



We Deliver
NET ZERO



KBR CLEAN AMMONIA SOLUTIONS

MARCH 2023

Delivering Solutions, Changing the World.™

GOVERNMENT SOLUTIONS



We deliver science, technology and engineering solutions to governments and companies around the world.

SUSTAINABLE TECHNOLOGY SOLUTIONS



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A Net-Zero Carbon Future is Built on a Foundation of KBR Innovation



Delivering a cleaner, greener future with KBR energy transition *expertise* and *proprietary technologies*

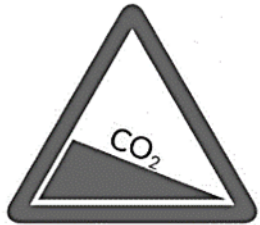
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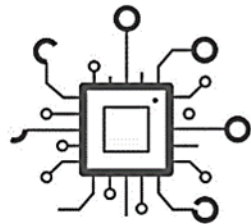
The Journey Towards Net Zero

More than 10% of the world's energy demand likely to be supplied by hydrogen

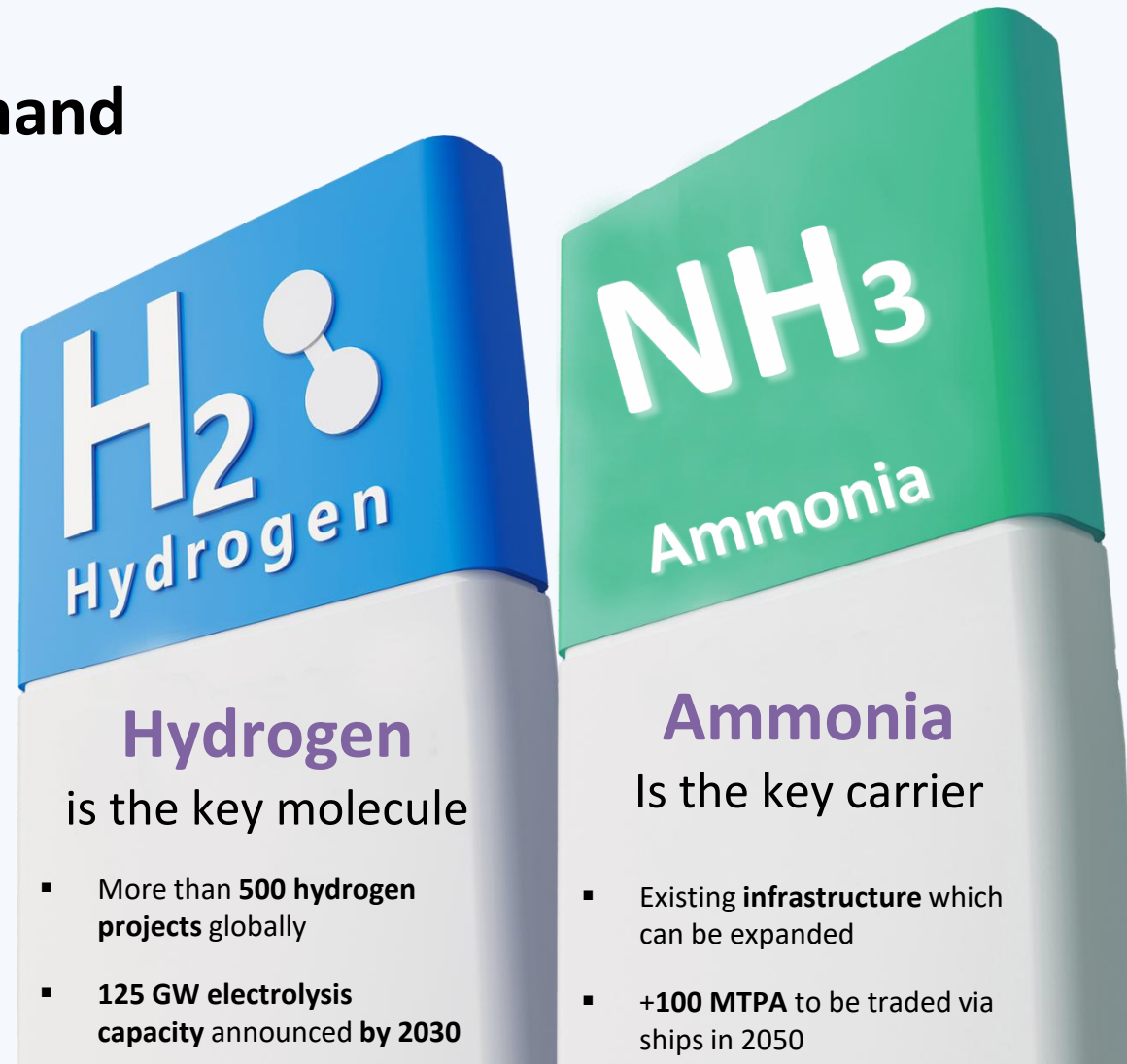


Decarbonization

and



Digitalization



H₂
Hydrogen

Hydrogen
is the key molecule

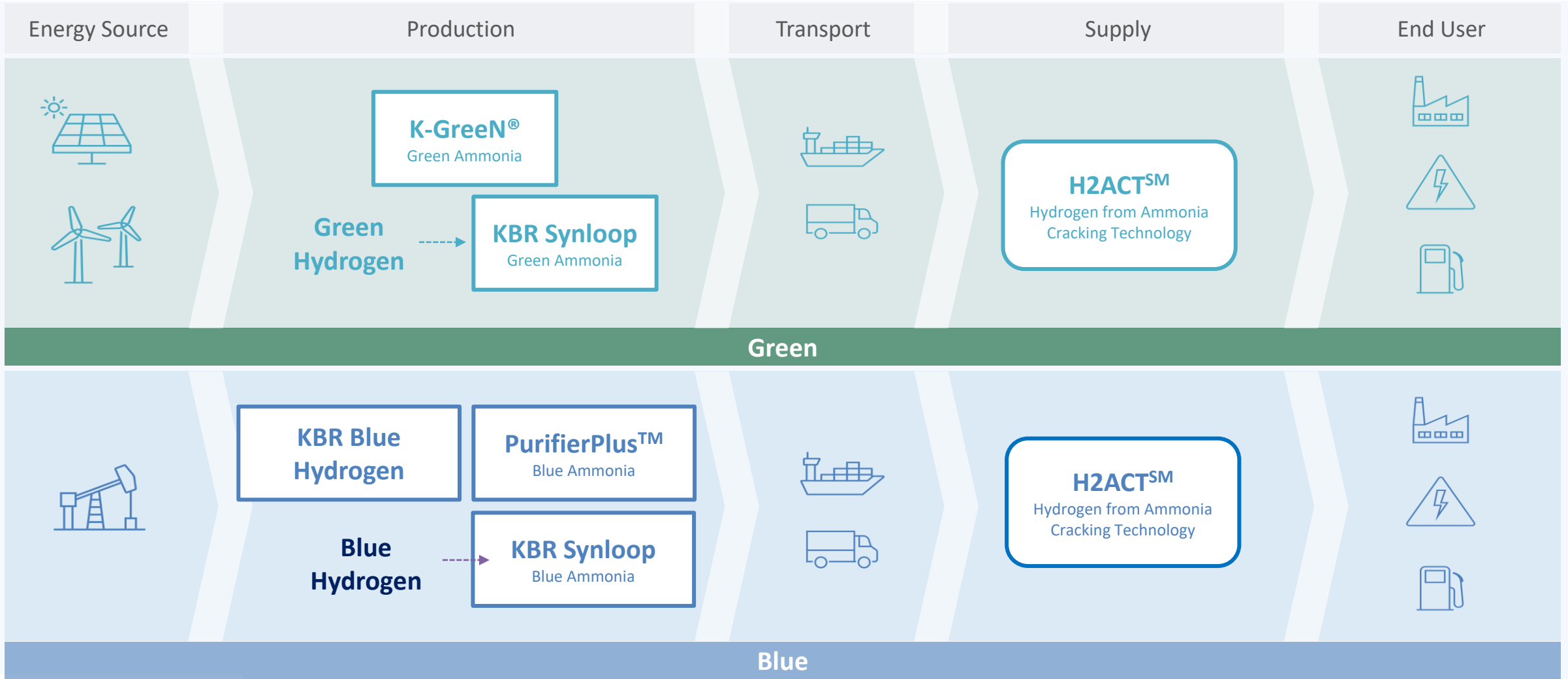
- More than **500 hydrogen projects** globally
- **125 GW electrolysis capacity** announced by 2030

