Natural gas based, ultra-low carbon ammonia without flue gas scrubbing

Hady Abdulhady – thyssenkrupp Uhde USA

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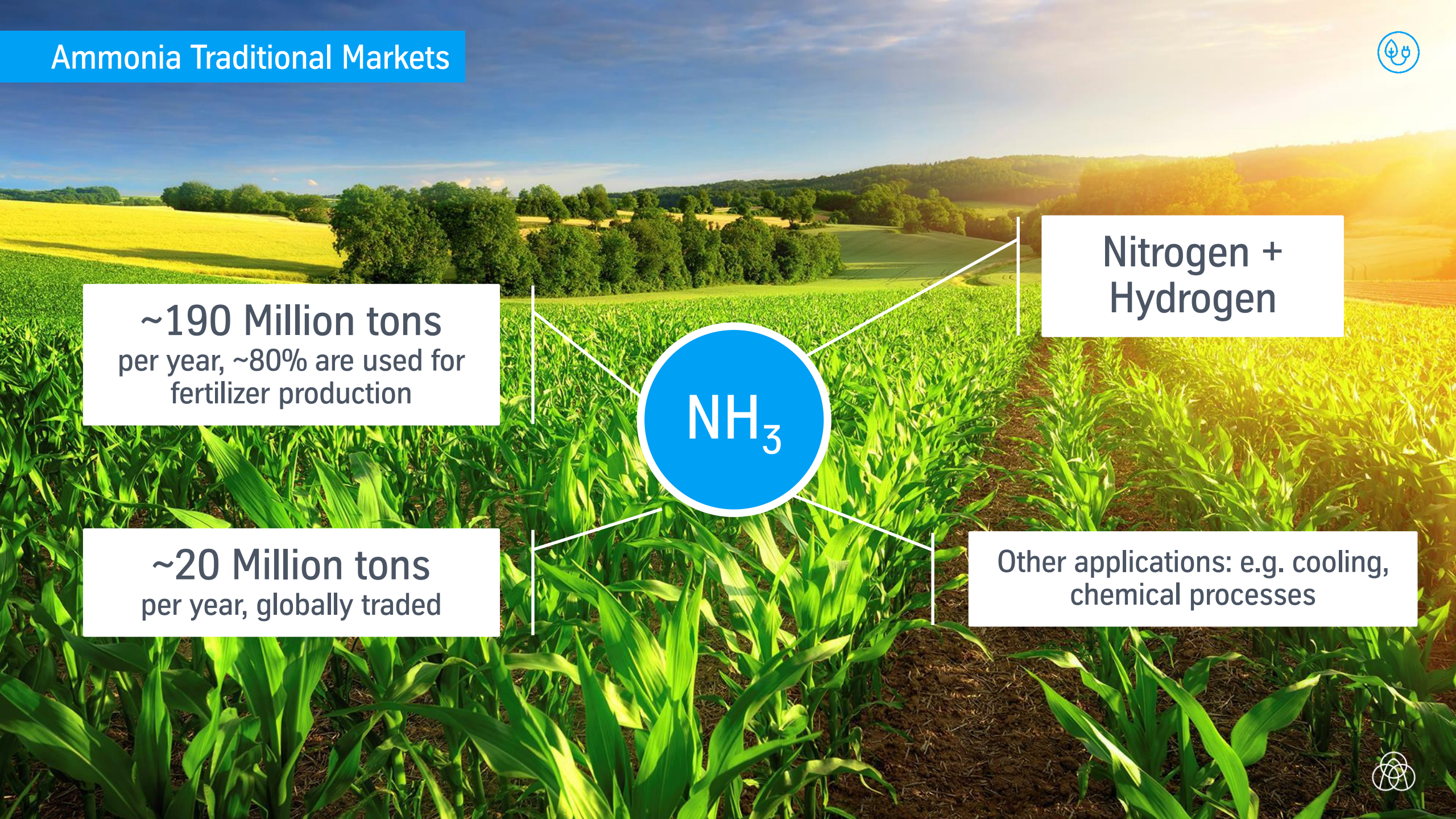
Ammonia Traditional Markets



