

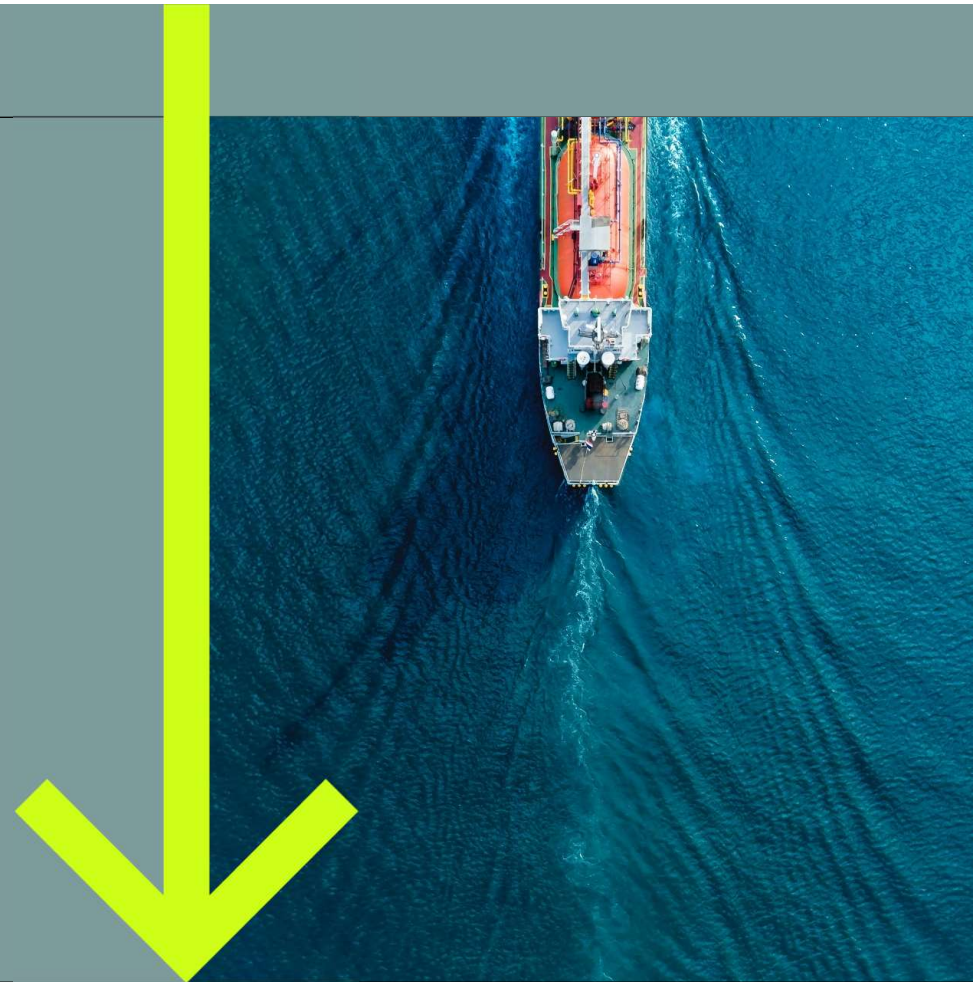
Hydrogen and P2X, 19-20th of June, Copenhagen

WHY CLEAN AMMONIA WILL SCALE AS HYDROGEN AND ENERGY CARRIER?

Rob Stevens

Sector Lead Green Fuels Topsoe Power to X

TOPSOE



CLIMATE CHALLENGE

CLEAN FUEL AND FEEDSTOCK IS THE SOLUTION

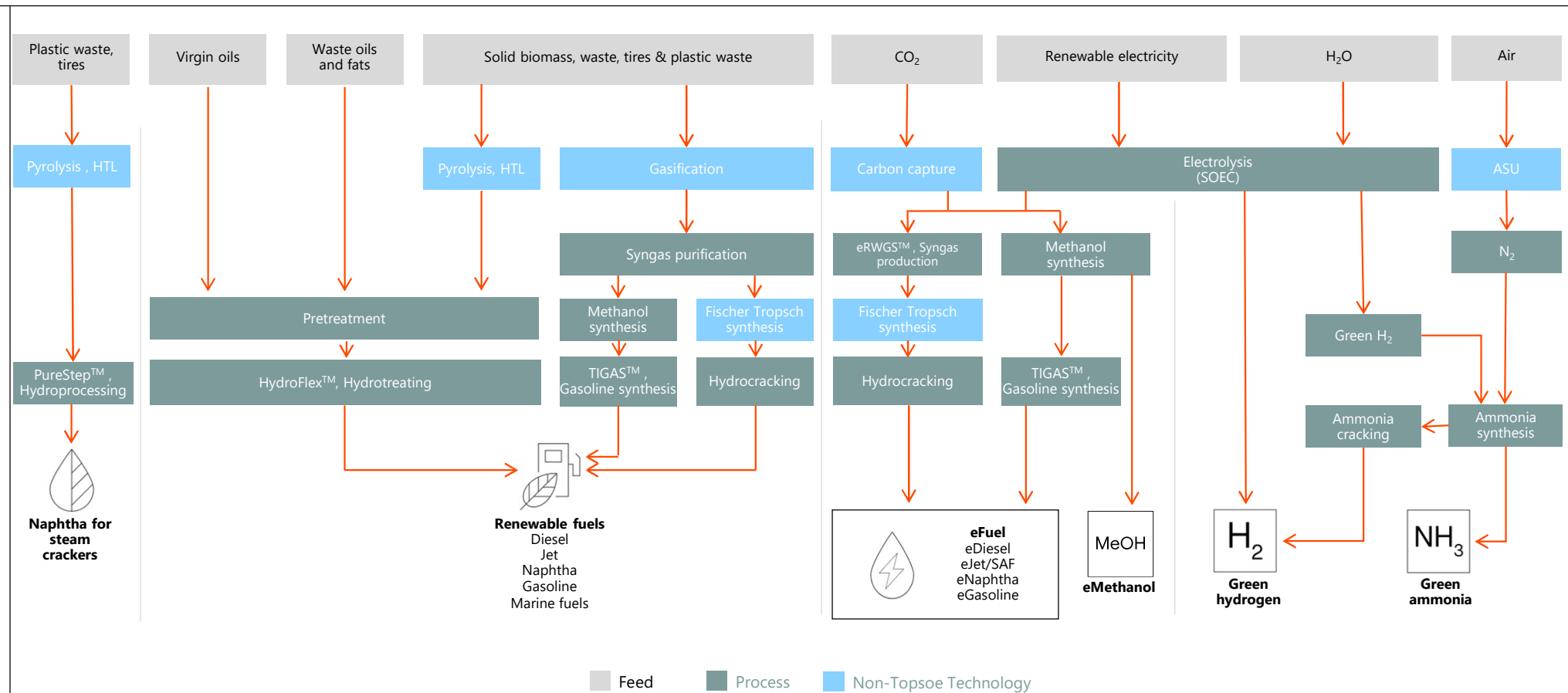
- Energy intensive industries and long-distance transport emit 30% of global Green House gas emissions
- These Hard-to-Abate (Hard-to-Incentivize) sectors require a journey to net zero
- The challenge is the difficulty to electrify
- As a consequence a potential delay in contribution to address climate change
- We **can do the fast-track** and roll out of technologies (and solutions) enabling Net-Zero

