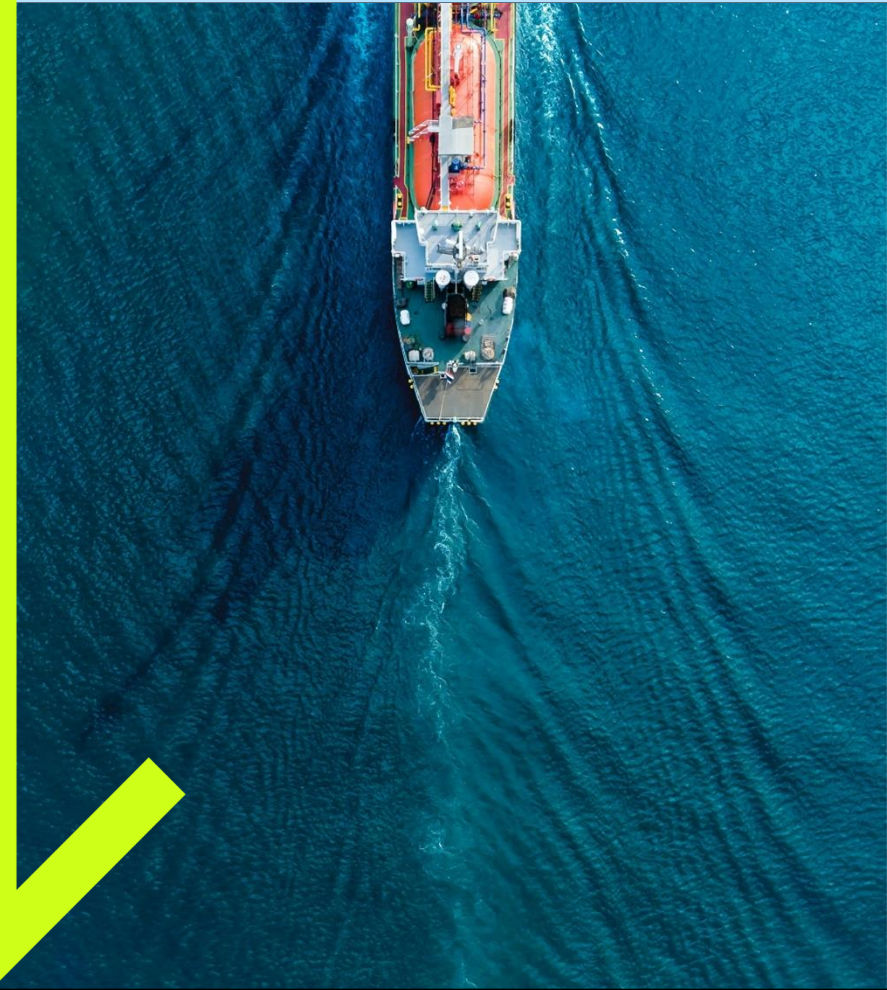


H2Retake™

**Ammonia Cracking -
TOPSOE's innovative
technology**

**Building on industrial
experience**

TOPSOE



Paulo Brito

AEA Conference - Ammonia Cracking Session
November 2024

#1

In ammonia

#1

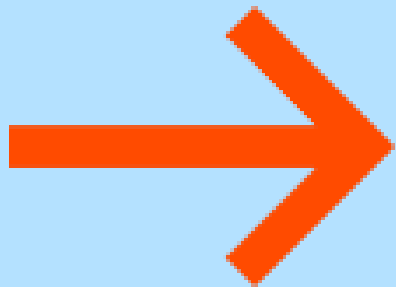
Sustainable Aviation Fuel

#1

In hydrogen

Top 3

In methanol



9%

Of revenue invested in R&D

+500

Patent families

918

In revenue (EUR million)