~190 Million tons
per year, ~80% are used for fertilizer production

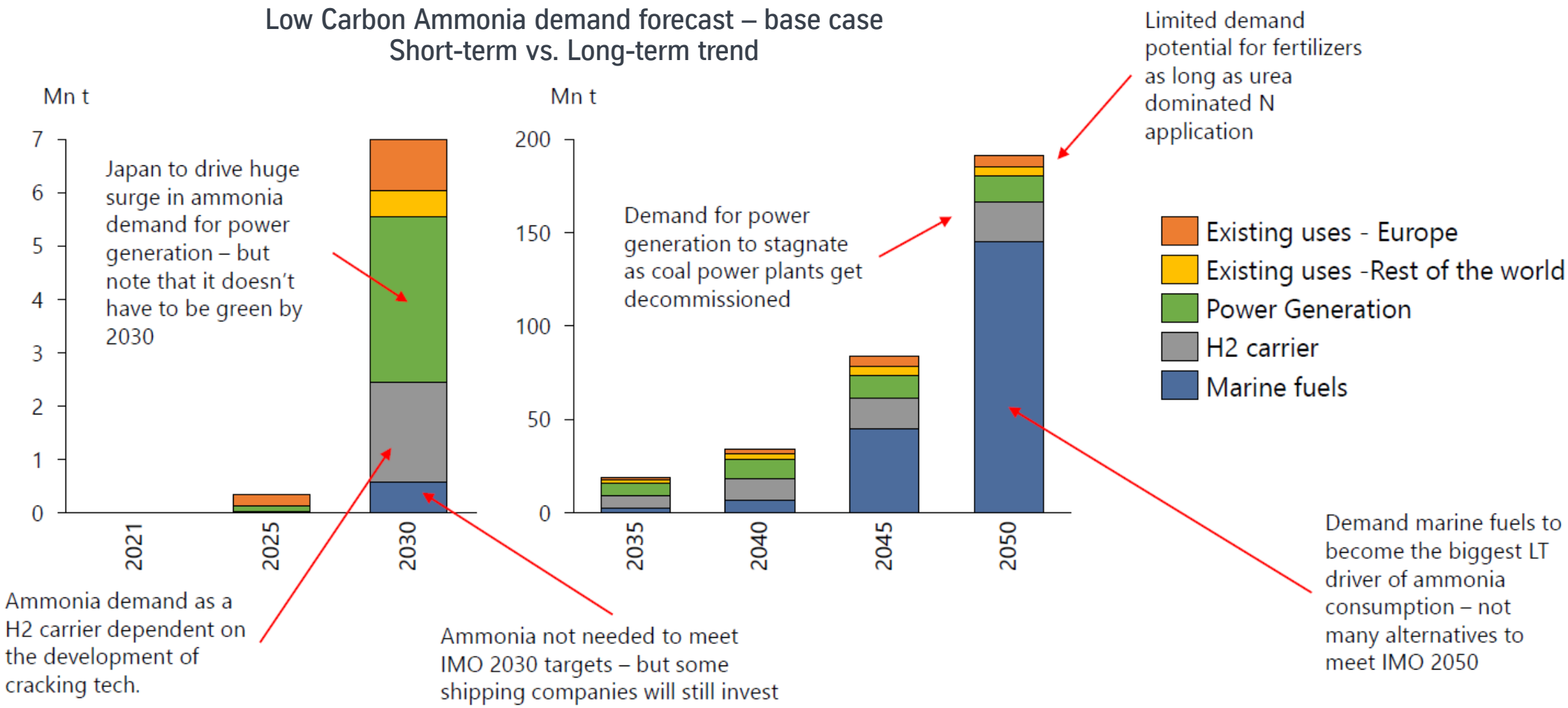
~20 Million tons
per year, globally traded

NH_3

Nitrogen + Hydrogen

Other applications: e.g. cooling, chemical processes

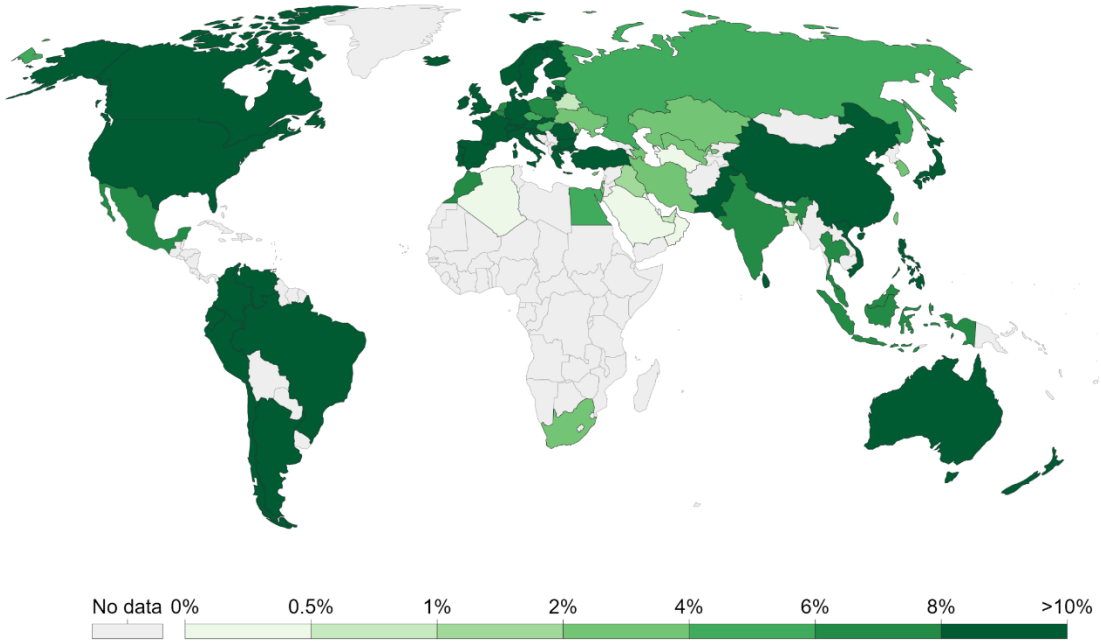
Ammonia New Markets: Non-fertilizer Low Carbon Ammonia Forecast