SCALE, SMART, SPEED

STARTING WITH CLEAN FUELS

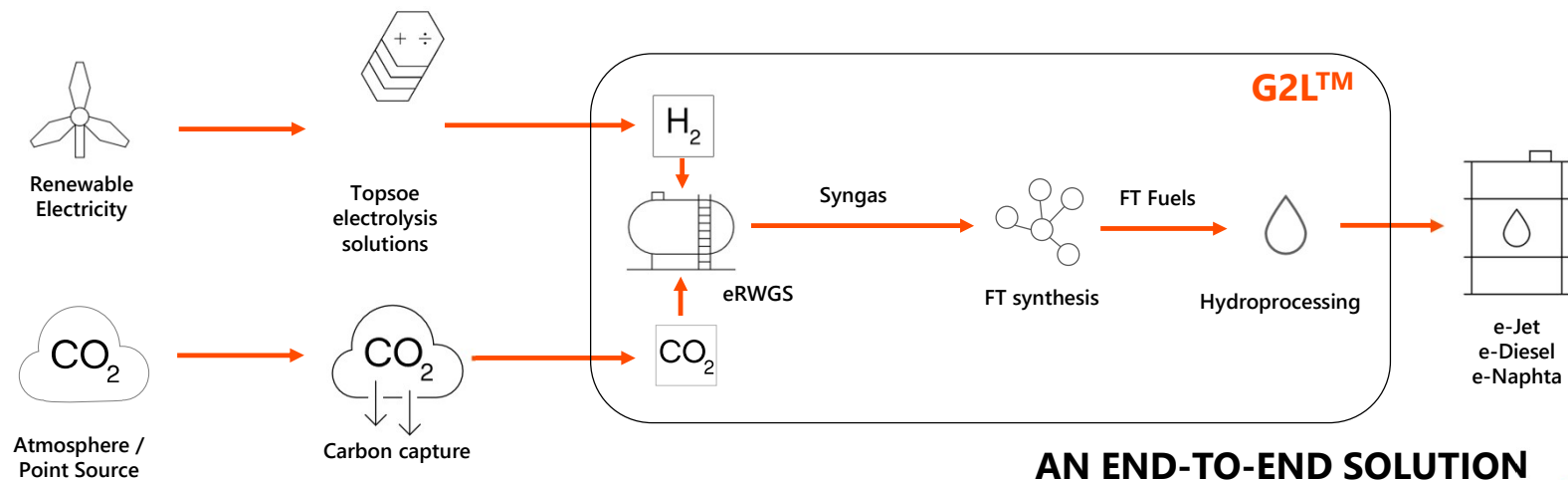
- Scale by doubling or tripling low-carbon and e-ammonia, instead business as usual
- Smart usage of scarce biogenic CO₂ through methanol as carrier
- Speed complementary Low-carbon ammonia and methanol to connect the world with clean energy

HARNESS THE POWER OF OUR UNMATCHED CONVERSION CAPABILITIES TO TRANSFORM ALMOST ANY FEED INTO GREENER FUEL, ENERGY, OR CHEMICALS



MOVING WITH SAF AND E-SAF

ZAFFRA A ONE-STOP-SHOP JOINT-VENTURE FOR SAF

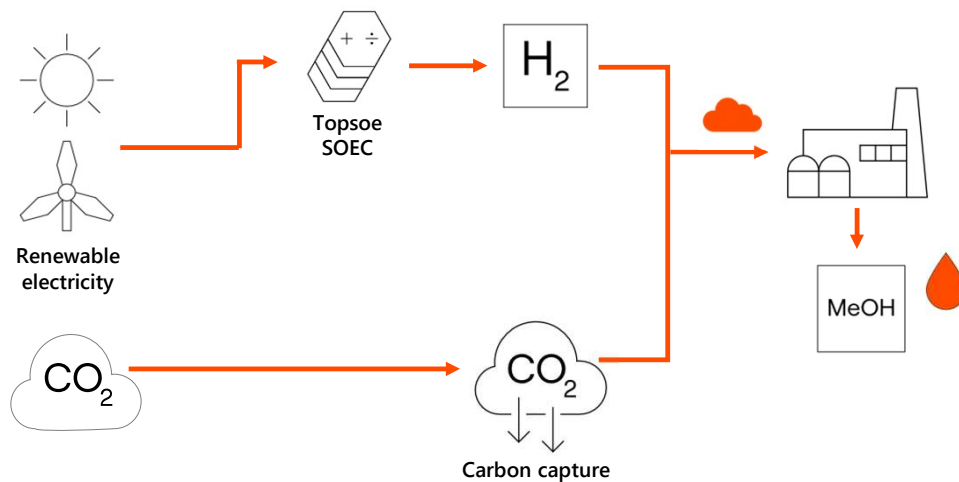


AN END-TO-END SOLUTION

- Fully integrated design
- Integrated guarantees
- Reliable production
- Bankable

MOVING WITH E-METHANOL

PARTNERING WITH LIQUIDWIND (METHANOL LOOP ONLY)



9 November 2023, 'Liquid Wind announces a further strengthening of its partnership .. decarbonization leaders to include plans of developing and marketing 10 additional eMethanol facilities (Nordics by 2027). The 2020 Partnership .. Alfa Laval, Carbon Clean, Siemens Energy and Topsoe....'