2,800

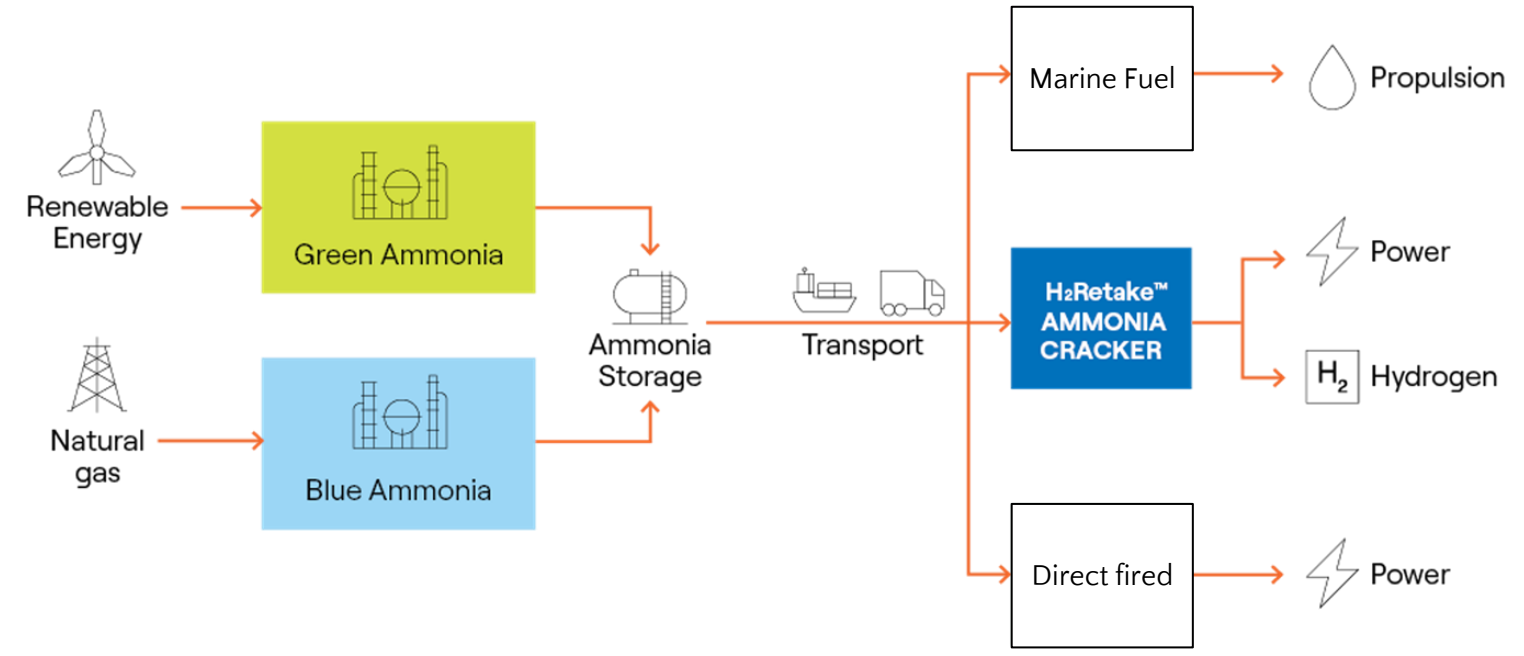
employees

AMMONIA: NON CARBON BASED COMMERCIALLY AVAILABLE ENERGY CARRIER

H2Retake™

Ammonia Cracking Technology

Building on industrial experience



AMMONIA CRACKING AT TOPSOE

SOME MILESTONES

1993

- Largest ammonia crackers installed in PIAP, Argentina
- 2 x 2400 MTPD NH₃



2023

- Launching of H2Retake™ process
 - **Market leading** H₂ and energy efficiencies
 - Improving the fully referenced process scheme
 - High performance ammonia cracking catalysts

1978

- First grassroot ammonia cracker in the world
- Part of the heavy water production

2022

- NH₃ cracking process for H₂ production
- Relied on the process referenced in heavy water plants
 - ✓ Fully referenced process at industrial scale
 - ✓ Fully referenced catalyst and catalyst manufacturing