Source: Argus Media Group © 2021

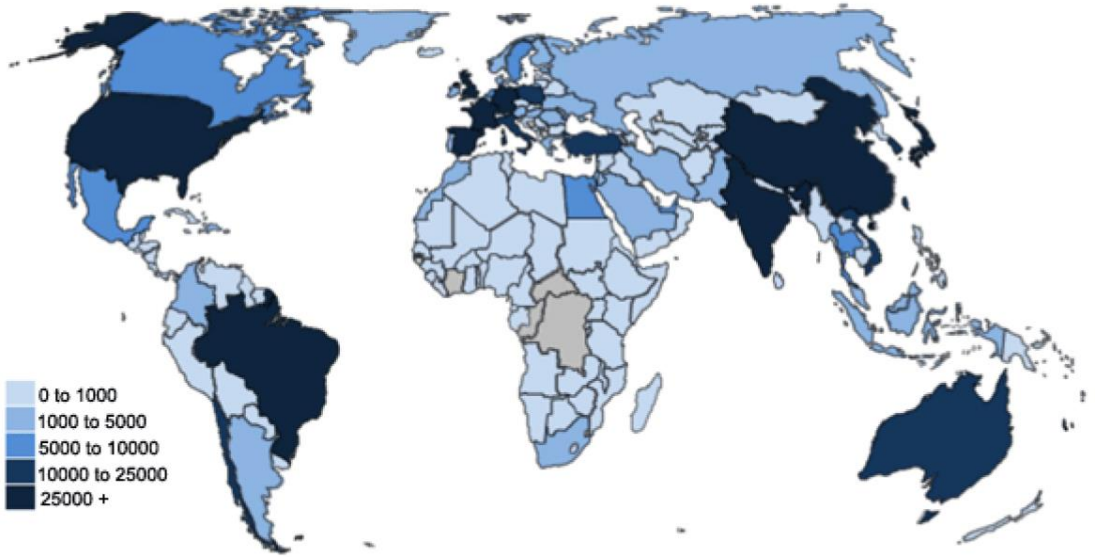
Renewable Energy Installations – Enough for Power-to-X?

Share of Primary Energy from Renewable Sources (2019)



Source: Our World in Data based on BP Statistical Review of World Energy (2020)

Renewables Capacity Additions by Country in MW (2020-2029)



Source: Fitch Solutions, Global Renewables Market Outlook, September 2020 (hydropower is neglected)

By the end of the decade, non-hydropower renewables capacity is expected to grow by just over 1,400 GW, with a total of 2,770 GW[1]

1 Source: Fitch Solutions, Global Renewables Market Outlook, September 2020

Key Drivers for Transition: Green and Blue Hydrogen / Ammonia

Key Drivers for Transition…

- Zero-Carbon Goals
- Carbon Taxes
- Incentive Programs

Key Drivers for Green…

- High availability of renewables
- Emerging electrolysis technologies
- Localized production

Key Drivers for Blue…

- CCS/CCU availability
- Abundance of Natural Gas
- Lower LCOH/LCOA
- Large Capacities

