Decarbonizing Energy sector: Low-Carbon Hydrogen and Ammonia as energy carrier

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Korean Hydrogen Roadmap
“the roadmap notes the government’s long-term aim of building
a specialized hydrogen pipeline network across the country
while the development of hydrogen-receiving infrastructure
is set to begin in 2022”
www.csis.org/analysis/south-koreas-hydrogen-industrial-strategy

“Decarbonization

EHB (European Hydrogen Backbone) group presents
a vision for a 39,700km hydrogen pipeline infrastructure in 21 countries

OCI to charter ammonia-fueled vessels
OCI NV -- the world's largest ammonia producers -- announced two new
charter ammonia-fueled vessels

More than 85% of export-oriented low-carbon hydrogen projects plan to ship ammonia, not H2
transition/more-than-85-of-export-oriented-low-carbon-hydrogen-projects-plan-to-ship-ammonia-not-h2/2-1-1144059

Import of green energy: RWE builds ammonia terminal in Brunsbüttel

RWE AG

OCI Announces ESG StrategyFocused on Capitalizing on the Hydrogen Opportunity
OCI NV

Decarbonization
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
Ammonia as Hydrogen carrier

Why Ammonia?

Transport of hydrogen

- Low volumetric energy density
- High pressure to transport as a gas or extremely low temperature of -253 °C for transport as a liquid
- High effort/energy input
- Infrastructure needs to be developed

Transport of ammonia

- High hydrogen density (17.8 wt-%)
- -33 °C for transport as a liquid
- High, but known effort
- Transport by ship is proven technology
- Large-scale infrastructure available

Transport of NH₃ over long distances is state of the art
Green Ammonia as energy carrier – Set up along the whole energy supply chain

The complete solution from one source

Ammonia production

Wind/solar/hydro

Electrolyzer

N\textsubscript{2}

Air separation unit

Ammonia cracking

Ammonia storage, loading & unloading

Transport

Power plants

Fuel

Green steel, Chemicals, fuel cells

Ammonia usage for energy transport, utilization as energy carrier or re-conversion to hydrogen
Ammonia New Markets: Non-fertilizer Low Carbon Ammonia Forecast

Low Carbon Ammonia demand forecast – base case
Short-term vs. Long-term trend

- Limited demand potential for fertilizers as long as urea dominated N application
- Demand for power generation to stagnate as coal power plants get decommissioned
- Demand marine fuels to become the biggest LT driver of ammonia consumption – not many alternatives to meet IMO 2050

Japan to drive huge surge in ammonia demand for power generation – but note that it doesn’t have to be green by 2030

Ammonia demand as a H2 carrier dependent on the development of cracking tech.

Ammonia not needed to meet IMO 2030 targets – but some shipping companies will still invest

Source: Argus Media Group © 2021
Renewable Energy Installations – Enough for Green Ammonia / Power-to-x?

Share of Primary Energy from Renewable Sources (2019)

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

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

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

1 Source: Fitch Solutions, Global Renewables Market Outlook, September 2020
Decarbonizing Conventional Ammonia Process
Conventional Ammonia Plant Block Diagram

- Natural gas feed
- Process steam
- Fuel
- Combustion air
- Process air

Primary reformer
- CO₂ shift
- CO₂ removal

Secondary reformer
- CO₂ shift

CO₂ removal

Syngas compressor

NH₃ and H₂ recovery

NH₃ synthesis

Methanation

Refrigeration

NH₃ product
Carbon Emissions

Sources of CO₂ Emission from Conventional Ammonia Production

Ammonia plant: Two points of CO₂ emission:

- Conventional plant with steam reformer: reformer flue gas
- Conventional plant with autothermal reformer: flue gas from fired heater

Sources of CO₂ Emission from Conventional Ammonia Production

Natural Gas → Reforming → Purification → Ammonia synthesis → ammonia

- CO₂ in flue gas
- CO₂ vent

- Low CO₂ quality, low pressure
- High CO₂ quality, low pressure
Low Carbon Ammonia Process
Low Carbon Ammonia

First Approach

Recovering flue-gas CO₂ in addition to standard CO₂ recovery

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

Carbon Recovery Rate: 89-94%
Low Carbon Ammonia

Second Approach

Plant with ATR, optimized: only 1 point of CO₂ emission to be tackled in case CO₂ emission shall be avoided

Almost no CO₂ in flue gas

Carbon Recovery Rate: up to 99%

* Lower H₂ recovery rate
Reformer Types
CO₂ 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 CO₂ in flue gas → higher CAPEX for CO₂ Removal unit
  - Large capacities has no little gain from economy of scale

**ATR**

- **Advantages:**
  - Less CO₂ in Flue Gas (overall approx. same amount of CO₂)
  - 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 (1.2 Million 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
Ammonia Cracking
Green Ammonia as energy carrier – Set up along the whole energy supply chain

The complete solution from one source

Ammonia usage for energy transport, utilization as energy carrier or re-conversion to hydrogen
Location of ammonia cracking
Centralized vs. local NH₃ cracking

1. Local small-scale cracking
   - No hydrogen infrastructure required
   - Advantages of ammonia transport up to consumer
   - Electrically heated process suitable
   - Additional ammonia infrastructure needs to be developed in parallel to hydrogen if available
   - Risks/restrictions for ammonia transport by train or truck
   - Higher specific investment/operation costs
   - Increased CO₂ footprint if electric power is not generated totally from renewables

2. Centralized large-scale cracking
   - Economy of scale
   - Integration into an existing regional hydrogen economy
   - Fired reactor technology suitable
   - Hydrogen infrastructure needs to be developed if not available
   - High effort for authorities’ approval

Centralized large-scale units can achieve higher energy efficiency and lower CO₂ emissions
Hydrogen from Ammonia - Ammonia cracking
thyssenkrupp Uhde developments

- Based on Uhde’s well proven SMR prop. equipment
- High catalytic NH₃ conversion to H₂ (above 98%)
- Purities adaptable to requirements of user
- Already proven in 1970’s in small-scale units
- Designed for large scale solutions up to 3,000mtpd
- State-of-the-art catalysts
Green ammonia to green hydrogen
Our technology, your market

Decision on:
- Product purity with respect to residual NH\textsubscript{3} and N\textsubscript{2} content
- Technology for last purification step (e.g. PSA, membrane)