NH₃
Ammonia

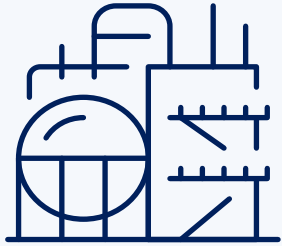
Ammonia
Is the key carrier

- Existing **infrastructure** which can be expanded
- **+100 MTPA** to be traded via ships in 2050

Hydrogen Value Chain – Presence and Scale



The World Leader in Ammonia Technology, 252 Ammonia Plants Awarded Since 1944



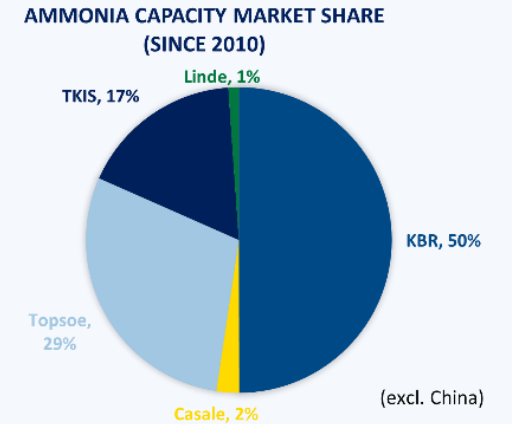
World's **largest** ammonia plant with single converter
+3000 MTPD



World's most **energy-efficient** ammonia plant
6.27 Gcal/MT



World's most **reliable** ammonia plant 2.162 consecutive days in operation



+50% Market share
All based on combined reforming

KBR can deliver a **10,000 MTPD NH₃** plant in one train, with a CO₂ recovery of 99%

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KBR Ammonia Technology in India



- ❖ Licensed 10 large ammonia plants
- ❖ Capabilities to supply PEQ and Catalysts
 - Proprietary designs
 - Modular solutions
 - Equipment including specially designed internals
 - Specialized service
 - State-of-the-Art Catalysts
- ❖ Conducting studies with specific clients for Green Ammonia production

KBR's customers are key players in the fertilizer market



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Green Ammonia Technology, K-GreenN[®]



One-Stop Shop
for
**Green
Hydrogen
and
NH₃**

KBR guarantees and delivers complete complex with integration of intermittent renewable energy, project/site specific electrolyzer selection and ammonia synthesis

Low turndown maximum benefit, but how low we can go?
KBR has unique operating experience of turndown operation @30%
10% turndown is possible

Dynamic operation with flexibility of ramp-up/ramp down

- 50% - 90% per hour
- Depending on the electricity profile, storage(s) not a strong function of ramp-down/ramp up

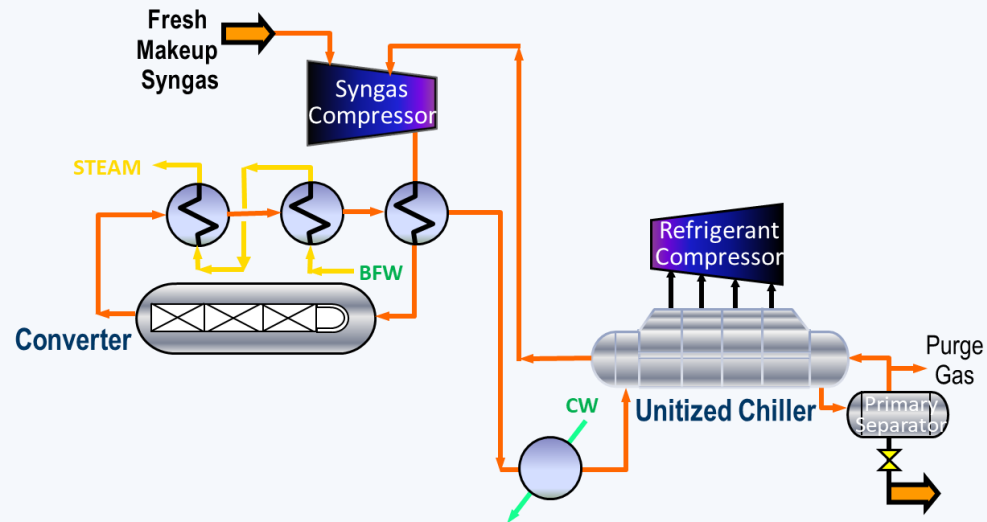
Site optimized solutions for storage of feedstock/product