Conventional Ammonia Process

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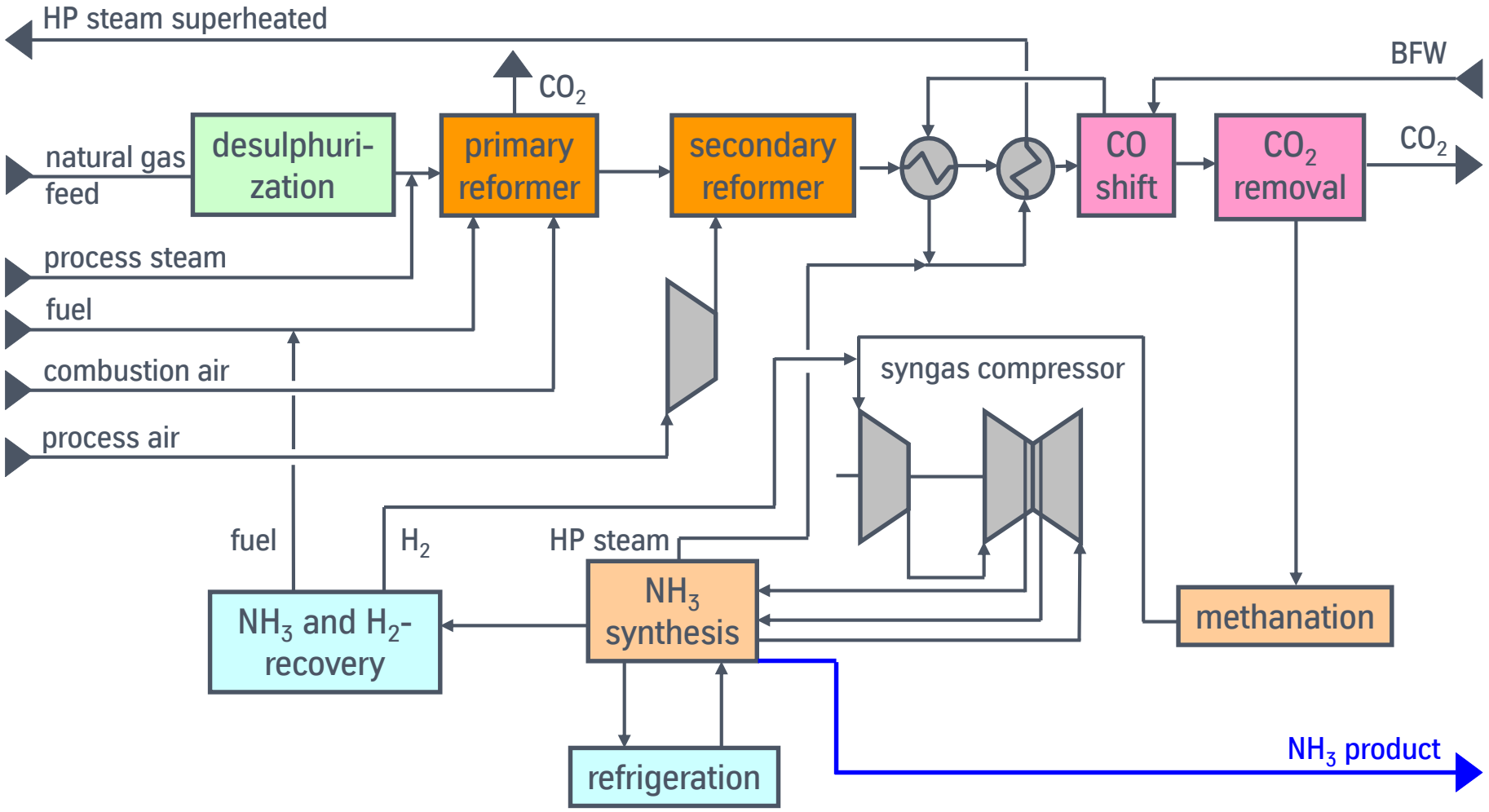
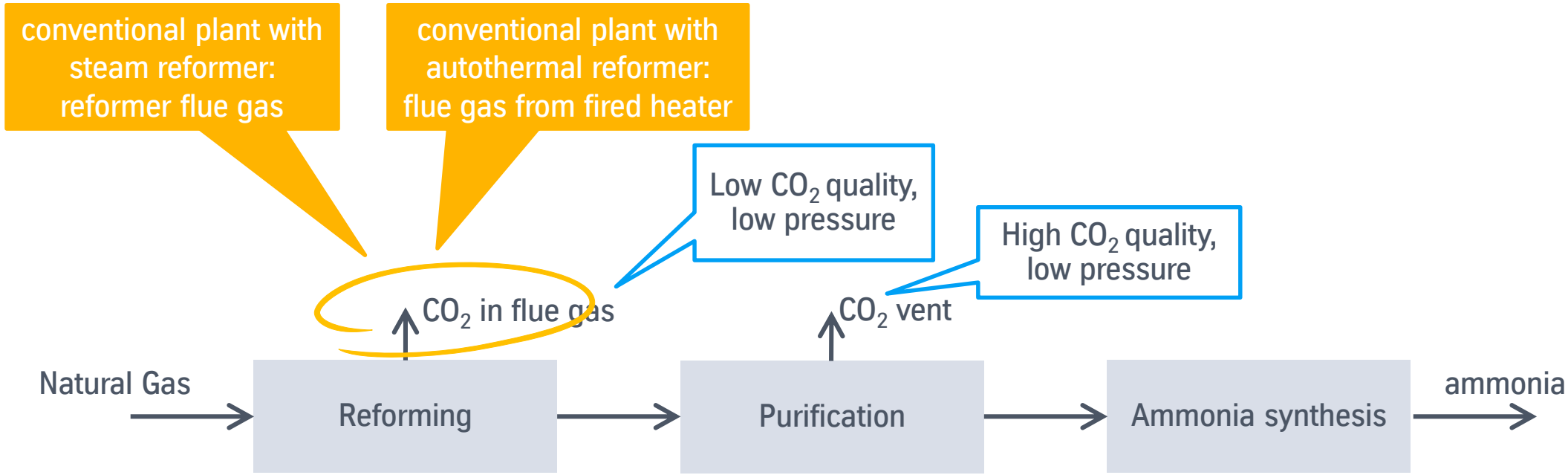
Conventional Ammonia Plant Block Diagram