KEY LEARNINGS AND PROVEN RESULTS FROM INDUSTRIAL AMMONIA CRACKERS



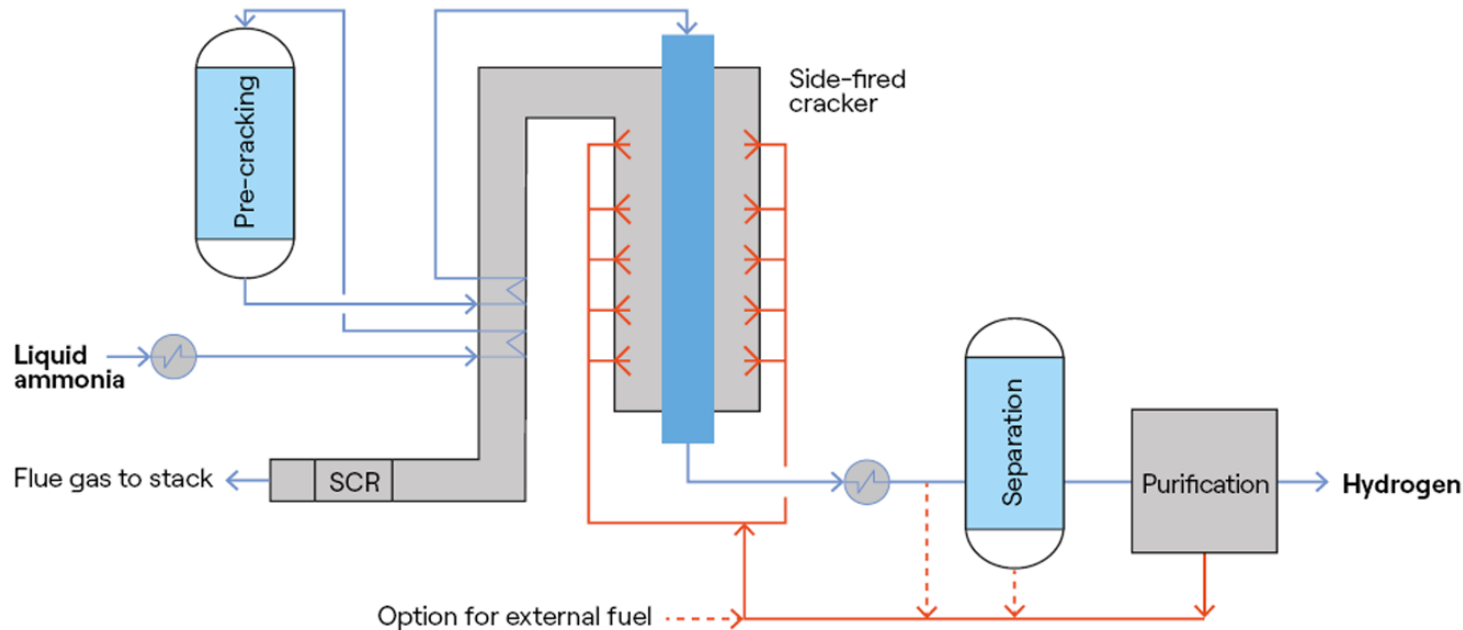
Key learnings and proven results

- Proven design for high temperature, high pressure, 100% ammonia process streams
- Proven materials to tolerate harsh nitridation conditions
- Catalyst optimization and proven manufacturing route
- Decades of operation and technical service experience
- Catalyst and tube life ≥ 100.000 hours proven

TOPSOE AMMONIA CRACKING TECHNOLOGY

BUILDING ON EXISTING KNOW-HOW AND IMPROVED FOR HIGHER EFFICIENCY

H2Retake™



Market leading hydrogen and energy efficiency

95% Energy efficiency based on actual state HHV

78 - 96% Hydrogen efficiency depending on fuel choice

Available for 100 - 3400 MTPD ammonia feed capacity range

Catering for various applications with hydrogen purity of up to +99.999%.

Default fuel option with zero CO₂ emission. External fuel such as NG optional.