Stick-built and modular approach

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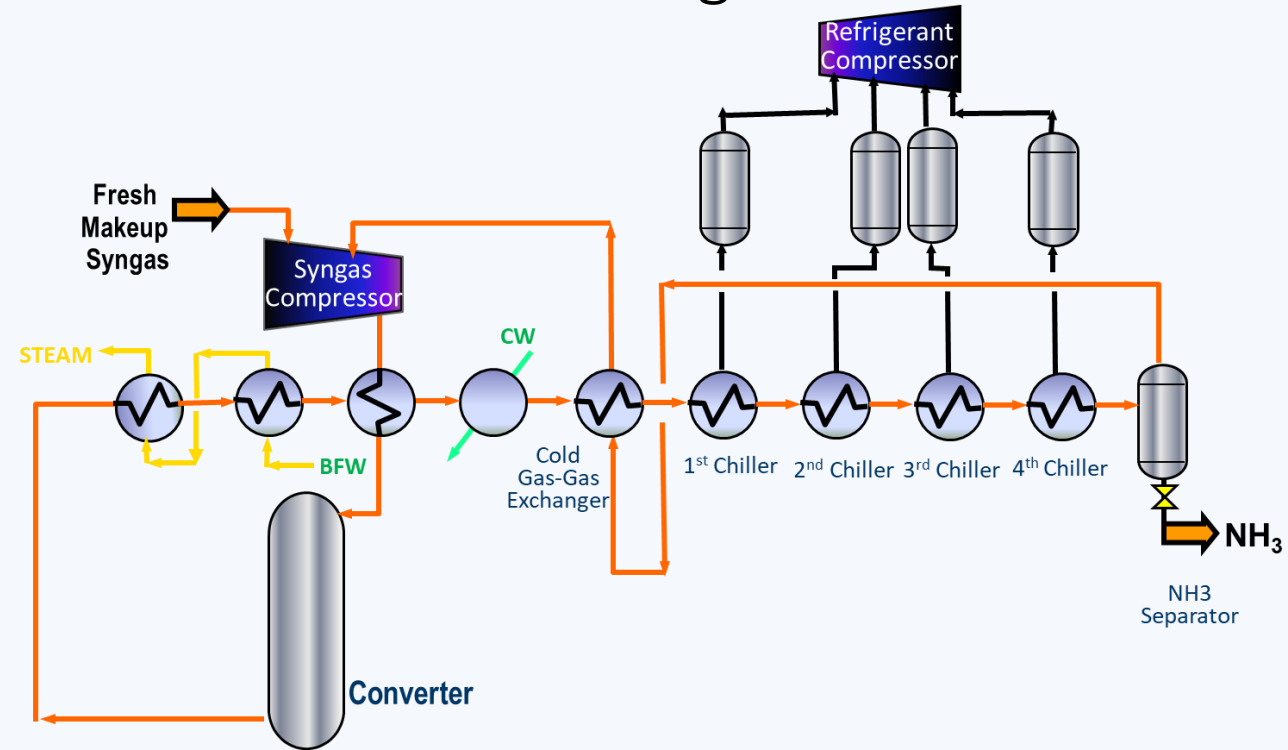
KBR vs. Competition

Simplifying the process flow and thus, CAPEX and OPEX savings



KBR

Only 7 equipment items in KBR ammonia synthesis loop.
6000 MTPD ammonia plant designed. Capabilities to design single train of up to 10,000 MTPD



Other technologies

Significantly more, highly pressurized, CAPEX intensive, equipment items

K-GreenN™ Large Scale 3Bed Horizontal Intercooled Converter

- ❖ Cold Wall Design
 - ✓ Made of 1.25 Cr
 - ✓ Less prone to cracking than hot wall designs
- ❖ Lower loop pressure drop
 - ✓ Fully axial flow at lower energy consumption & operating cost
- ❖ Easy Basket Removal
 - ✓ Basket rolls out on tracks
 - ✓ No need for expensive overhead crane
- ❖ Well proven
 - ✓ 20+ converters in operation/design



Challenges



Ammonia synthesis from green hydrogen poses new challenges

Several Ramp Up/Ramp Down cycles due to renewable power intermittence

Minimum turndown for effective catalyst performance

Poisons (oxygen, others)