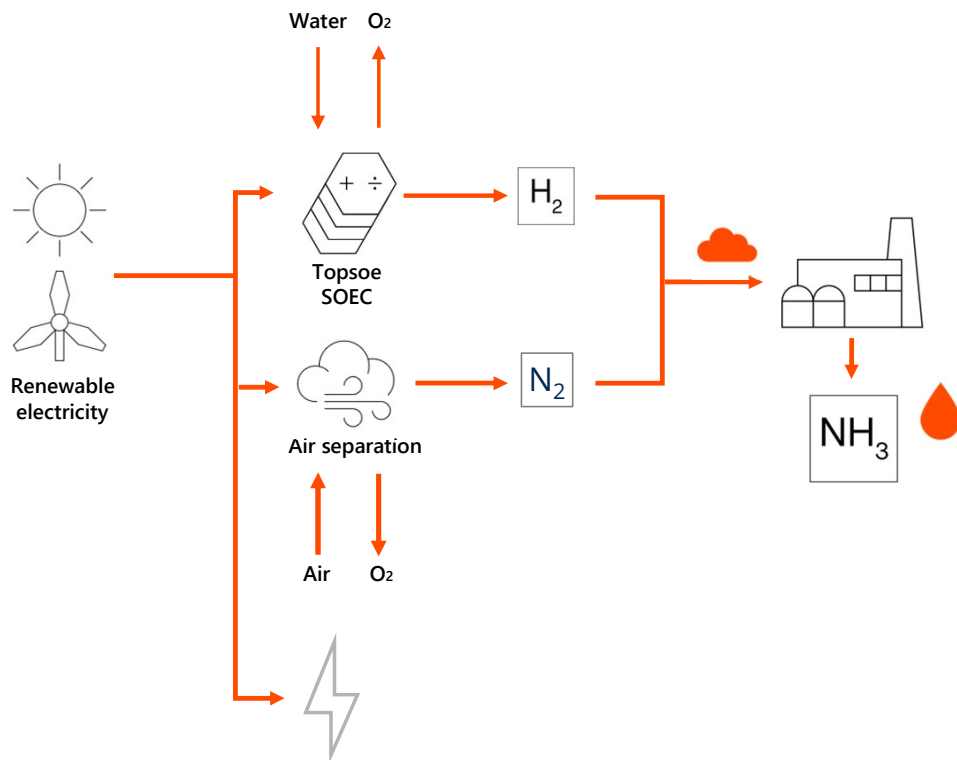
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<https://www.liquidwind.se/news/liquid-wind-and-industry-leaders-solidify-partnership-to-accelerate-efuel-production-capacity-enabling-significant-reduction-of-co2-emissions-in-hard-to-abate-industries-such-as-global-shipping>

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MOVING WITH GREEN AMMONIA

PARTNERING WITH FIRST AMMONIA IN TEXAS



TOPSOE

<https://www.uniper.energy/news/de/first-ammonia-und-uniper-kuendigen-zusammenarbeit-bei-der-herstellung-von-gruenem-ammoniak-in-texas-an>

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MOVING WITH HYDROGEN SOLID OXIDE ELECTROLYSER

TOPSOE SOEC STACK MANUFACTURING FACILITY (HERNING, DK) AND POTENTIALLY USA



Topsoe awarded EUR 94 million for the construction of electrolyzer manufacturing facility in Herning, Denmark.



Initial capacity: 500 MW/year, expandable to 5GW



Production plant size 23,000 m²



Total land area size 72,000 m²



150 employees, on-site, when production begins in 2025.

About the Innovation Fund

The Innovation Fund is the EU fund for climate policy, with a focus on energy and industry. It aims to bring to the market solutions to decarbonize European industry and support its transition to climate neutrality while fostering its competitiveness. The Innovation Fund is financed through the EU Emissions Trading System (EU ETC).

Disclaimer: Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.

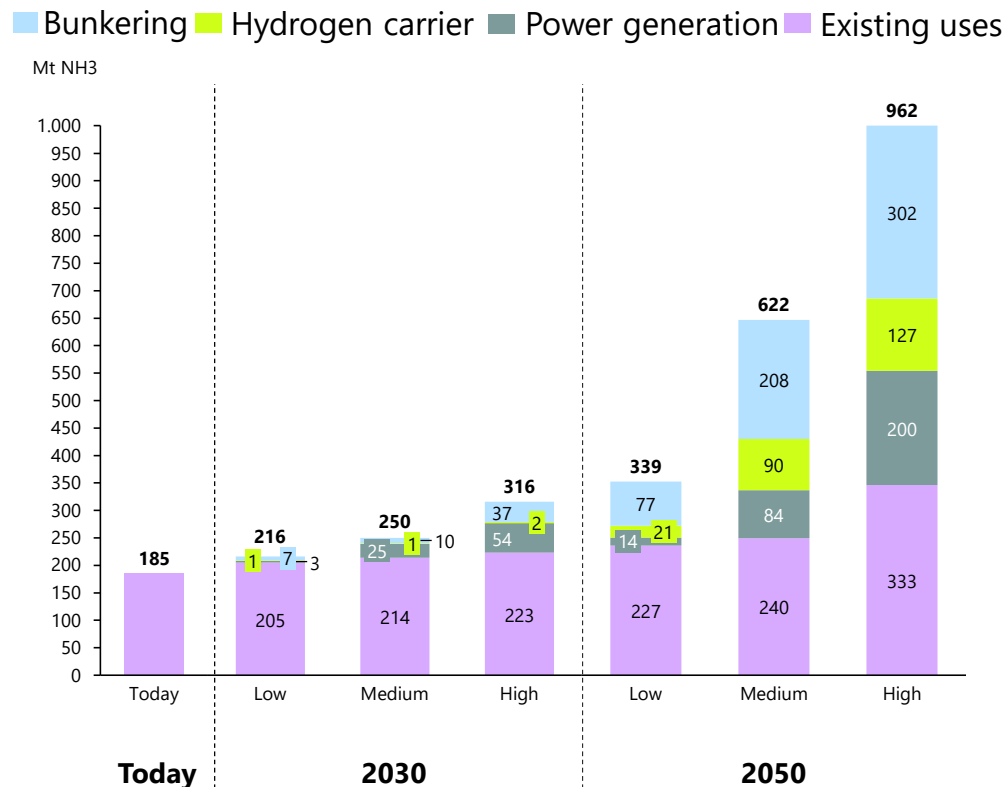
SCENARIOS

Fuel, feed and energycarrier/vector

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SCENARIO FORECAST CLEAN AMMONIA SECTOR DEMAND

NET-ZERO PATHWAYS AFFECT THE MEDIAN/AVERAGE OUTLOOK. TODAY'S 185MTPA TO 216-316MTPA (2030) AND 339-962 MTPA (2050)



2030:

Low-Medium: BAU (business as usual) with some new users. Still **50% trade growth**

High: **BAU, no efficiency gains**

Carrier (IRENA 1.5°C). Significant for **power**. Significant **bunkering** (IEA Net-Zero).

2050:

Low: Existing as 2030. Pessimistic for **power** and **carrier**. High **bunkering** in competition.