Carbon Emissions

Sources of CO_2 Emission from Conventional Ammonia Production

Ammonia plant: Two points of CO_2 emission:



Low Carbon Ammonia Process

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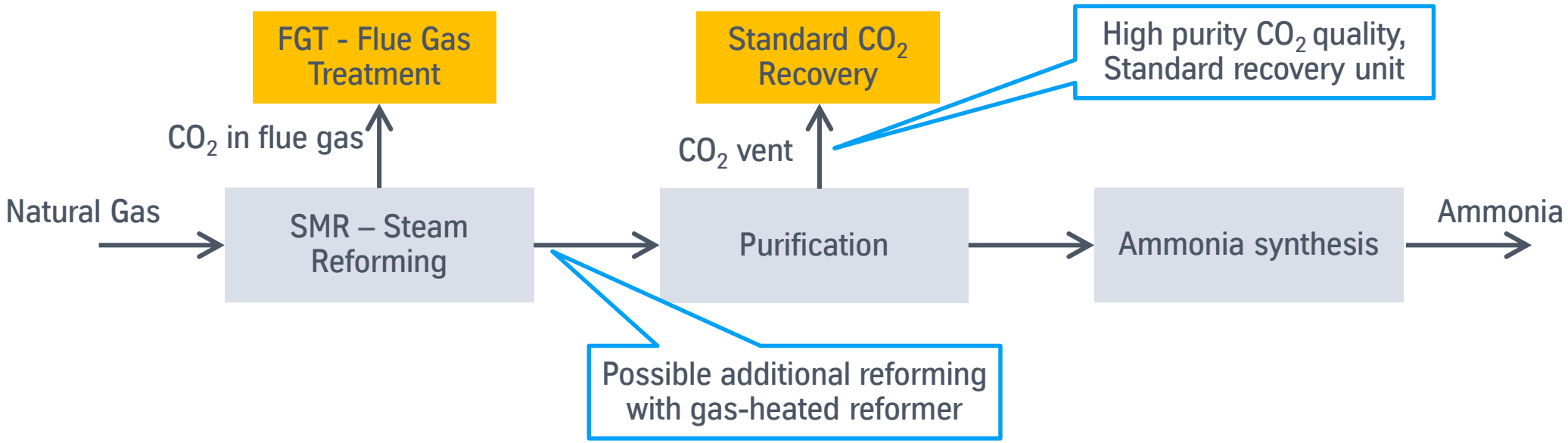
Low Carbon Ammonia