H2Retake™



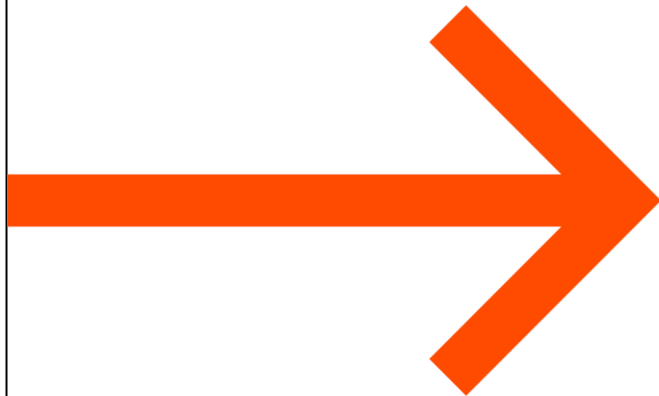
TOPSOE AMMONIA CRACKING

| Option | | 1 | 2 |
|---------------------------|--|------------------------------|----------------------------|
| Fuel | | NH3 (Cracked) + PSA tail gas | Natural gas + PSA tail gas |
| H2 purification unit | | Single-stage PSA | Double-stage PSA |
| Ammonia feed | MTPD | 3400 | 3400 |
| Hydrogen product | MTPD | 470 | 575 |
| Energy efficiency* | % | 95% | 95% |
| Hydrogen efficiency | % | 78% | 96% |
| Natural gas consumption | Nm ³ NG / Kg H ₂ | 0 | 0.6 |
| CO ₂ footprint | kg CO ₂ /kg H ₂ | 0 | 1.2 |

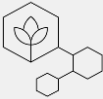





AMMONIA CRACKING - CATALYSTS

DNK SERIES

| DNK-2R (LOW-HIGH TEMPERATURE) | DNK-20 (LOW - MED TEMPERATURE) | DNK-30 (MED - HIGH TEMPERATURE) | DNK-40 (HIGH TEMPERATURE) |
|---|---|---|---|
| <ul style="list-style-type: none">▪ Fe-Co based▪ Industrially Proven▪ Highest activity among base-metal catalysts▪ Demonstrated durability | <ul style="list-style-type: none">▪ Ni based catalyst▪ High performance▪ Techno-economical optimization options | <ul style="list-style-type: none">▪ Ni based catalyst▪ High performance▪ Low pressure drop▪ Techno-economical optimization options | <ul style="list-style-type: none">▪ Ni based catalyst▪ High performance▪ High strength▪ Low pressure drop▪ Techno-economical optimization options |



H2RETAKE FEATURES AND BENEFITS

| | | Impact | Results |
|--|--|--|--|
| Industrial references with proven Technology |  Catalyst | <ul style="list-style-type: none"> Catalyst guarantees available Catalyst manufacturing route in place | <ul style="list-style-type: none"> Reduced technical, financial and project risk Prolonged tube and catalyst lifetime Plant load flexible and adjust on end-product consumption |
| |  Side fired cracker | <ul style="list-style-type: none"> Mature and proven design Best available temperature control Automated load following operation | |
| Process optimized |  Energy | <ul style="list-style-type: none"> No need for active cooling No steam production | <ul style="list-style-type: none"> Every 1% Ammonia feed savings is -0.9% lower hydrogen cost 10% lower investment at fixed capacity is -1% lower hydrogen cost. |
| |  Cost | <ul style="list-style-type: none"> Reduced investment per installed capacity Increased max capacity to 3400MTPD | |
| Clean and sustainable operations |  Effluents | <ul style="list-style-type: none"> Internal waste handling, no other effluents generated | <ul style="list-style-type: none"> Environmentally clean Meeting regulatory requirements |
| |  Emissions | <ul style="list-style-type: none"> Flue gas NOx emissions meeting strictest project requirements | |

H2RETAKE™ – BUILDING ON INDUSTRIAL EXPERIENCE

February 19, 2024

TOPSOE AMMONIA TECHNOLOGY TO BOOST APPROTIIUM'S HYDROGEN PRODUCTION IN SOUTH KOREA



- Approtium plans to build an ammonia cracking plant to produce 75,000 metric tons of low-carbon hydrogen annually using Topsoe H2RETAKE™ technology.
- Topsoe has completed process design package
- The plant will be built in Ulsan, South Korea, and production is expected to start in 2027.



H2RETAKE™ – BUILDING ON INDUSTRIAL EXPERIENCE

- ✓ Proven technology ✓ Catalysts ✓ Energy efficiency
- *2400 MTPD ammonia crackers*
 - *Decades of operation*
- *Proven, high performance catalyst available*
- *Technology risks fully mitigated.*
- All components referenced, tested and verified
- *Technology updated to meet market demand*
 - *95% energy efficiency*
 - *78% to 96% hydrogen efficiency*
- *ATC cracker and eCracker development*





Thank you!