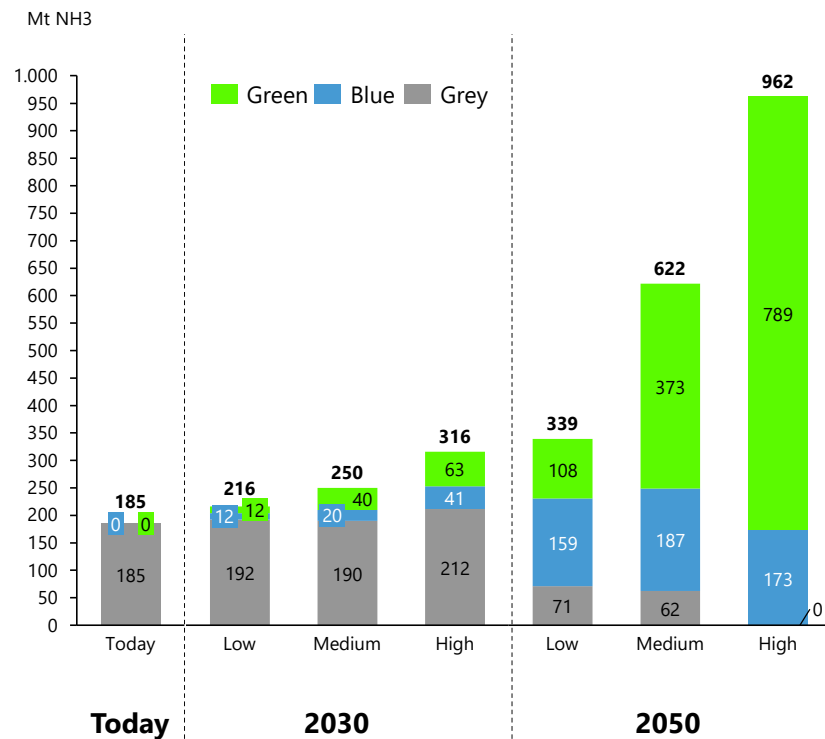
Medium: Existing as for 2030. **Power** (IEA Net-Zero). **Carrier** median. High **bunkering** (average).

High: Existing as 2030.

- Optimistic **Power** (33% of ISPT (600mtpa).
- **Carrier** (IRENA 1.5°C).
- High **bunkering** with ammonia as preferred fuel.

CLEAN AMMONIA PRODUCTION FORECAST

GLOBAL GREEN AMMONIA DEMAND: UNCERTAINTY IN SCENARIOS



Now to 2030

Increase of grey ammonia. Limited blue/green ammonia.

Green ammonia *Low – High*: 12-63 mtpa in 2030.

Low-carbon ammonia *Low – High*: 12-41 mtpa in 2030.

Post-2030

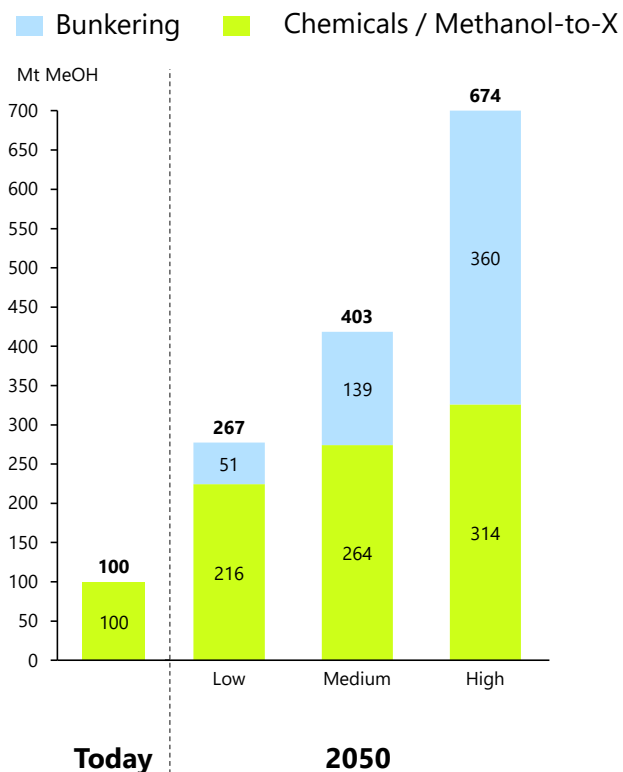
Green/blue ammonia at large-scale by bunkering and power.

Green ammonia *Low – High*: 108-789 mtpa in 2050.

Low-carbon ammonia *Low – High*: 159-187 mtpa in 2050.

METHANOL MARKET FORECAST

DEMAND FOR METHANOL IS EXPECTED TO INCREASE 2 TO 6-FOLD FROM NOW TO 2050



Methanol could grow from 100 mtpa to **267-674 mtpa in 2050**.

More granularity required for Methanol as feedstock

2050:

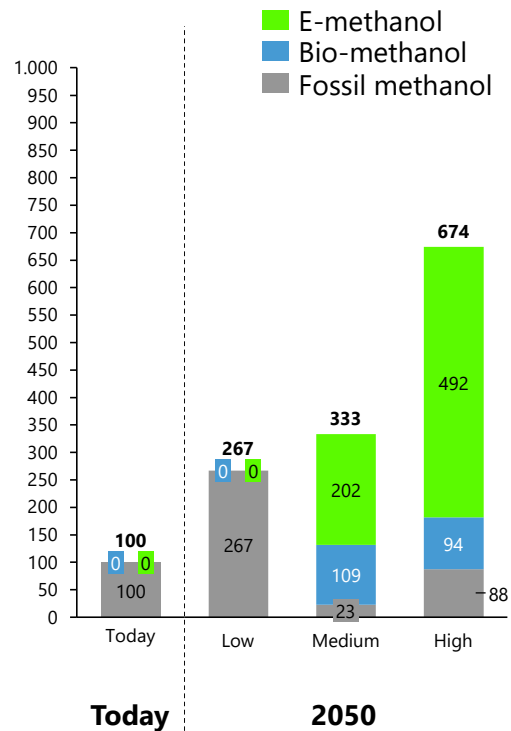
Low: Methanol-to-X increases significantly. Bunkering limited.

Medium: Methanol-to-X increases significantly. Bunkering significant.

High: Methanol-to-X increases significantly. Bunkering significant implementation and challenging ammonia as preferred shipping fuel.

METHANOL MARKET FORECAST

GLOBAL GREEN METHANOL DISPLAYS UNCERTAINTY



2050

e-methanol and bio-methanol will gain traction towards 2030, as bunkering fuel and methanol-to-X feed for circular e-chemicals.

E-methanol supply *Low - High: 0-492 mtpa in 2050.*

LCA and carbon intensity is of essence.

