Using G2M2 to Model Hydrogen and Ammonia in Natural Gas Markets

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Energy Market Simulation Systems

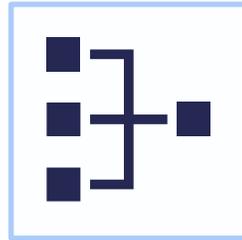**Robert Brooks, RBAC, Inc.**

NING LIN, RBAC, Inc.

Dongmei Chen, KAPSARC
Giovanni Bettinelli, GFB Insights

Modeling Motive

Collaborating among multiple organizations on data inputs and modeling framework

Leveraging the existing natural gas network modeling system (G2M2)

**Will that be a realistic way to add hydrogen and ammonia as parallel value chains?**

1. **USAEE 2024, Baton Rouge: only incorporating hydrogen with the natural gas network, in the regional market (US or Europe)**
2. **IAEE 2025, Paris: incorporating hydrogen and ammonia for regional markets in a global setting, allowing regional trades.**

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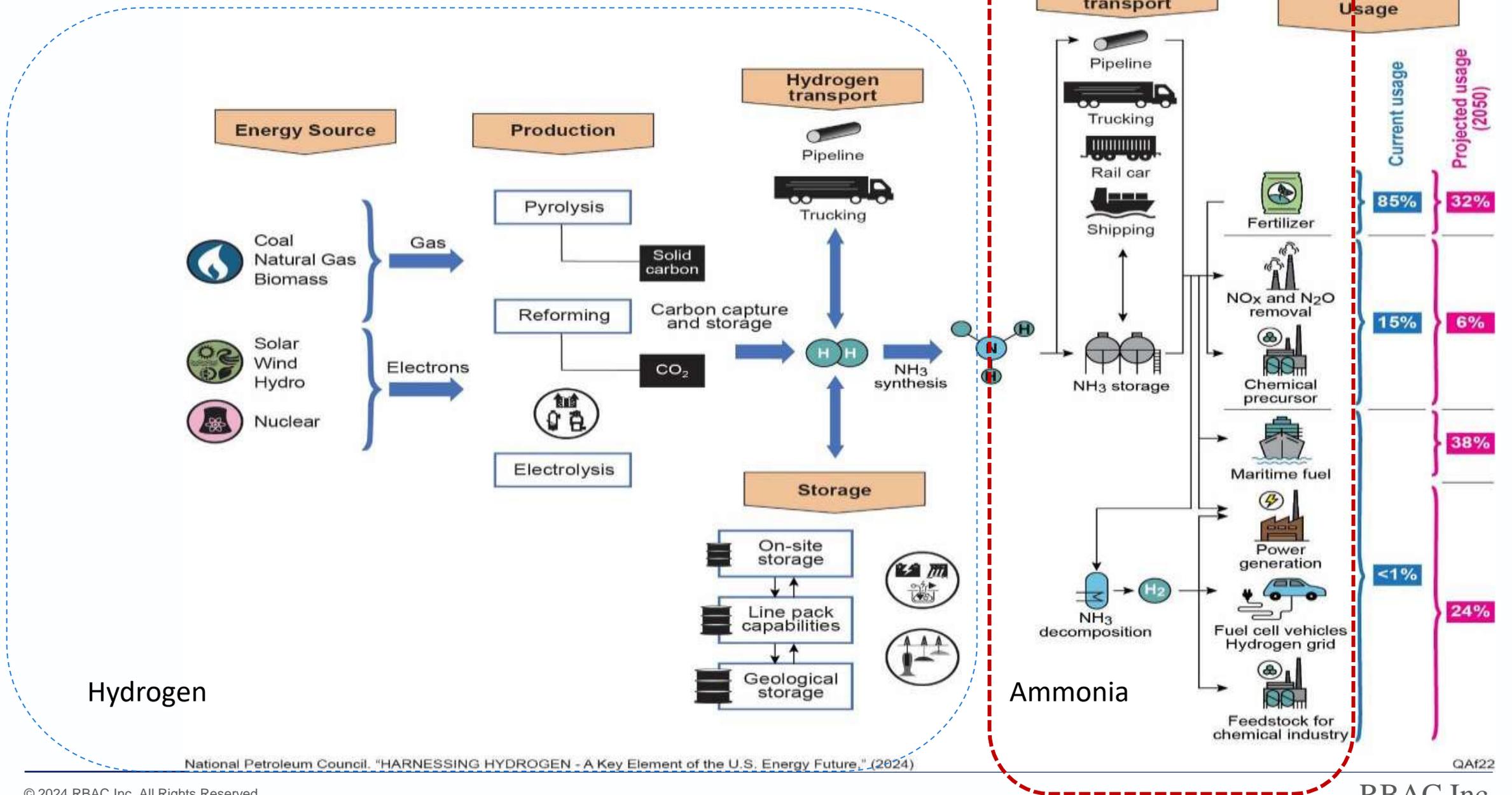