First Approach

Carbon Recovery Rate: up
~ 68-73% without FGT
~ 95% with FGT

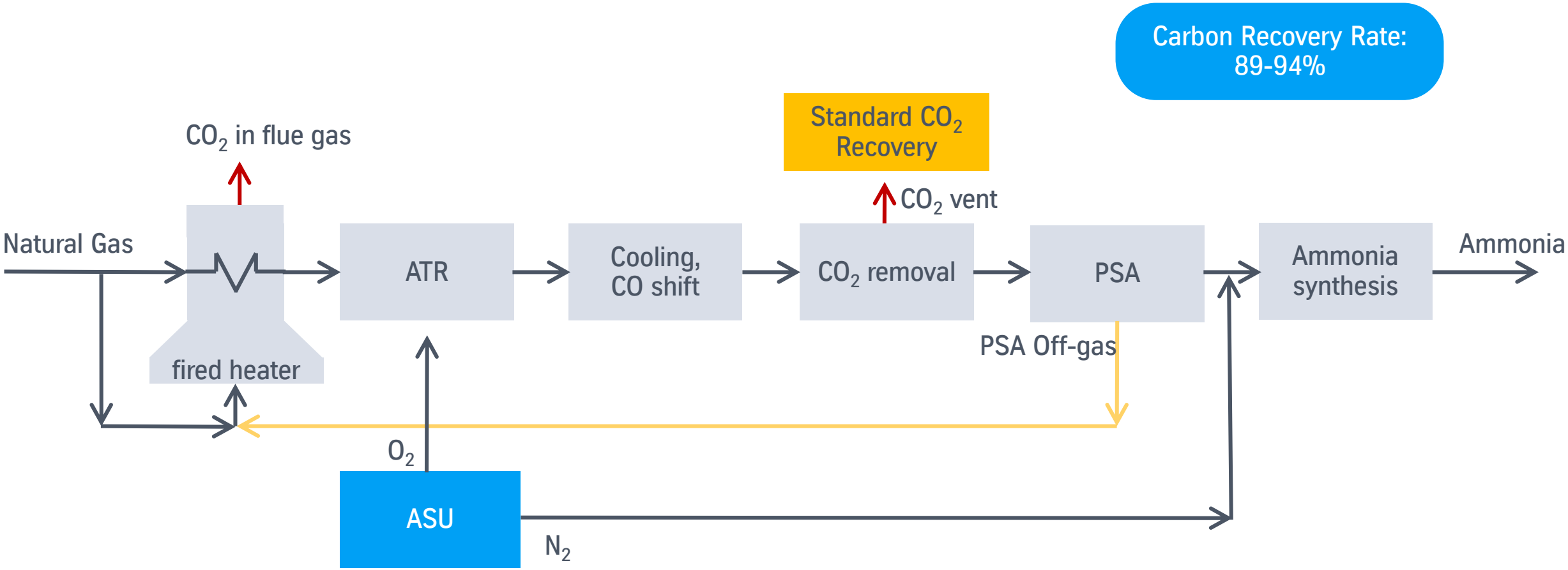
Recovering flue-gas CO_2 in addition to standard CO_2 recovery



Low Carbon Ammonia

Second Approach

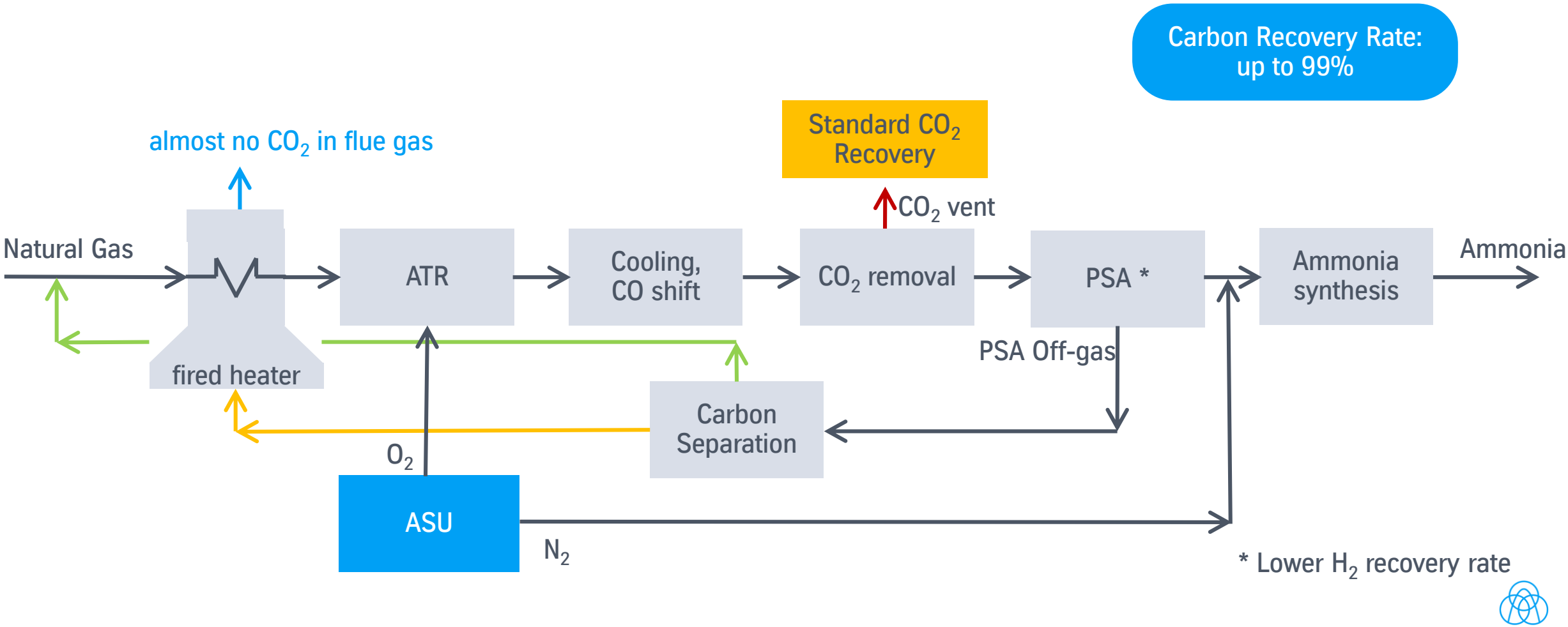
Plant with ATR: 2 points of CO_2 emission to be tackled in case CO_2 emission shall be avoided