Topsoe A/S

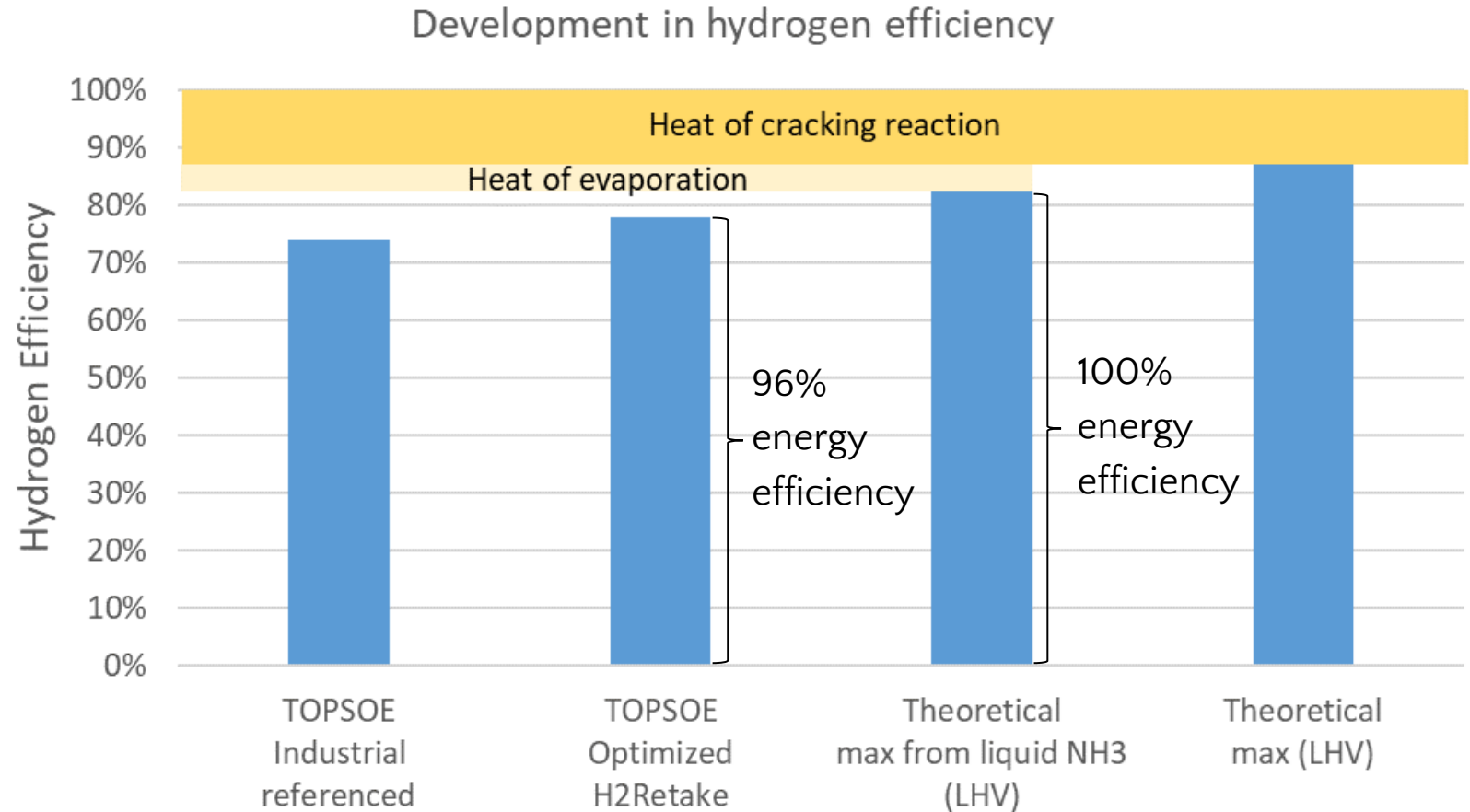
TOPSOE

BACKUP

HYDROGEN EFFICIENCY

THEORETICAL LIMIT

AMMONIA / CRACKED GAS FUEL CASE



TOPSOE AMMONIA CRACKING DEVELOPMENT CAPABILITIES

BASED ON EXTENSIVE CATALYST AND TECHNOLOGY CATALOGUE

H2Retake™

- Building on proven fired cracker technology and catalysts
- Optimized for high H₂ efficiency
- Commercially available now