National Petroleum Council. "HARNESSING HYDROGEN - A Key Element of the U.S. Energy Future." (2024)
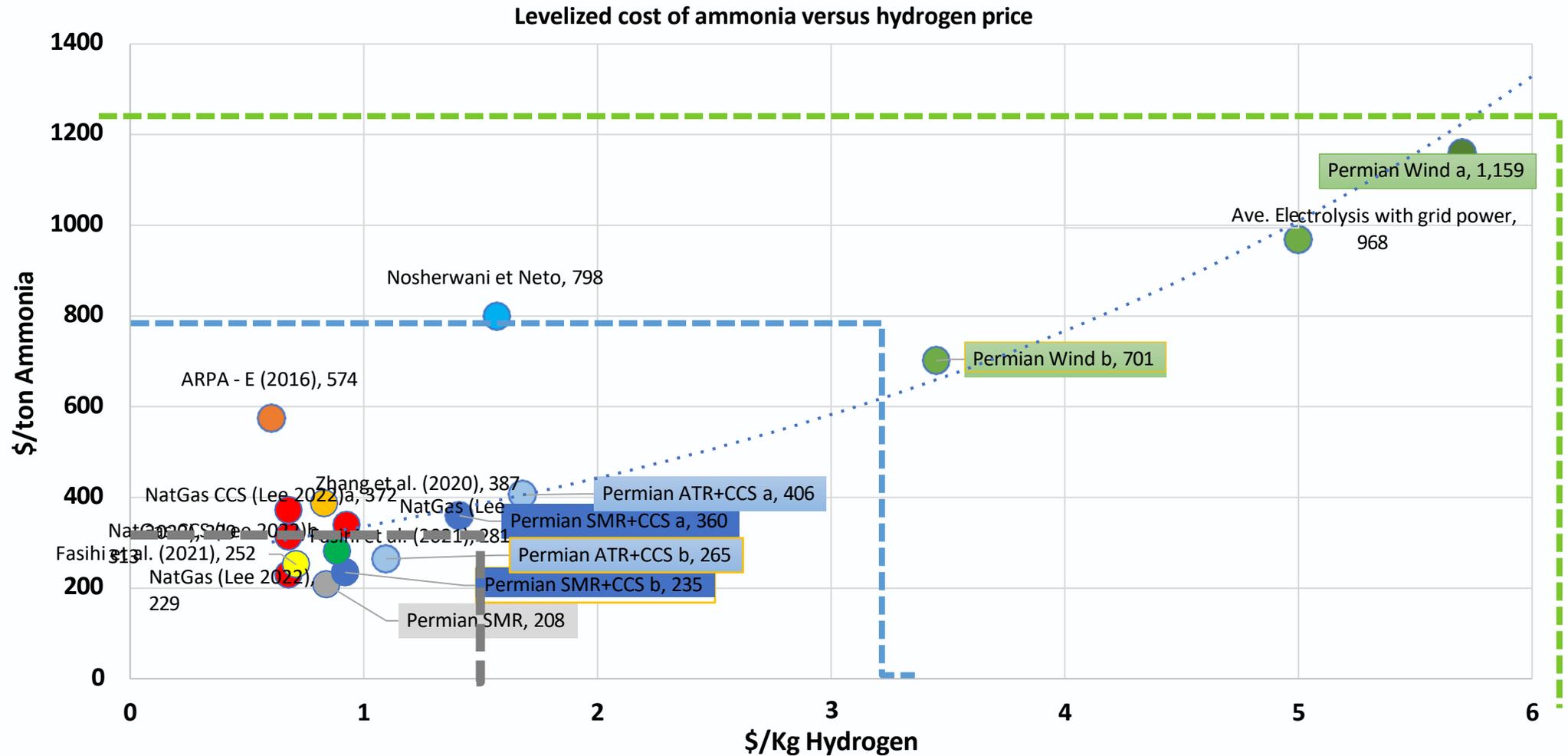
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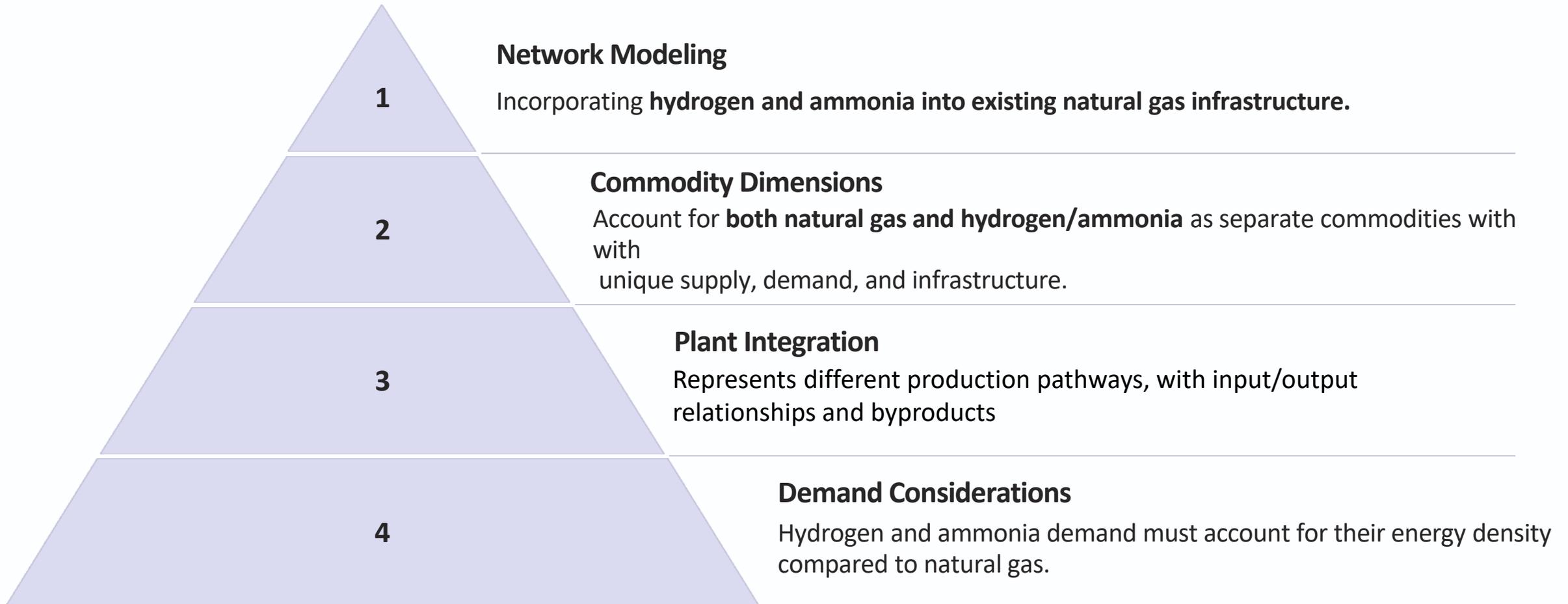# Forecasted Demand of Ammonia
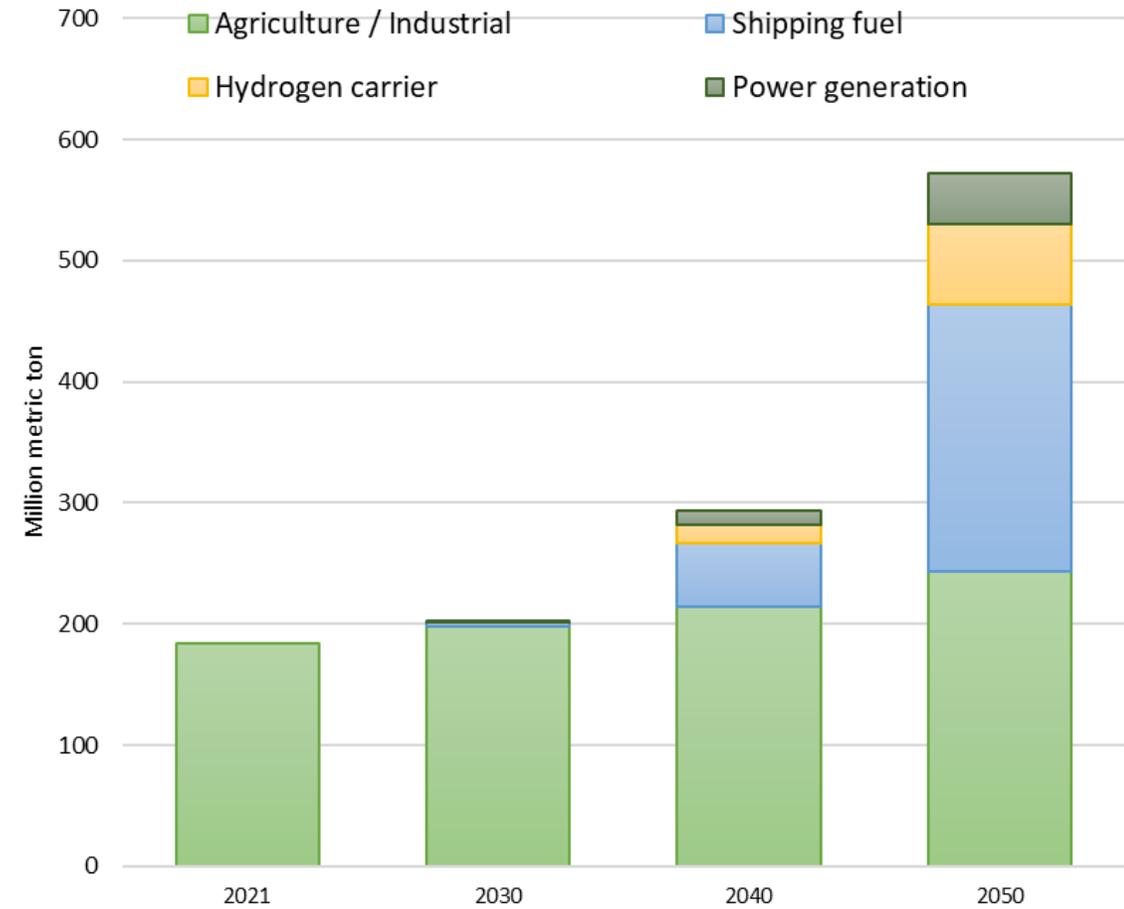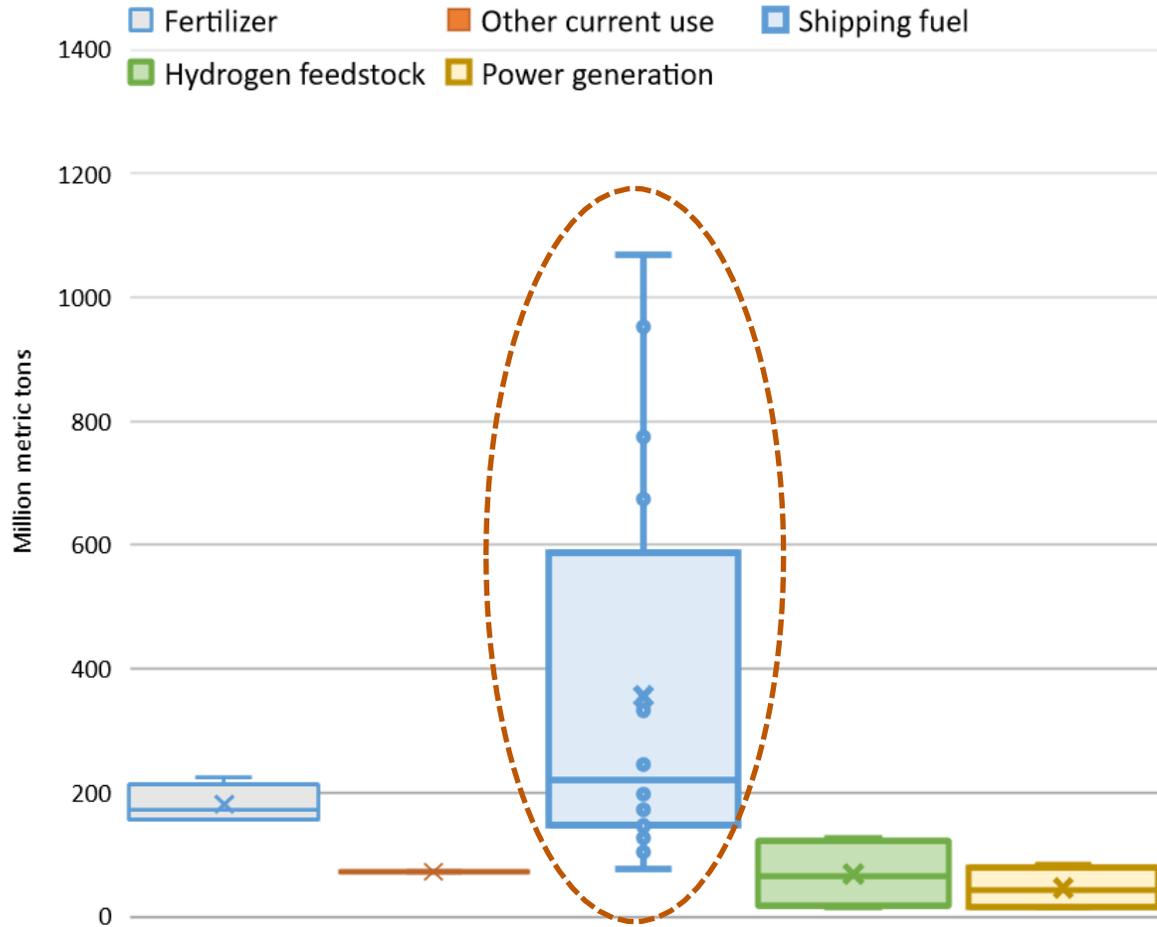
Although energy applications will drive growth, the potential for new demand remains highly conditional and uncertain.