Low Carbon Ammonia

Second Approach

Plant with ATR, optimized: only 1 point of CO_2 emission to be tackled in case CO_2 emission shall be avoided



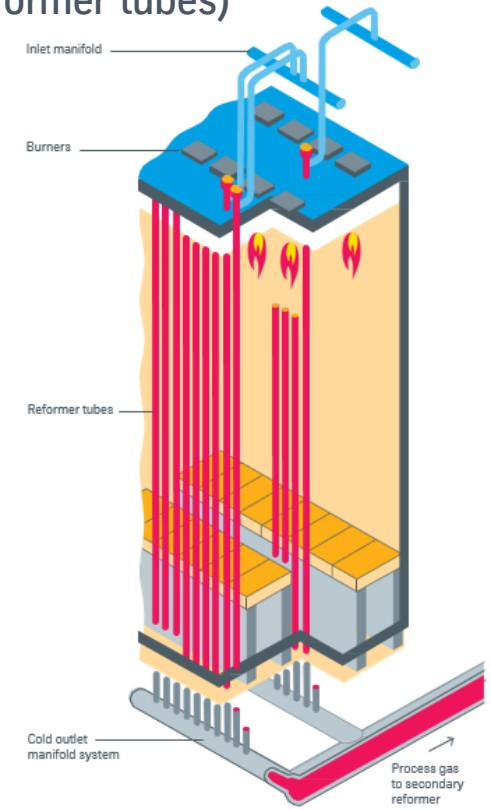
Reformer Types

CO_2 Capture: Steam Reformer (SMR) vs. Autothermal Reformer (ATR)

Comparison

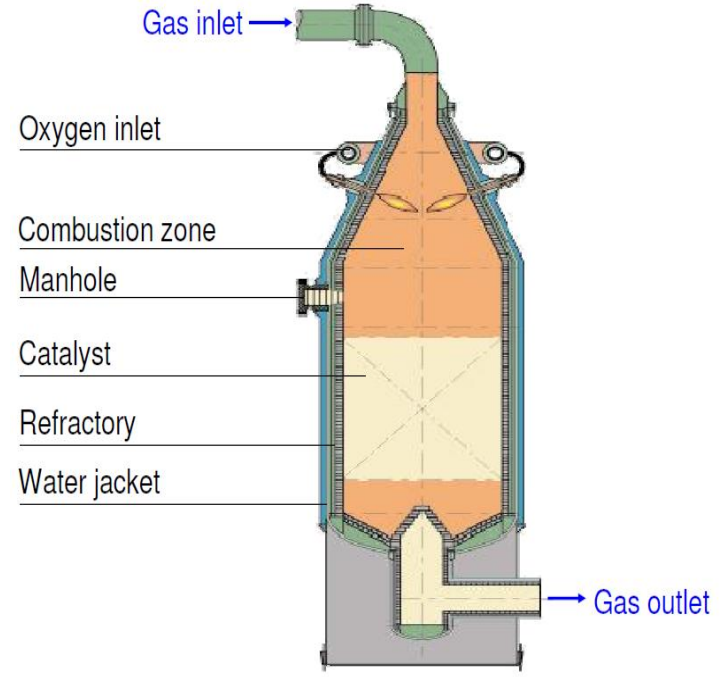
Steam Methane Reformer:

- Heat for reforming is supplied by combustion and heat transfer into the process equipment (reformer tubes)
- High amount of flue gas for preheating of inlet streams and steam superheating



Autothermal Reformer:

- Heat for reforming is supplied by combustion of a portion of the feedstock inside the process vessel ⇒ more feedstock needed
- Separate fired heater needed for preheating of ATR inlet streams



Reformers Comparison

SMR vs. ATR

SMR

- **Advantages:**
  - Reference plants available
  - Syngas composition is already as required d/s reformer section (integrated Ammonia plant with Front/Back End)
    → No ASU necessary
  - Better CAPEX for small capacities
- **Disadvantages:**
  - More CO_2 in flue gas → higher CAPEX for CO_2 Removal unit
  - Large capacities has no little gain from economy of scale