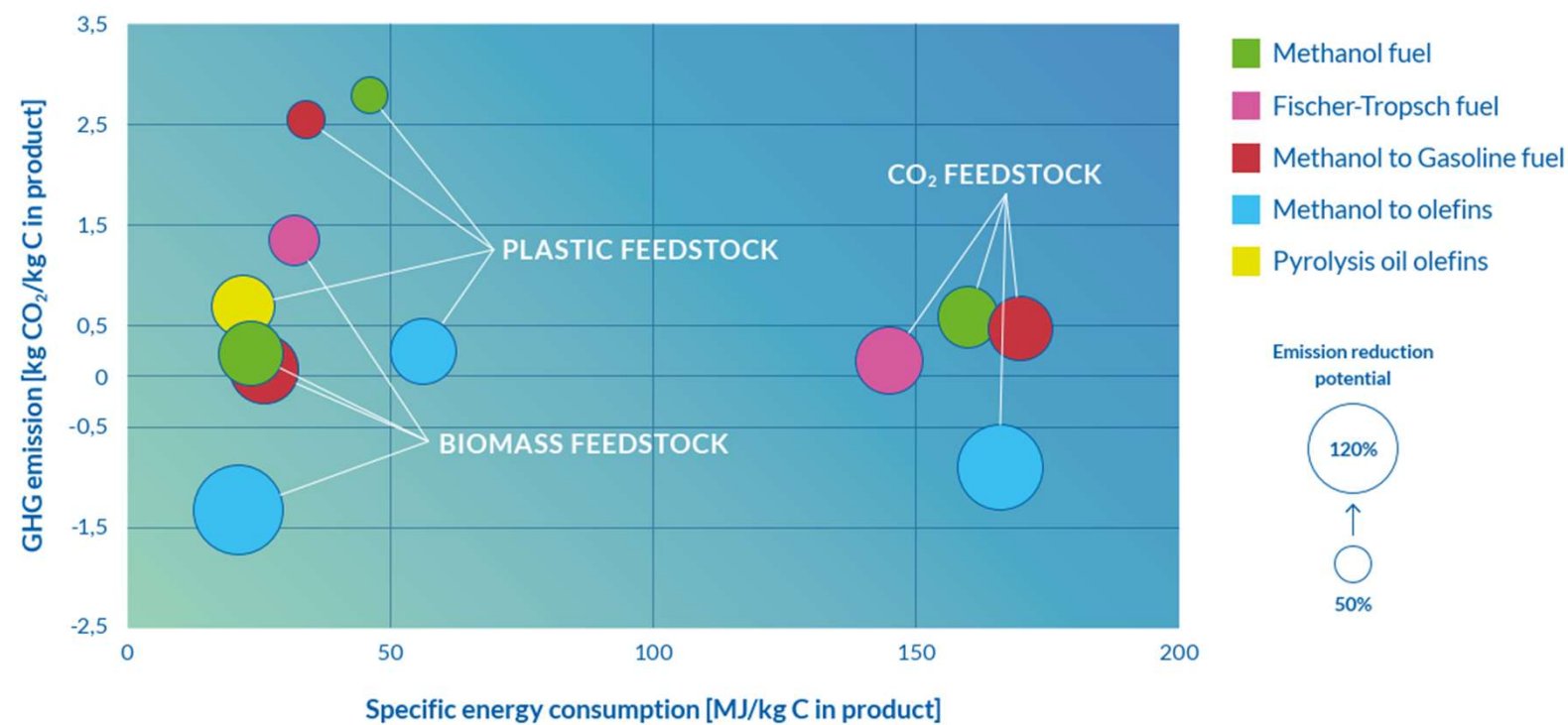
Bio-methanol *Low -Medium: 0 - and 109 mtpa in 2050.*

REALITY CHECK

Carbon based or ammonia?

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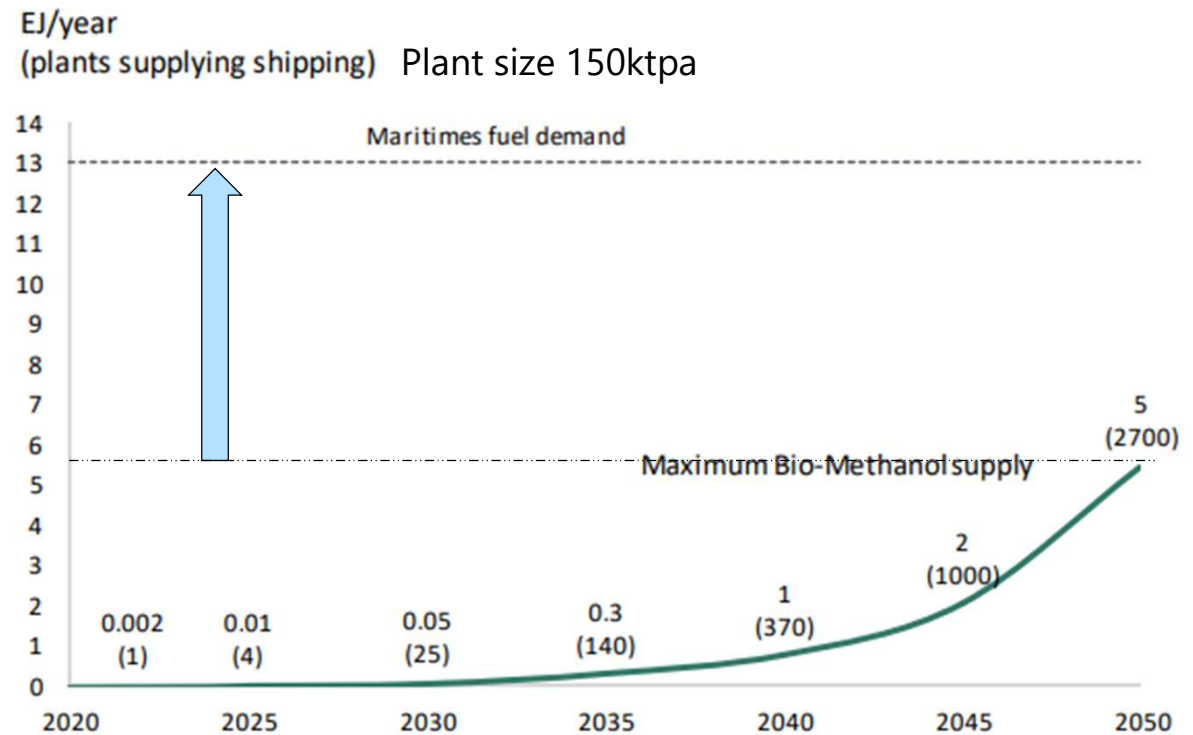
VOLTACHEM (TNO) CIRCULAR CARBON MERIT ORDER
METHANOL-TO-X FEED ROUTES HAVING THE BIGGEST IMPACT