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Levelized cost of ammonia vs. hydrogen as feedstock

Levelized cost of ammonia versus hydrogen price

Low-carbon ammonia holds a significant premium over conventional alternatives.

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Integrate H2/NH3 in Natural Gas Pipeline Networks

1 **Network Modeling**

Incorporating **hydrogen and ammonia into existing natural gas infrastructure.**

2 **Commodity Dimensions**

Account for **both natural gas and hydrogen/ammonia** as separate commodities with with
unique supply, demand, and infrastructure.

3 **Plant Integration**

Represents different production pathways, with input/output relationships and byproducts

4 **Demand Considerations**

Hydrogen and ammonia demand must account for their energy density compared to natural gas.
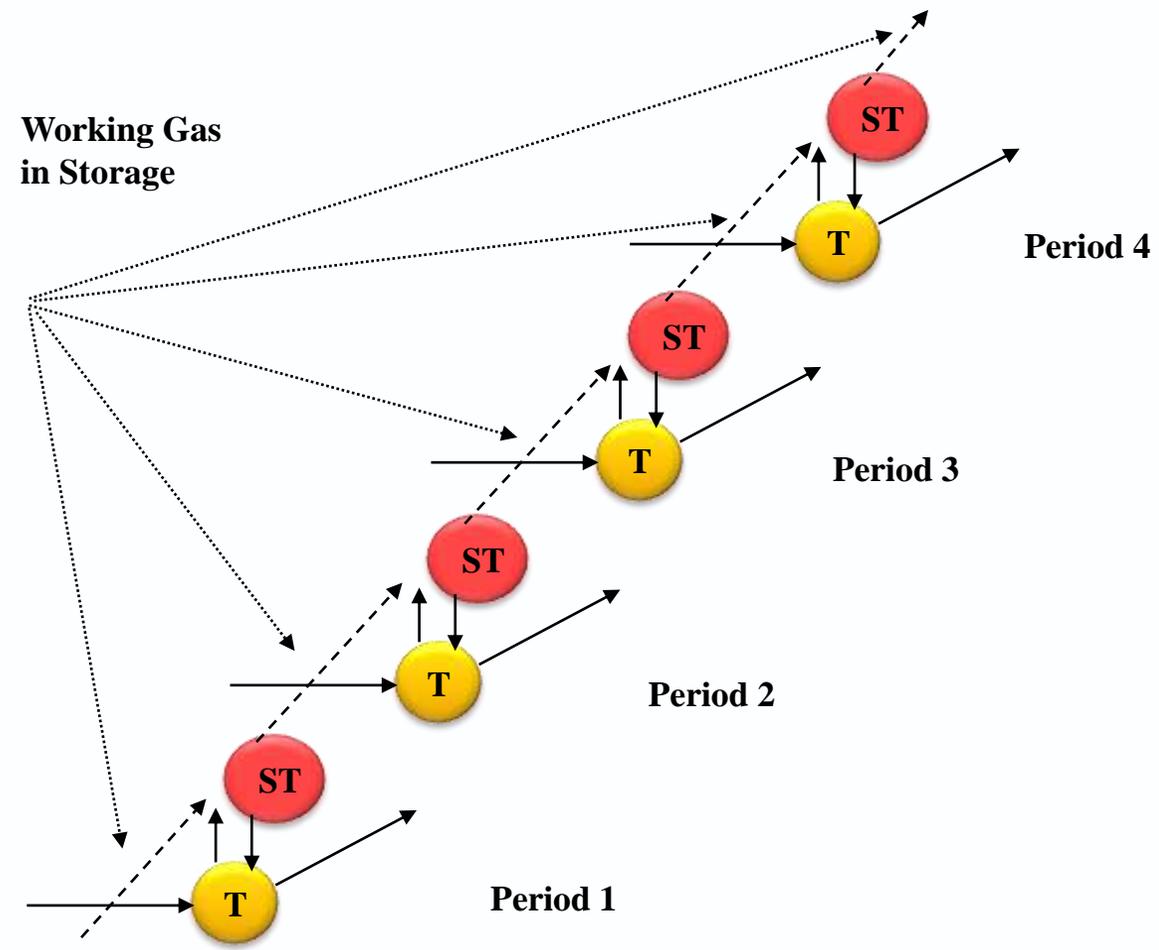
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Network Flow Model

- A partial equilibrium model for a single commodity, i.e., Natural Gas.

- Concepts of Node and Arc models

- Multi-period modeling linked by storage, price-dependent supply, and demand

- Market-clearing conditions and transportation constraints.