ATR

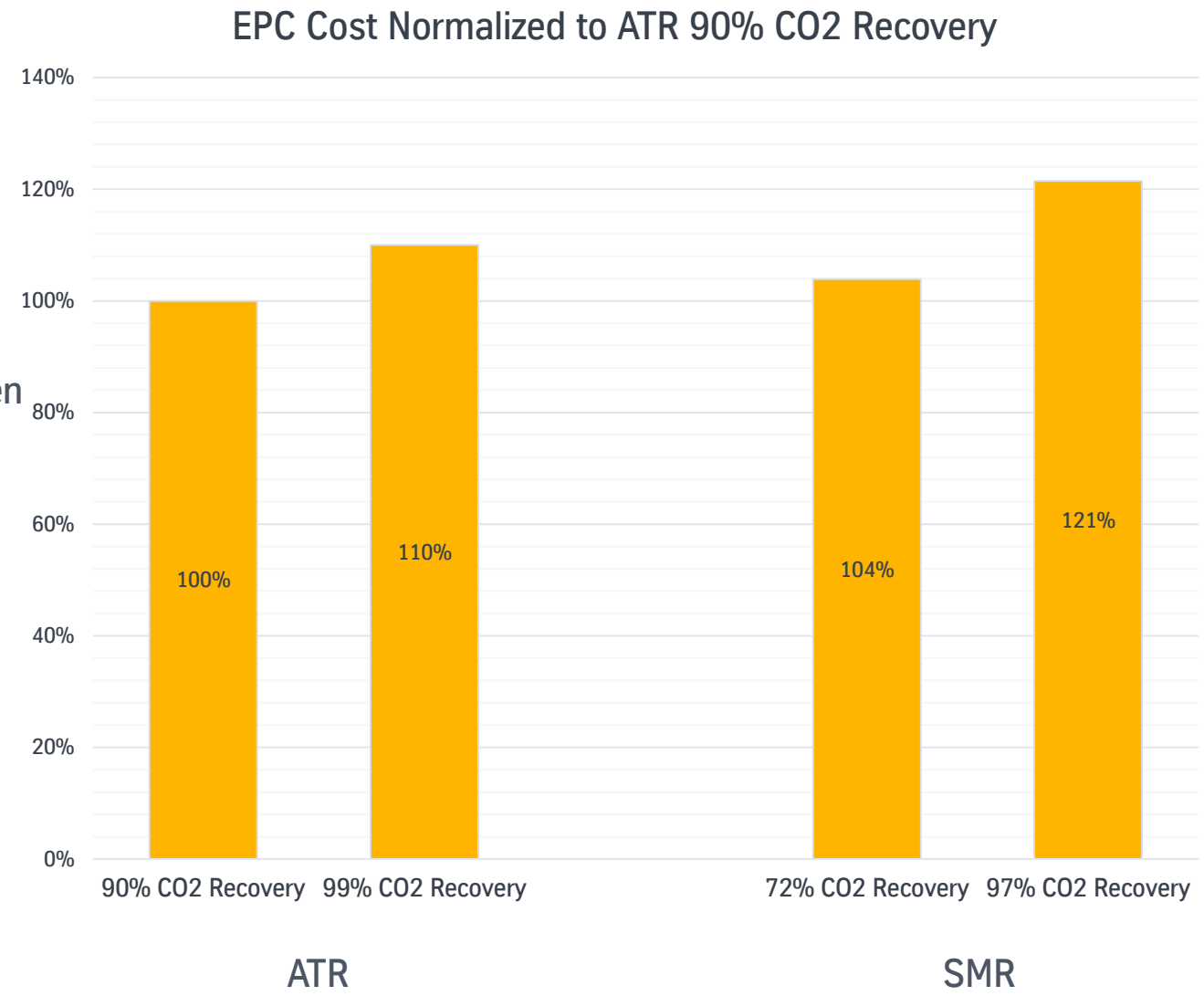
- **Advantages:**
  - Less CO_2 in Flue Gas (overall approx. same amount of CO_2)
  - Blue Ammonia solution without flue gas scrubbing possible
  - Better CAPEX for large capacities
  - Blue Hydrogen as additional (by-)product possible
  - Easier integration/transition to Green Ammonia
- **Disadvantages:**
  - Higher CAPEX for smaller capacities
  - Higher space requirement for the overall plant
  - First reference is still being built (1.2Million mtpa)

Best option depending on client's requirements & boundaries

EPC Cost Estimate of ATR vs SMR

Assumptions

- Capacity 3,500 MTPD
- ASU is included for ATR cases
- Flue gas scrubbing system and additional hydrogen for fuel are included for SMR 97% CO2 recovery
- Carbon Capture equipment are included



Thank you for attention!

hady.abdulhady@thyssenkrupp.com

www.thyssenkrupp-uhde.com

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