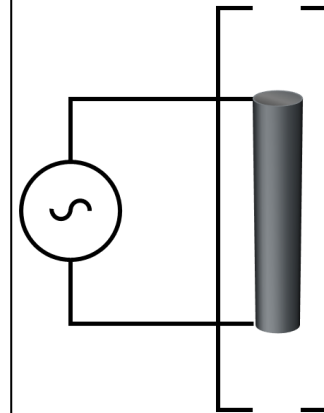
ATC cracker

- Heat by in-process combustion of NH₃ / H₂ mixture
- Economy of scale in limited space
- Proven for ammonia production

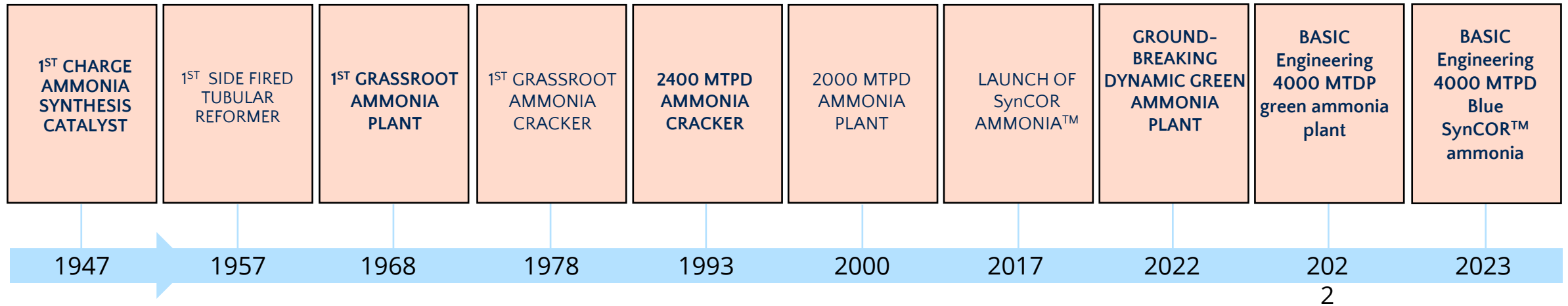


eCracker

- Process energy from electrically heated catalysed hardware
- Maximizes the hydrogen output
- Topsoe eReact™ is proven in pilot scale for SMR and RWGS