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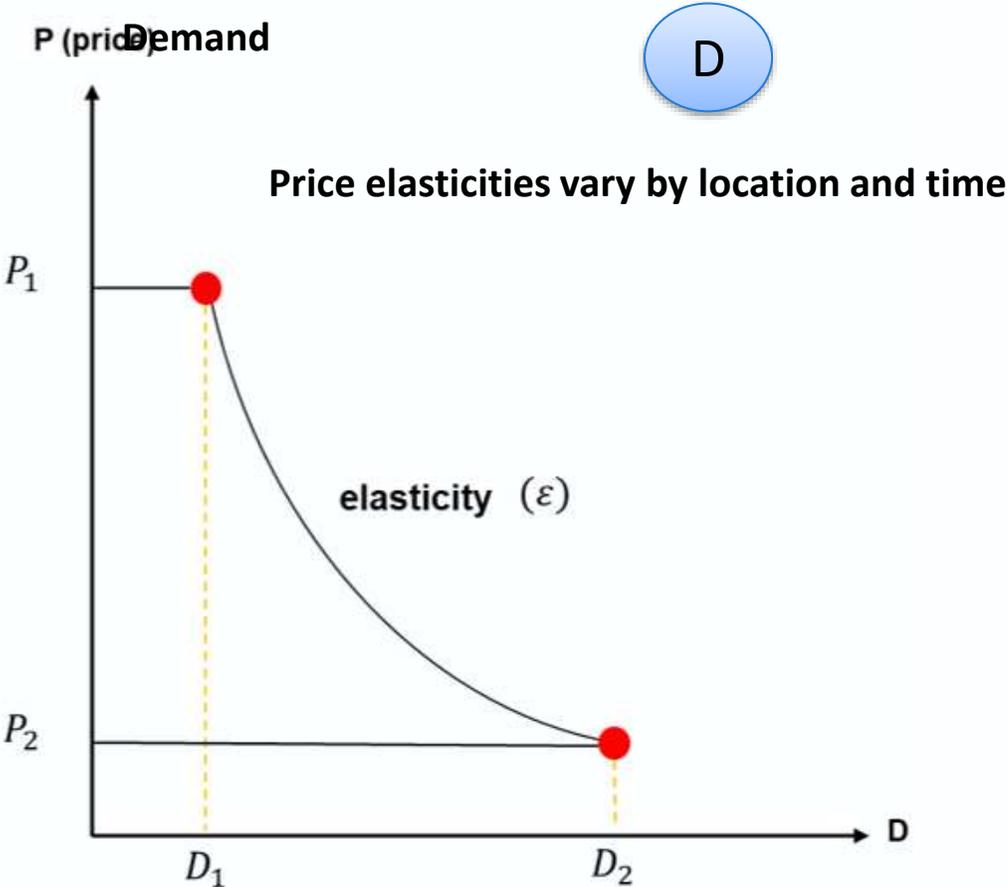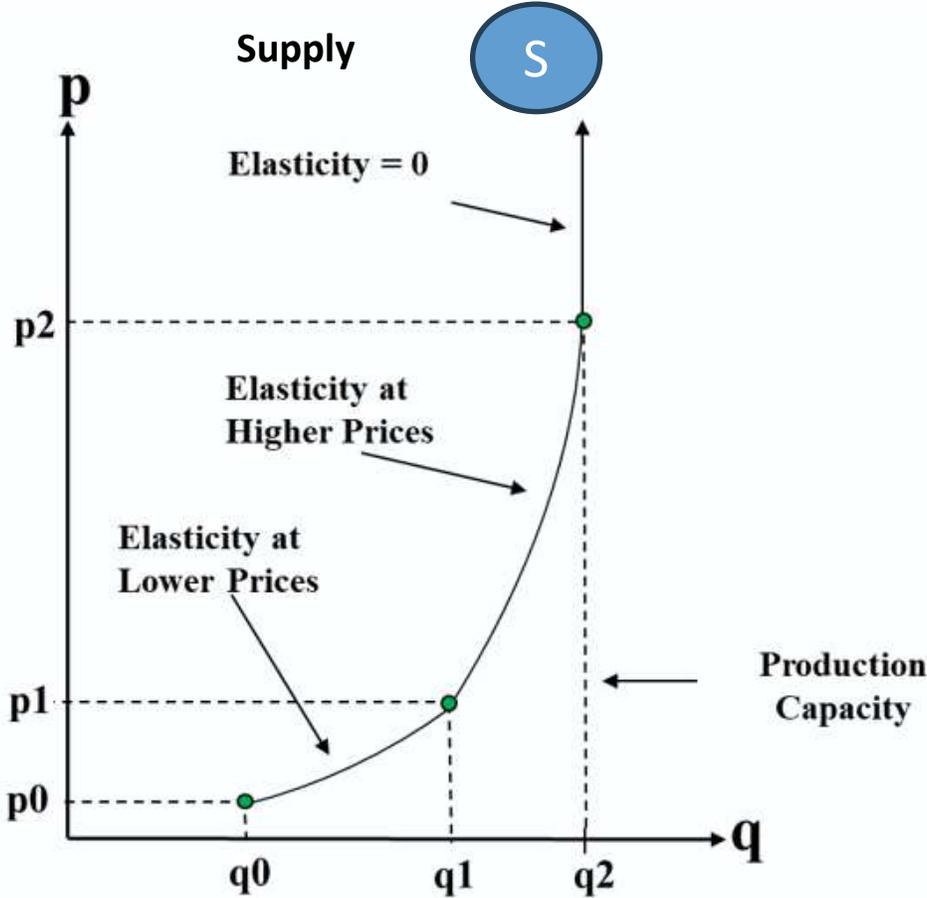
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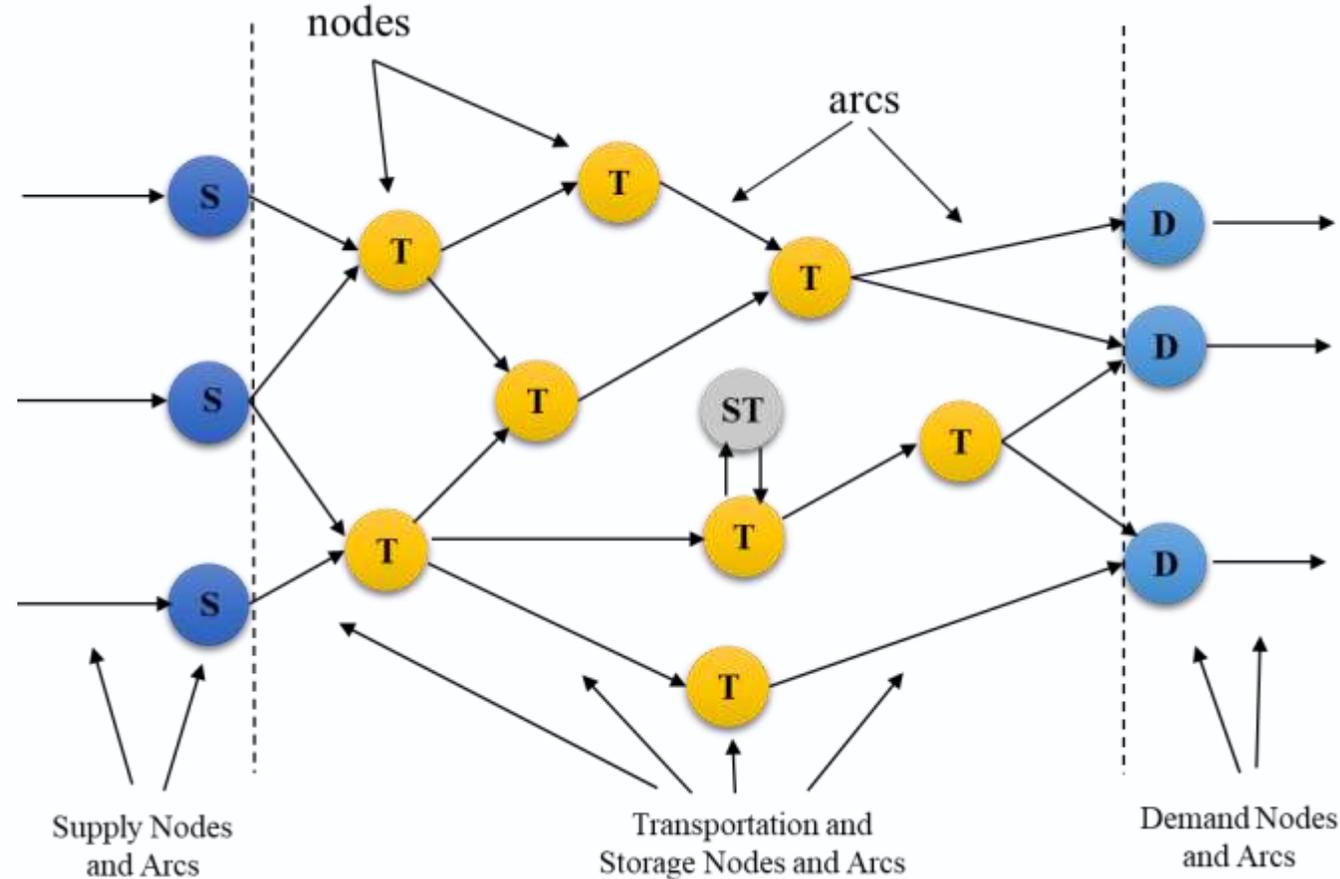
Network Model – Multiple Periods – Linked by Storage

