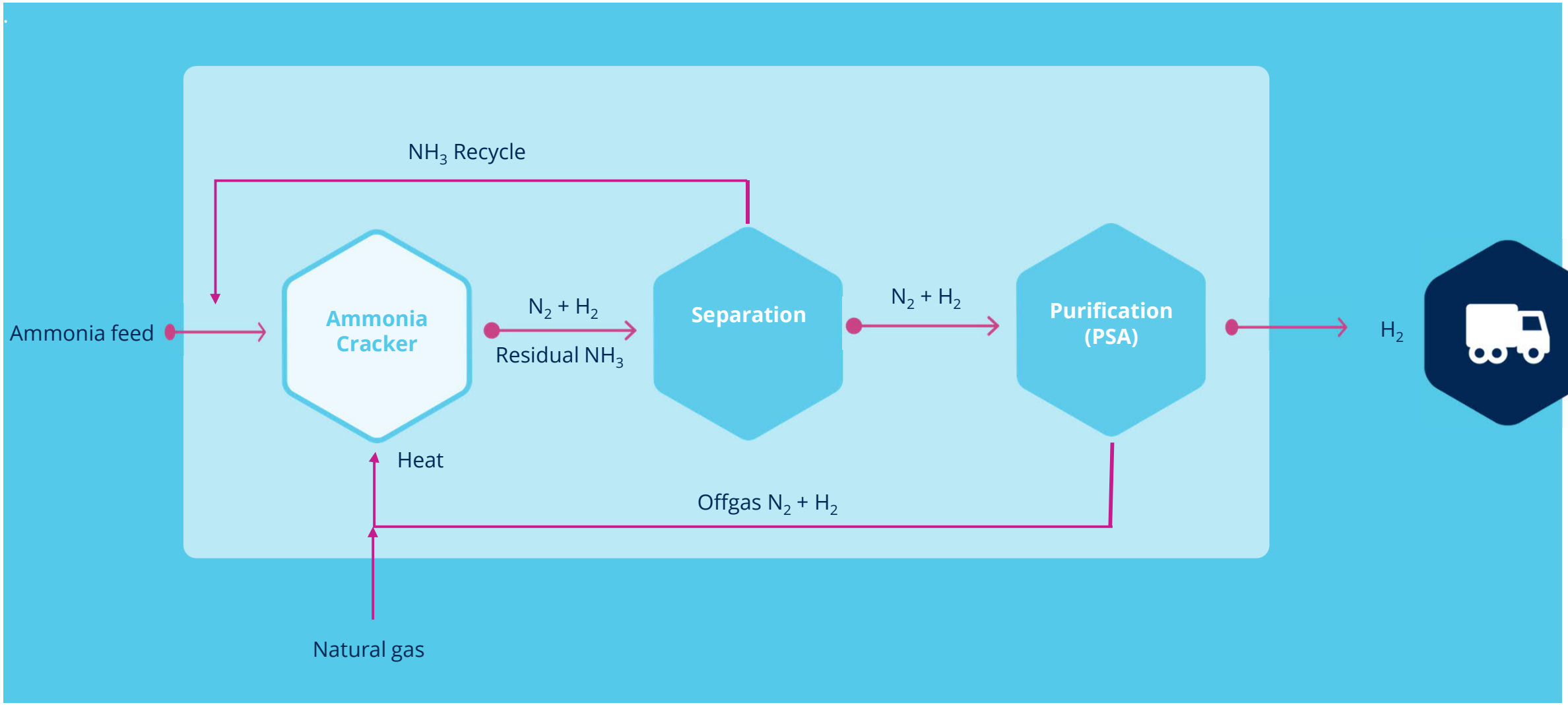
Electrically heated cracking (eCracker)

H_2

Fired ammonia cracker – energy provided by fired heating (like trad. SMR)

How it works

Topsoe high efficiency ammonia cracker ensures near to full conversion of the ammonia feed to high purity hydrogen