BIOGENIC CARBON AVAILABILITY

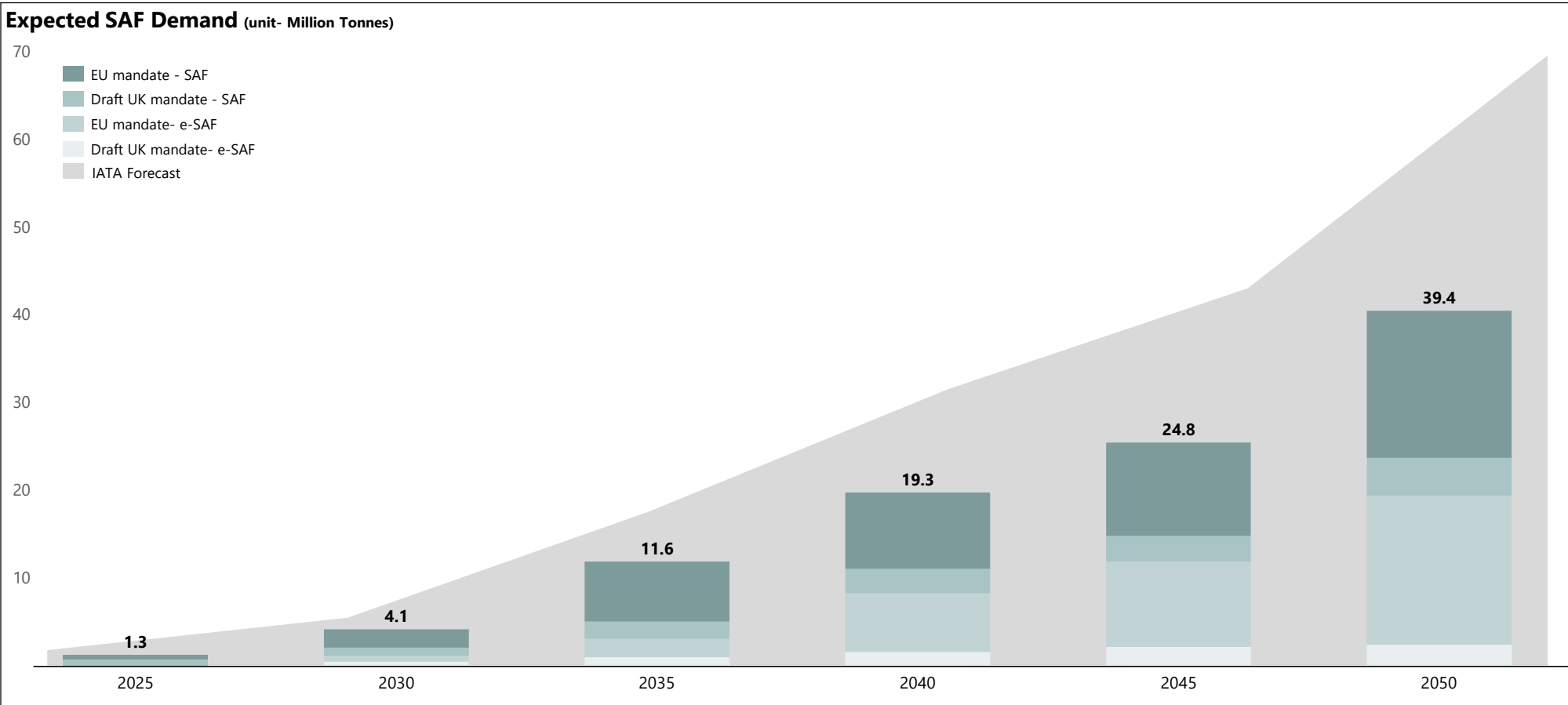
GREEN BIOMETHANOL CANNOT SERVE MARITIME FUEL DEMAND SOLELY

GAP 60-80%*



*upper value when taking CO2 merit order into account, hence other markets like e-SAF or e-chemicals
Max value set at 16% of availability (current shipping consumes 8% of non-electrifiable energy demand)

SAF DEMAND IN EU+ EXPECTED TO BE >4,1MT (2030) AND >39.4MT BY 2050
IATA >75MTPA (2050) GLOBALLY



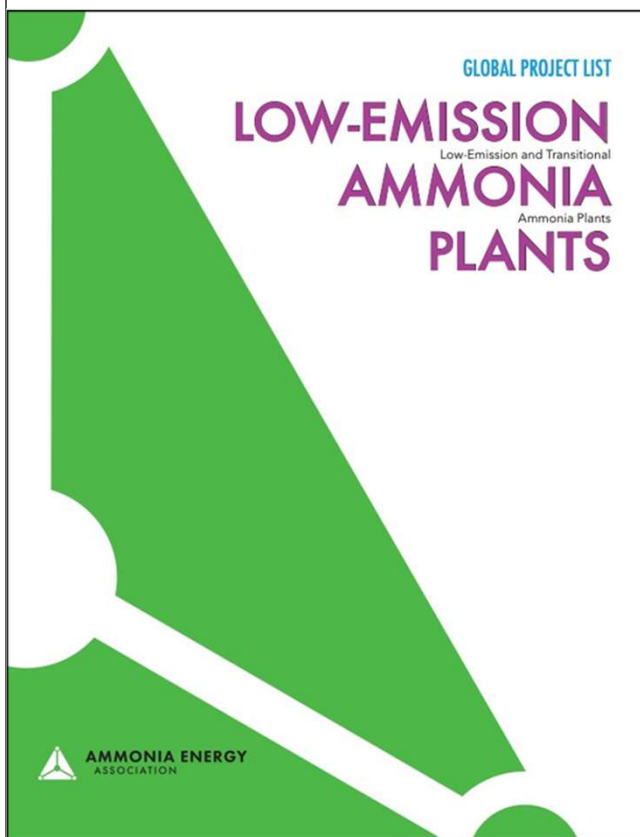
STATUS AMMONIA

Ammonia Energy Association low-carbon projects

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LOW EMISSION AMMONIA PLANTS

AMMONIA ENERGY ASSOCIATION UPDATE 2024



Available to members of the AEA since April 2022,

- December 2022: 103 unique projects
- December 2023: 279 unique projects

The database includes **green, low-carbon and “transitional”** plants.
Transitional meaning byproduct hydrogen or enhanced oil recovery

Projects are categorized according to **hydrogen pathway**:

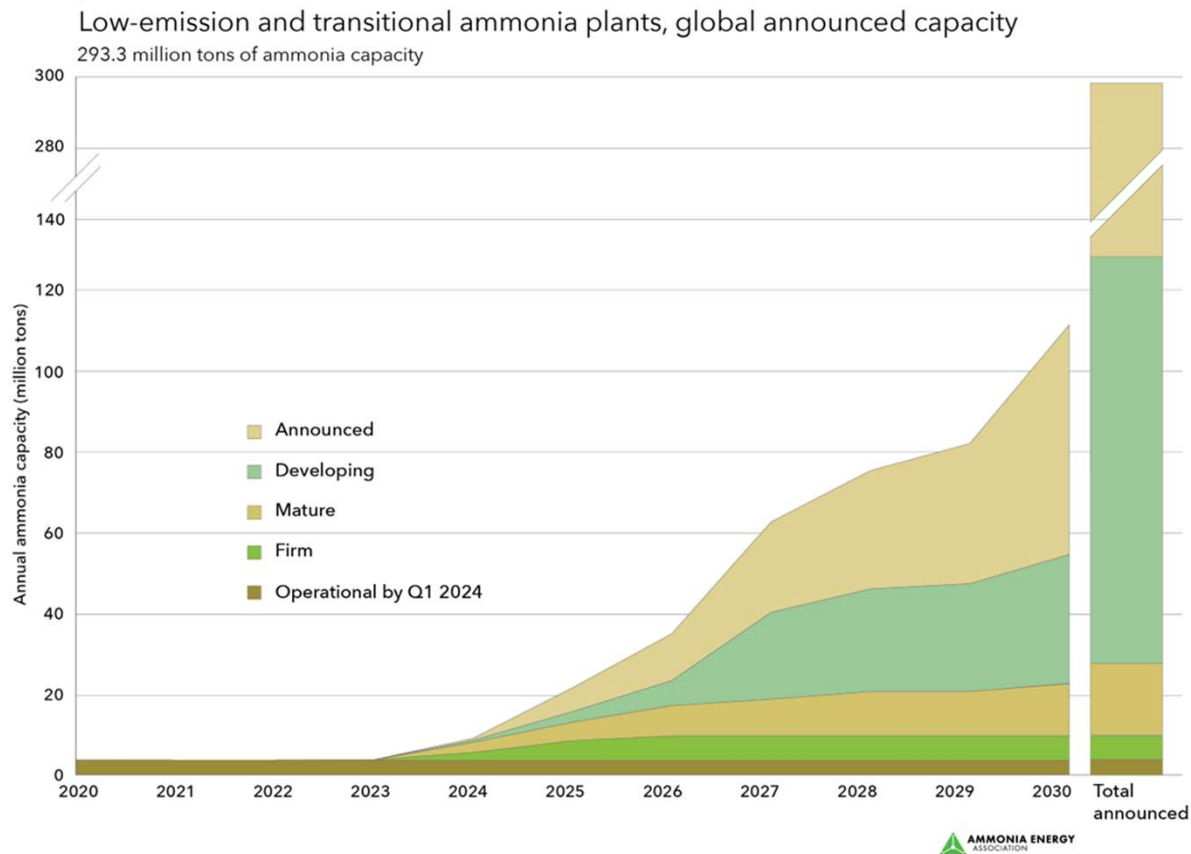
- gas reforming (CCS, CCU, EOR, biogas)
- water electrolysis (renewable, grid, nuclear)
- other (pyrolysis, gasification, electrochemical, byproduct hydrogen, etc)

Projects are categorized according to **completion status**

- FEED ongoing/completed, existing ammonia complex, existing operator (ammonia, chemicals, energy), existing infrastructure, hydrogen technology vendor selected, ammonia licensor selected, plant operator selected, offtaker selected, financing / funding (pre-FID).

LOW-CARBON AND TRANSITIONAL AMMONIA ANNOUNCED CAPACITY 293MTPA

NINE CRITERIA TRANSLATED INTO 5 OBJECTIVE STATUS LEVELS

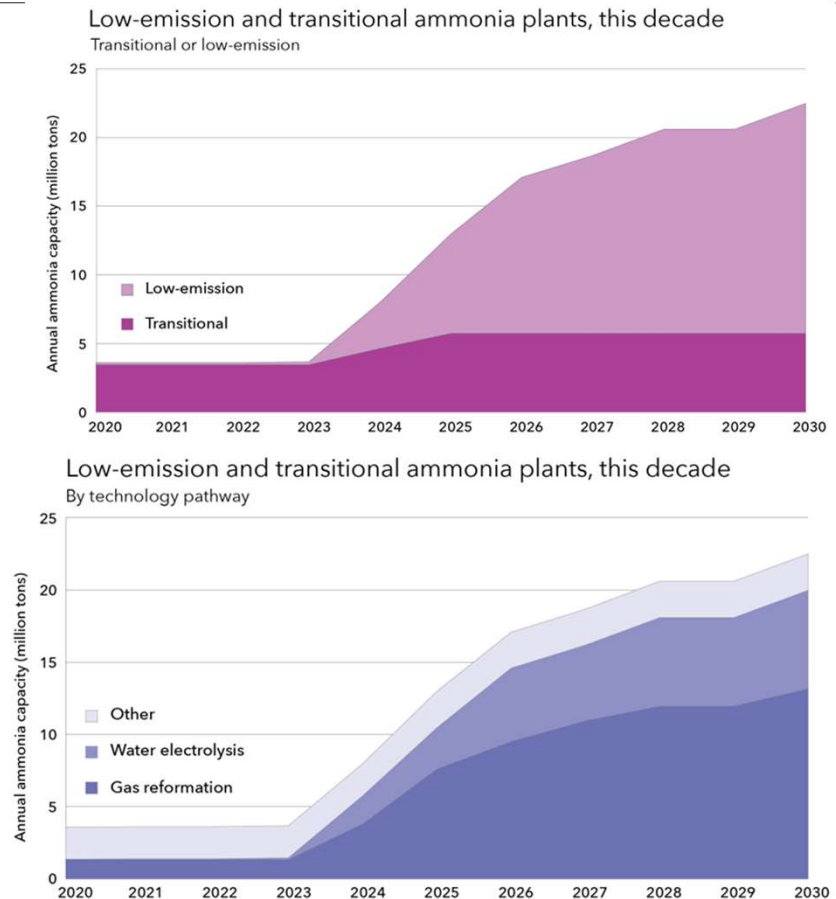


- **Operational:** the plant is operational
- **Firm:** the plant has reached FID or is under construction
- **Mature:** 5+ out of 9 criteria have been met
- **Developing:** 3+ out of 9 criteria met
- **Announced:** 2 or less out of 9 criteria met
- **Defunct:** the plant has closed, or the project is on hold or not ongoing.
- 165MTPA is announced (few public details)
- 100MTPA is making clear progress to FID)
 - of which 31.8 MTPA to start this decade