- A partial equilibrium model for a single commodity, i.e., Natural Gas.

- Concepts of Node and Arc models

- Multi-period modeling linked by storage, price-dependent supply, and demand

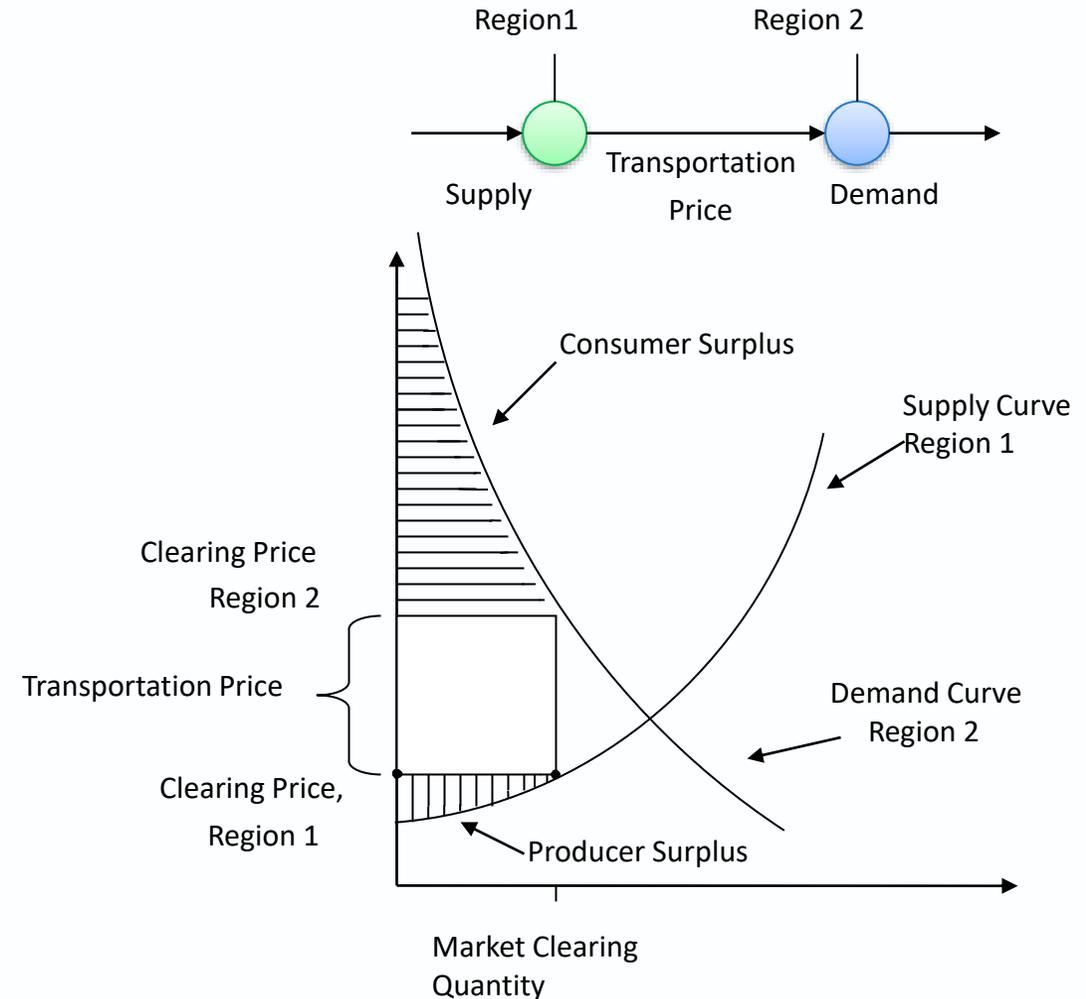- Market-clearing conditions and transportation constraints.