Catalyst Design



Traditional Iron-based catalyst are the option of choice

Cost competitive, helping to minimize LCOA

Deoxo systems are needed to remove traces of Oxygen from the H₂O

Collaboration with suppliers for Lab and pilot plant testing of expected operation conditions

Reactor Design



State-of-the-Art KBR horizontal converter

Ensure even flow distribution both at normal conditions and Turndown

Must withstand repeated pressure cycling

Vertical for small capacities

KBR Blue Ammonia — The Most Efficient Route To Net Zero



KBR's blue ammonia process is based on our proven, safe, reliable, low CAPEX and OPEX PurifierPlus™ technology.

Ensuring the highest energy efficiency and low CO₂ generation

PurifierPlus™ — A Superior Technology

- Results in **high energy efficiency, high reliability** and **low CAPEX**
- Generates **lowest CO₂ per unit** of ammonia produced
- Ability to recover **>99% CO₂** ready for CCUS activities
- Leverages economy of scale with **single train ammonia plant up to 10,000 MTPD**

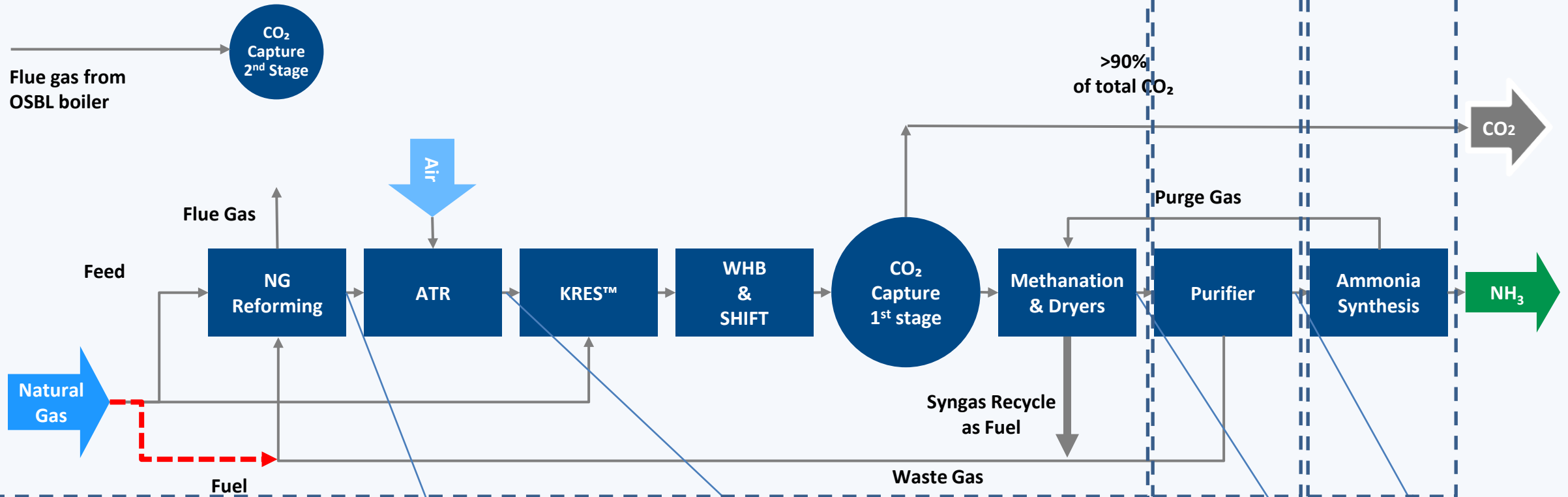
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Blue Ammonia – KBR PurifierPlus™, 10,000 MTPD, 99% CO₂ recovery



Syn Gas Production

Syn Gas Purification & Ammonia Synthesis



T ~ 700 C
CH₄ ~27-29%

- Smaller reformer
- Longer catalyst life
- Less tubes count
- Extended tube life