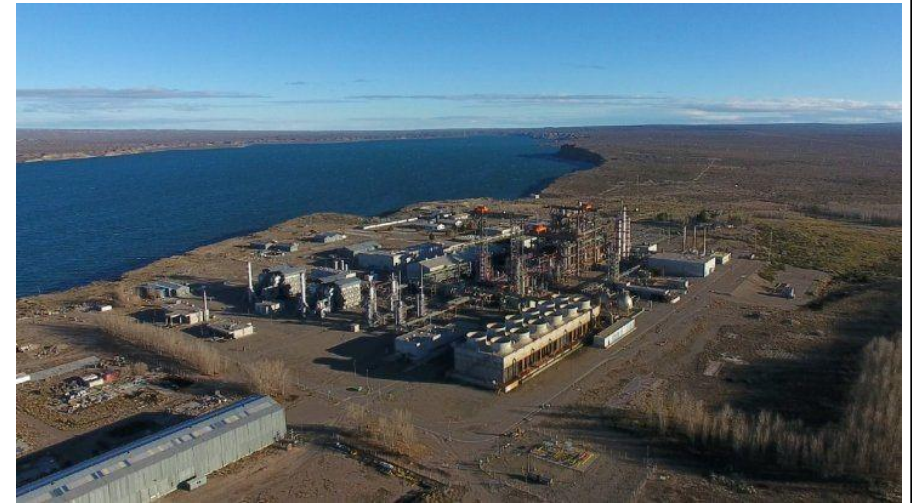


TOPSOE AMMONIA MILESTONES



TOPSOE AMMONIA CRACKING REFERENCES

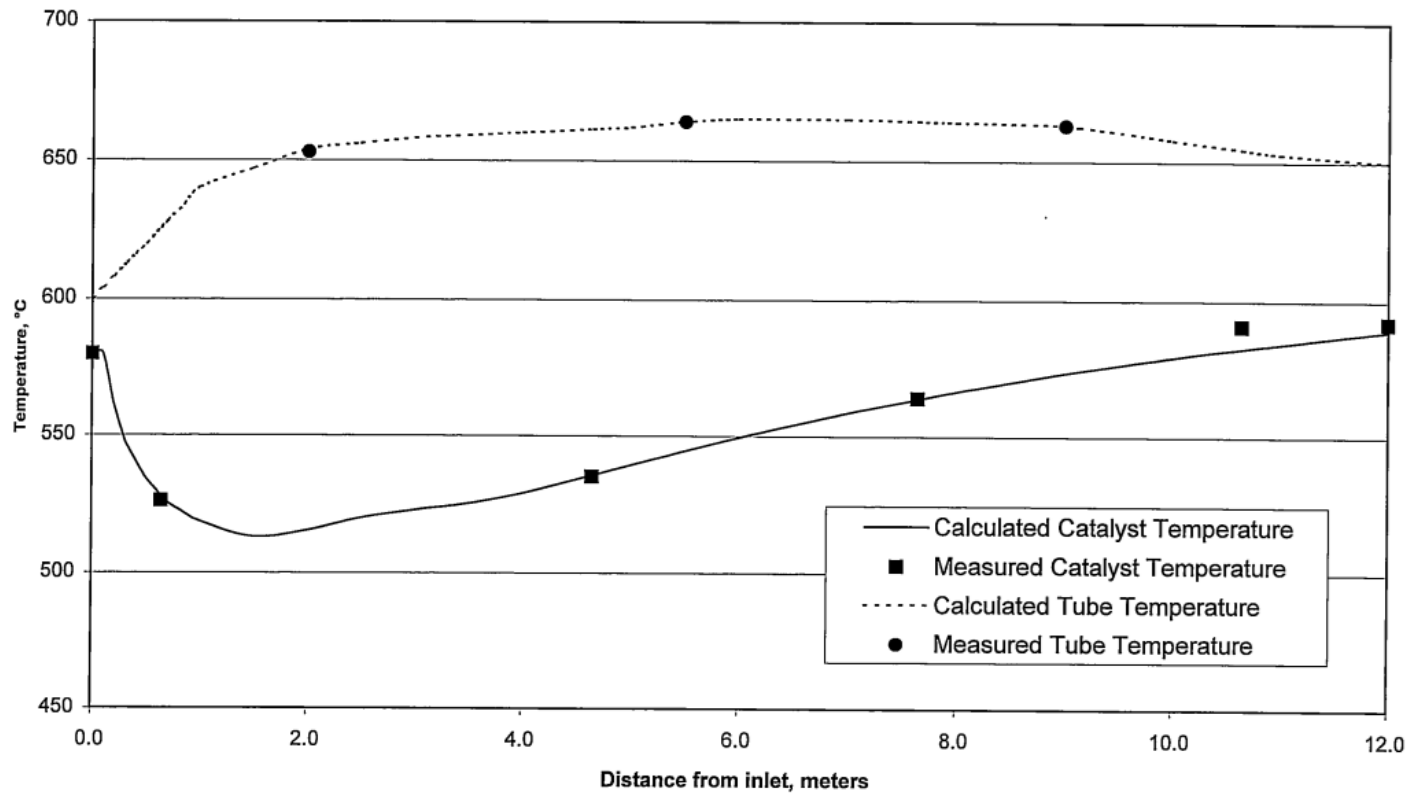
| Start-up year | Plant / Client | Location | Capacity MTPD NH3 | Status |
|---------------|---|----------------------|----------------------|----------------------------------|
| 1993 | Planta Industrial de Agua Pesada 1 (PIAP 1) | Arroyito, Argentina | 2400 | Stand-by |
| 1994 | Planta Industrial de Agua Pesada 2 (PIAP 2) | Arroyito, Argentina, | 2400 | Stand-by |
| 1991 | Undisclosed | Undisclosed | 2x308 | In continuous operation since SU |
| 1987 | Undisclosed | Undisclosed | 2x308 | In continuous operation since SU |
| 1978 | Undisclosed | Undisclosed | 2x308 | Decomissioned |



TOPSOE HAS THE ONLY LARGE-SCALE AMMONIA CRACKING REFERENCES, GLOBALLY

TOPSOE RADIANT WALL CRACKER PERFORMANCE SIMULATION

Ensi S.E. Unit 16.1 21 August 1998 Calculation no. 768338



- Accurate calculation of heat transfer from furnace to tubes and from tube to catalyst
- Accurate calculation of catalytic activity, i.e. ammonia cracking reaction