Working Gas in Storage

ST

T

Period 4

ST

T

Period 3

ST

T

Period 2

ST

T

Period 1

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Price Dependent Supply and Demand Models

Supply

S

p

Elasticity = 0

p2

Elasticity at
Higher Prices

Elasticity at
Lower Prices

Production
Capacity

p1

p0

q

q0   q1   q2

Demand

P (price)

D

Price elasticities vary by location and time

P_1

elasticity (ε)

P_2

D_1 D_2

D

Spatial Equilibrium

- A partial equilibrium model for a single commodity, i.e., Natural Gas.

- Concepts of Node and Arc models

- Multi-period modeling linked by storage, price-dependent supply, and demand

- Market-clearing conditions and transportation constraints.

Region1   Region 2

Supply   Transportation Price   Demand

Consumer Surplus

Supply Curve Region 1

Clearing Price Region 2

Transportation Price

Demand Curve Region 2

Clearing Price, Region 1

Producer Surplus

Market Clearing Quantity

This chart shows the market clearing condition when supply is produced at a different location than demand and must be transported to the demand area to be consumed.

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# Spatial Equilibrium with Constrained Transportation
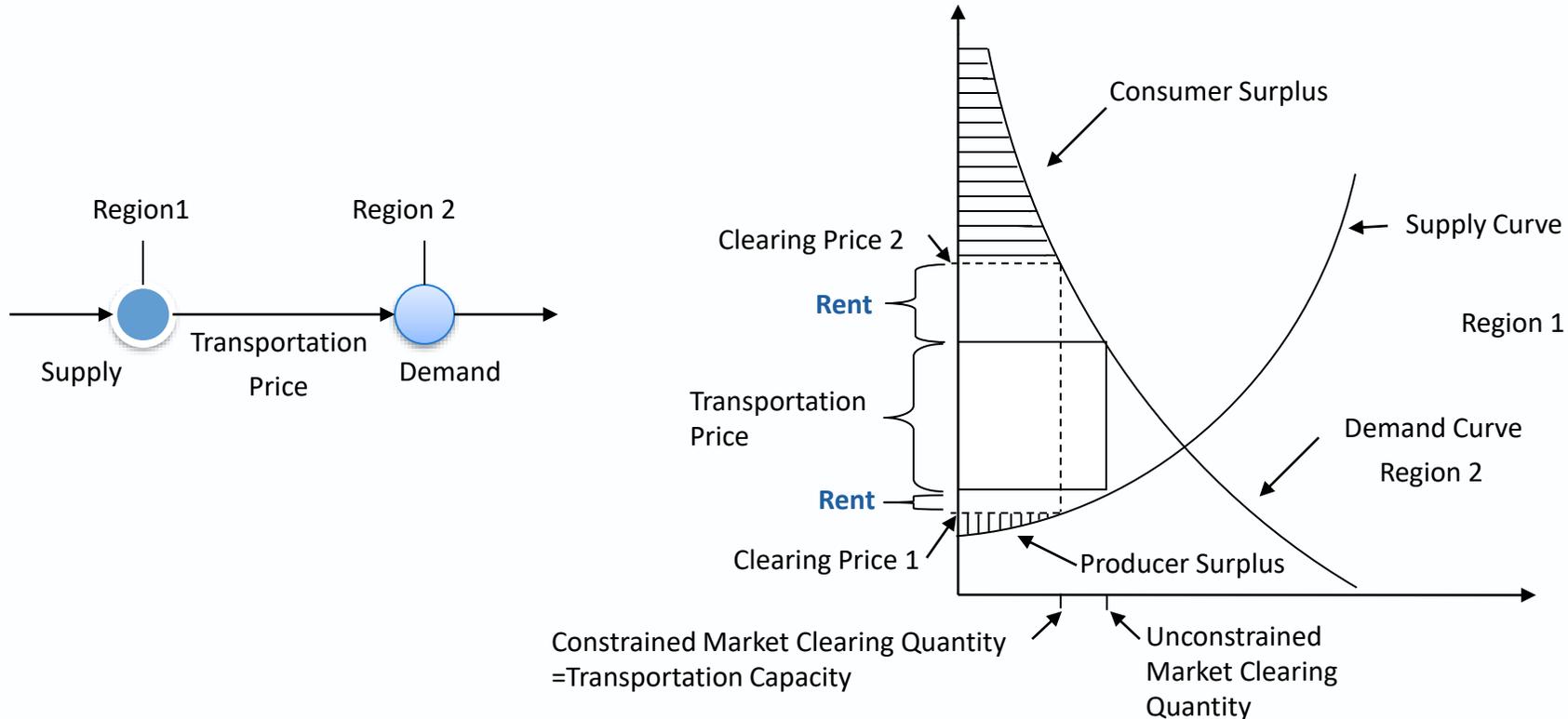
Transportation constraints raise prices in delivery areas, reduce prices in supply areas, and lower both consumer and producer surplus. Rent can be quantified to justify the infrastructure options.
This is relevant for Hydrogen and Ammonia, when there is insufficient infrastructure at the beginning of the scenarios.