T = 890 C
CH₄ ~1.5-2.5%
- Relatively longer catalyst life

H/N=2
CH₄ ~2-3%

H/N=3
Inerts ~0.3%



Chemical Reactions in the Ammonia Flowsheet

Catalytic Step	Reaction	Catalyst Type	Equipment
Hydrodesulfurization	$R-SH + H_2 \rightarrow H_2S + R-H$	Cobalt Molybdenum	Pressure vessel
Zin Oxide Beds	$ZnO + H_2S \rightarrow ZnS + H_2O$	Zinc Oxide	Pressure vessel
Primary Reformer	$heat + CH_4 + H_2O \rightarrow 3H_2 + CO$	Nickel-based catalyst	Catalyst-packed tubes in a furnace
Secondary Reformer	$O_2 + 2H_2 \rightarrow 2H_2O + heat$ $heat + CH_4 + H_2O \rightarrow 3H_2 + CO$	Nickel-based catalyst	Refractory-lined pressure vessel
High Temperature Shift	$CO + H_2O \rightarrow CO_2 + H_2 + heat$	Iron-chrome catalyst	Pressure vessel
Low Temperature Shift	$CO + H_2O \rightarrow CO_2 + H_2 + heat$	Copper-Zinc Catalyst	Pressure vessel
Methanation	$CO + 3H_2 \rightarrow CH_4 + H_2O$ $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$	Nickel-based catalyst	Pressure vessel
Ammonia Synthesis	$3H_2 + N_2 \rightarrow 2NH_3 + heat$	Iron based catalyst	Pressure vessel

Strategic Alliance



Well-established catalyst technologies for Blue Ammonia – KBR Purifier Plus™

KBR has partnerships with leading catalyst companies for the supply and design of required catalysts

KBR continuously evaluates and approves world-class vendors suitable for its technology

Reactors Design



KBR-Supplier collaboration is essential

KBR has well-proven reactor designs and design tools.

Works in close collaboration with catalyst supplier to meet targets of performance, efficiency and product quality

Challenges



Cost-effective catalysts to meet both, KBR technology goals and market competitiveness