LOW-CARBON AND TRANSITIONAL AMMONIA ANNOUNCED CAPACITY 22.5MTPA(2030)

13.2MTPA LOW-CARBON AND 6.7MTPA GREEN

- By 2030, expect 22.5 MT to be operational
 - 3.6 MT is Operational (up to Q1 2024)
 - 5.9 MT is Firm (eg, construction / FID)
 - 12.9 MT is Mature (eg, offtake / EPC)
- 3.5 MTPA is transitional and already operational.
 - to increase to 5.8 MTPA (2025).
- 0.2 MTPA is Low-Carbon today
 - rising to 7.2 MTPA (2025) and 16.7 MTPA (2030)
 - Of which 13.2MTPA low-carbon
- Electrolysis projects start operating at scale in 2024-2026 and reach 6.8 MTPA capacity in 2030



Plants by region

Operational, Firm, and Mature projects:

- mostly in developed economies, at existing plants serving existing markets – with some notable first-mover offtakes into energy markets,
- but also new capacity, especially in China, Indonesia, Chile, and West Asia (Middle East).

Developing projects:

- overwhelmingly in Australia, Egypt, Oman, Saudi Arabia, and the United States (82% of capacity), largely focused on export markets,
- important domestic markets also visible, especially in Morocco, Norway, and India.

Announced projects may suggest long-term view:

- Latin America, Africa, South Asia, and Oceania dominate the pipeline (80% of capacity).
- Clear challenges for de-risking investments.

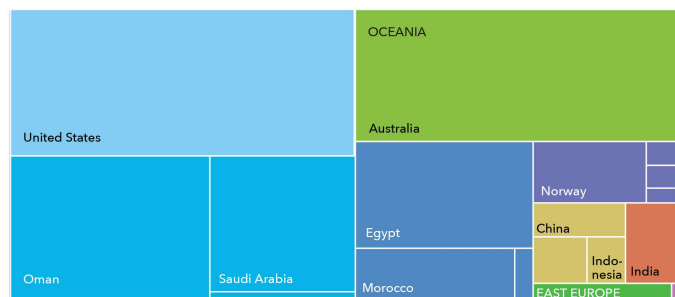
Low-emission and transitional ammonia plants

By location

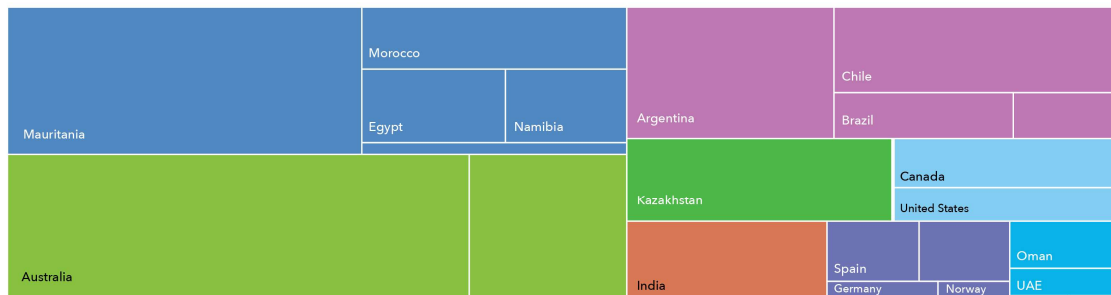
Operational, Firm, Mature
28.0 million tons



Developing
100.4 million tons



Announced
165 million tons



AMMONIA ENERGY
ASSOCIATION

North America

Latin America

West Europe

East Europe and Central Asia

West Asia

Africa

South Asia

East Asia

Oceania

Plants by Technology

Operational, Firm, and Mature projects:

- Dominated by fossil pathways, including CCS, EOR, byproduct hydrogen, methane pyrolysis, much of which is Transitional.
- First-mover electrolysis projects use many inputs, including nuclear, grid, and unspecified renewables.

Developing projects:

- Gas reformation pipeline dominated by CCS.
- Water electrolysis pipeline dominated by solar+wind combination, with hydro and others.

Announced projects:

- Water electrolysis dominates long-term pipeline.
- Challenges for de-risking technologies may be overcome by first-mover projects. Firm demand required to support such scale-up of supply.

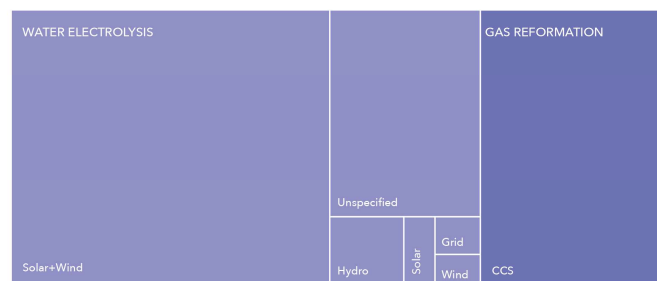
Low-emission and transitional ammonia plants

By technology

Operational
28.0 million tons



Developing
100.4 million tons



Announced
165.0 million tons



CURRENT PROJECTS ARE JUST A START

SMART CHOICES IN FUEL

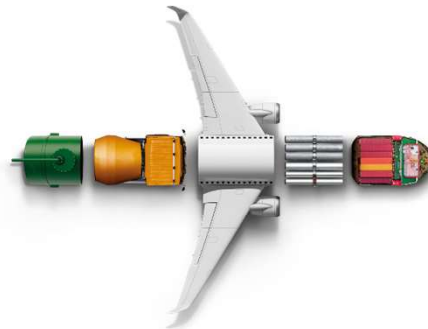
#LETSDOTHEHARDPART

Technology is ready

Infrastructure is maturing

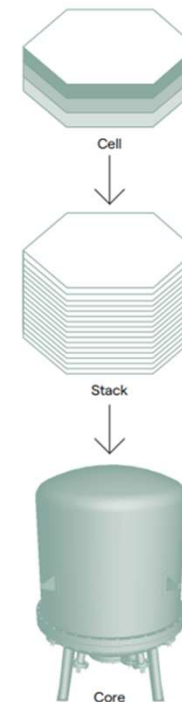
Regulation is getting clearer

Value chain de-risking is lacking



#LETSDECARBONIZE

SOEC CELL, STACK AND CORE



CONNECT THE WORLD WITH CLEAN ENERGY
OUR INDUSTRY IS WELL POSITIONED



**GROW GREEN
HYDROGEN AND E-
DERIVATIVES**

**ASSIST WITH LOW-
CARBON HYDROGEN
IN THE TRANSITION**

**OPTIMISE SCARCE
BIOGENIC CARBON**

THANK YOU,

Do you see the ammonia opportunities?

TOPSOE



Rob Stevens

Sector Lead Green Fuels

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