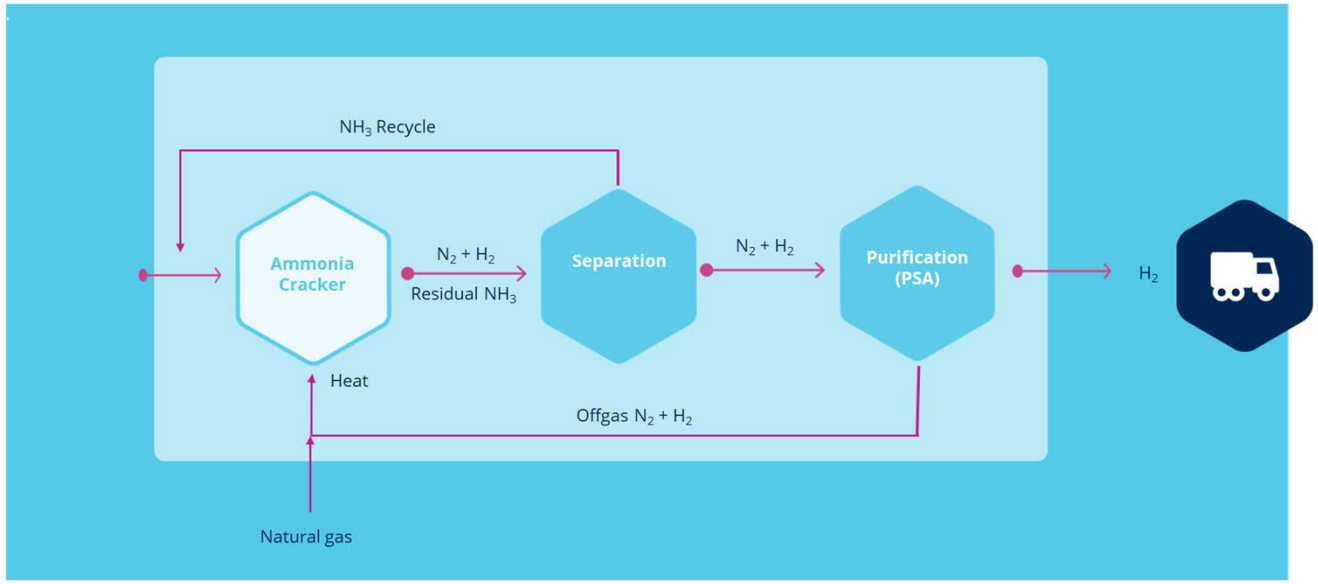


The Topsøe Ammonia Cracking Technology

Optimise for local optimum

- Large scale plants
  - 5-500 MTPD H_2
  - Highly energy efficient process
  - ~97% NH_3 to H_2
  - Process optimisation built on top of current references
  - May be tailored to the individual demands

- Example: (30 MTPD H_2):
  - Energy input - Natural gas: 740 Nm^3/t_{H_2}
  - Operation pressure 30-50 barg
  - Carbon footprint 15 H_2/CO_2
  - PSAs for H_2 separation – 99.9% purity
  - <1 ppm NH_3 in H_2
  - Ideal for FCEV - hydrogen fuel



The Topsøe Solutions

- Strong experience from existing plants
  - Both on catalyst and technology
  - Knowledge on all the small details
  - Our expertise area is design of large scale plants
    - >5 MTPD Hydrogen

- We combine knowledge from catalyst and process
  - We can optimise for local infrastructure
  - Adjust for local legislation
  - Available energy source dictates ideal process solution

- SOFC may be a future alternative
  - Generate H_2 + Power
  - Flexible operation

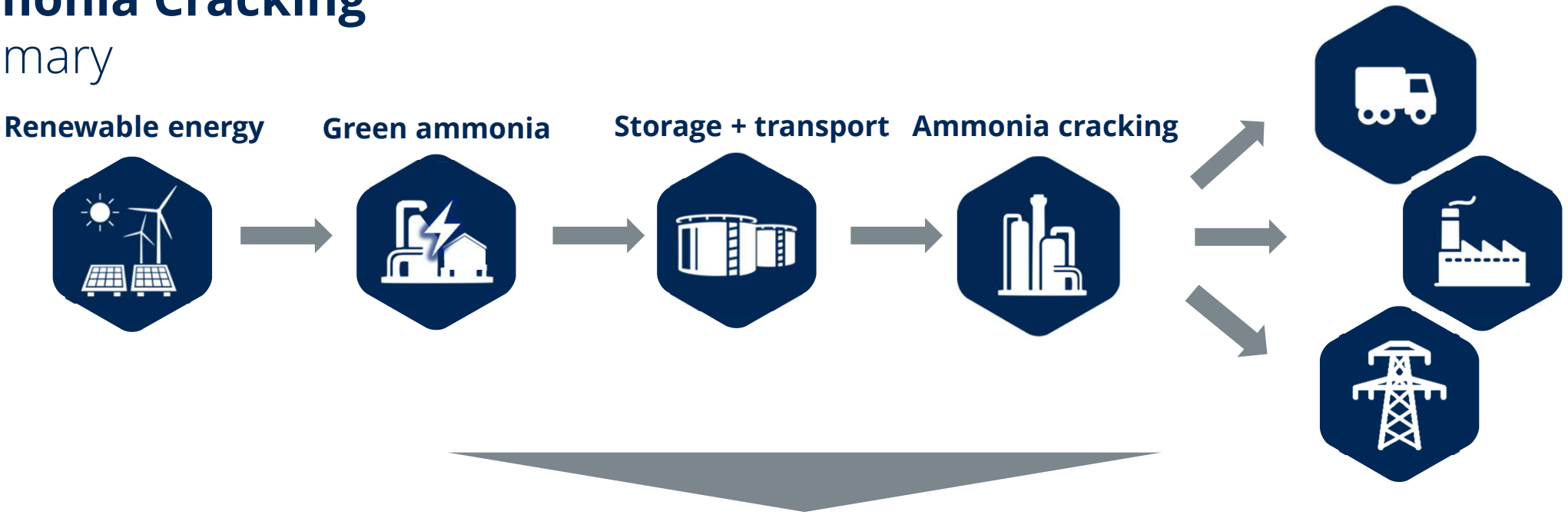
Energy is key		
Heat source	**External input**	**NH_3 efficiency**
Natural gas	~740 Nm^3/t_{H_2}	>97%
NH_3 (H_2)	0	~75%
Electricity	6-8 MWh/t_{H_2}	>95%
HP Steam	6-10 MWh/t_{H_2}	>95%

Ammonia cracking potential

- Ammonia cracking still market in early phase
  - Where will the market be strongest?

- Hydrogen for transport
  - FCEVs
- Power generation
  - Eg. in combination with gas turbines etc
- Greener refineries
- Replacement of fossil heat sources
  - Steel industry etc.
- Hydrogen as pilot fuel for engines
  - Ships/power etc

Ammonia Cracking
Summary



- Ammonia is an excellent energy vector: fuel and energy storage
- Ammonia cracking – many potential opportunities
- Topsoe have long experience in ammonia cracking
- High TRL level on catalyst + technology
- We can tailor the process to each individual market

Thank you!

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