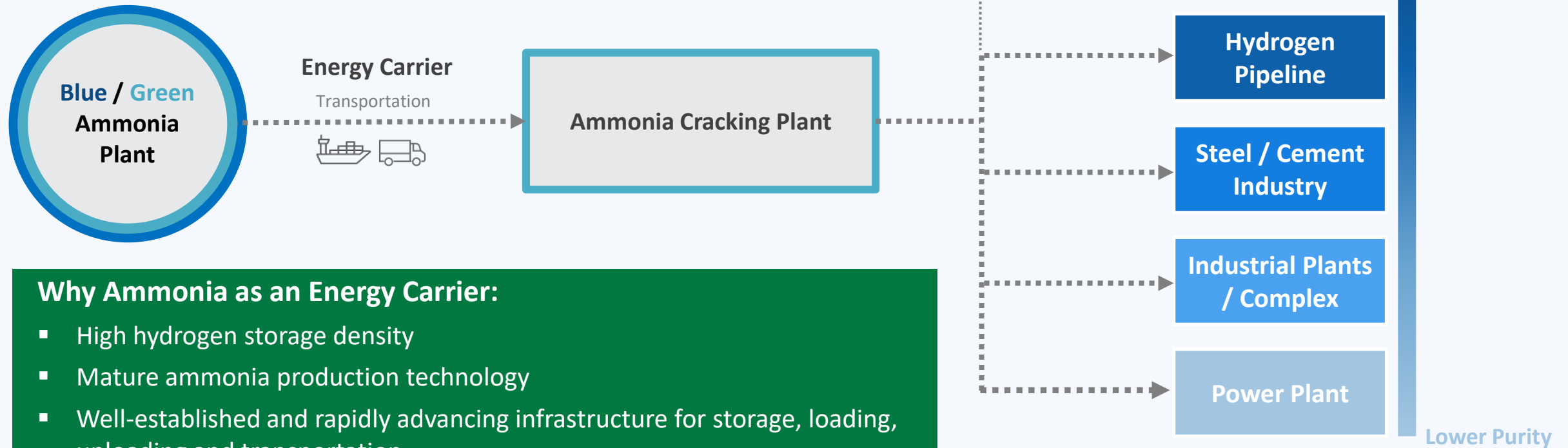
Safe to use

CAPEX / OPEX minimization

Energy efficiency

Ammonia as Energy Carrier

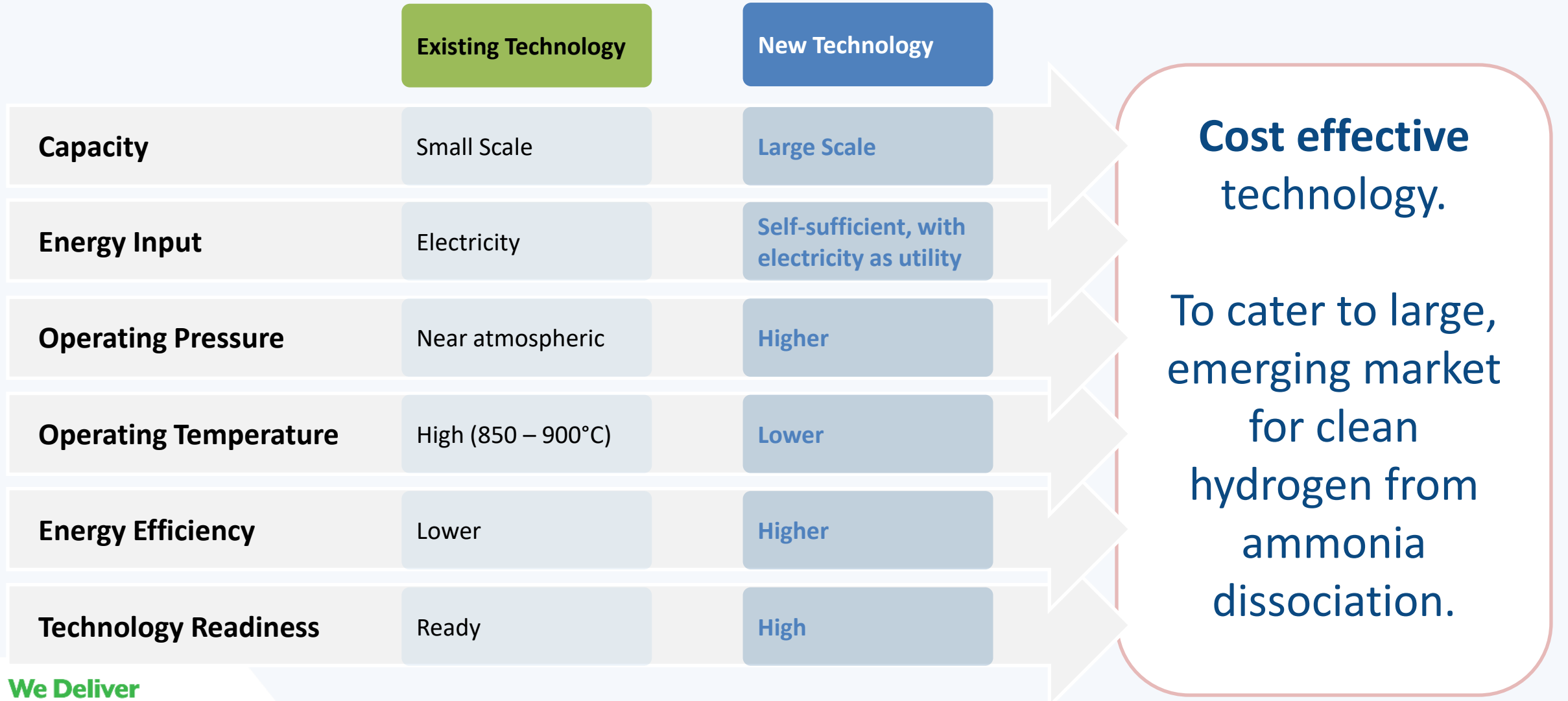
The most promising clean hydrogen carrier for long distances in the short-to-medium term



Why Ammonia as an Energy Carrier:

- High hydrogen storage density
- Mature ammonia production technology
- Well-established and rapidly advancing infrastructure for storage, loading, unloading and transportation
- Most economic and optimal way to transport energy today

Technology Advancement for Emerging Market



Catalyst



Co-operate with world-leading catalyst suppliers, commercial catalysts available

Benchmark and compare both proven and novel catalysts

Reactor Design



Use well-proven KBR reactor design, with decades of success in design and reliable operation


Evaluate alternative reactor options and configurations

Flow Scheme



Fully-functional cost-effective process scheme developed

Process scheme tailored to meet project specifics (purity, delivery conditions, etc.)

A small, detailed globe is positioned on the right side of the slide. It shows a lush green landscape with a blue river, a small pond, and a hot air balloon floating in the sky. The globe is tilted and appears to be a miniature version of Earth.

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