Supply / Demand Area Model
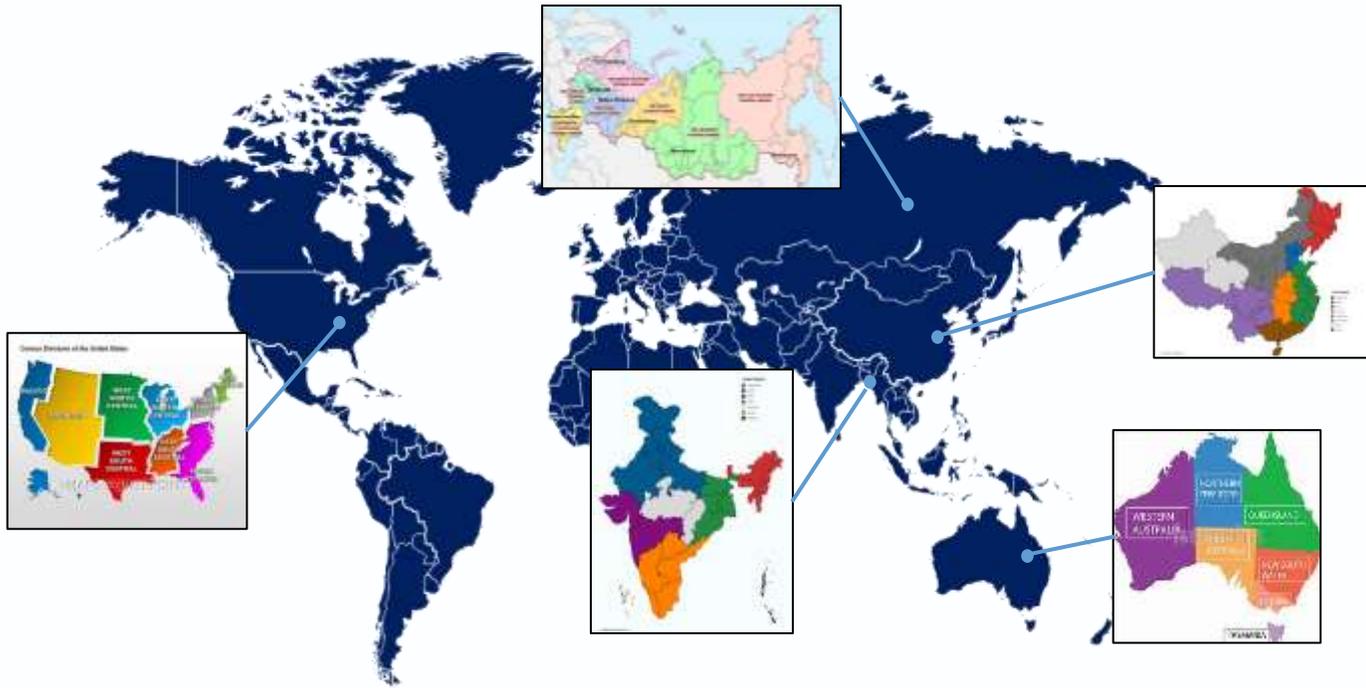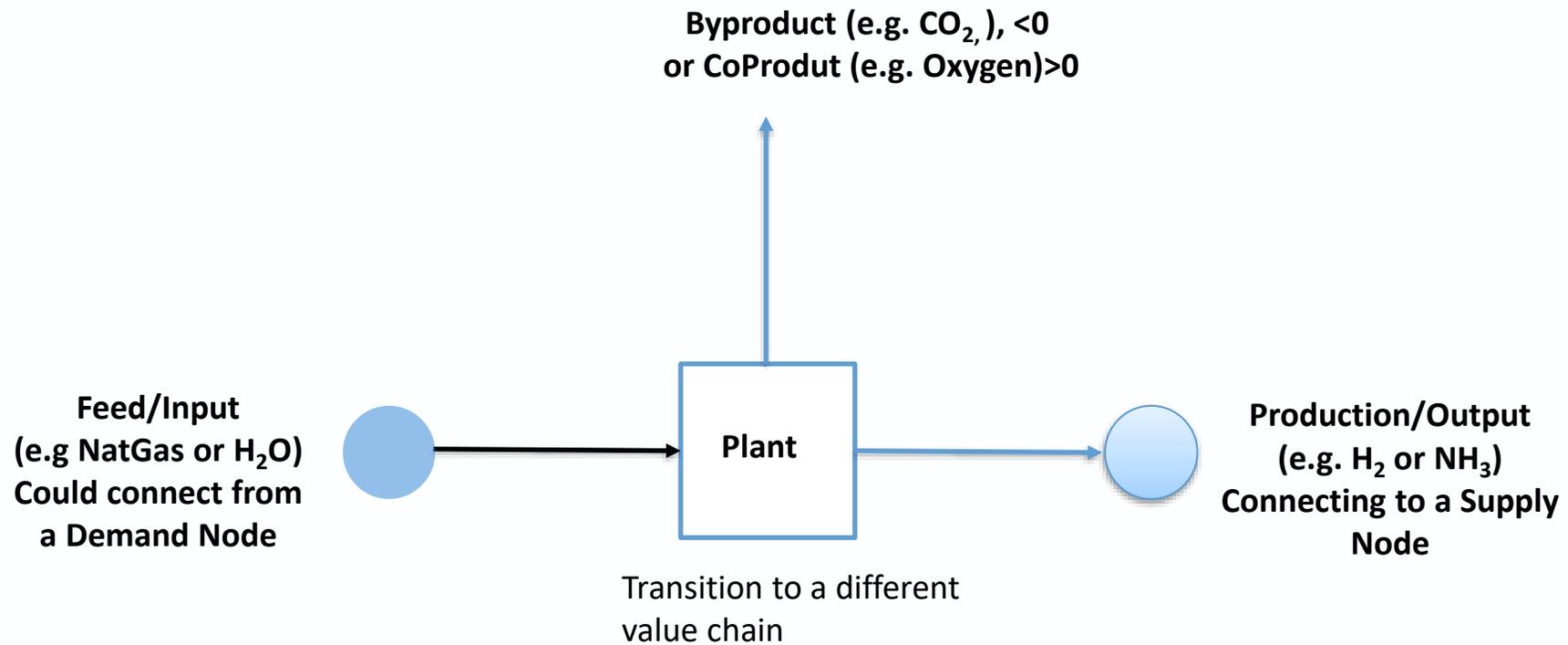# GPU = Geo-Political Unit (Country or Sub-Country Area)
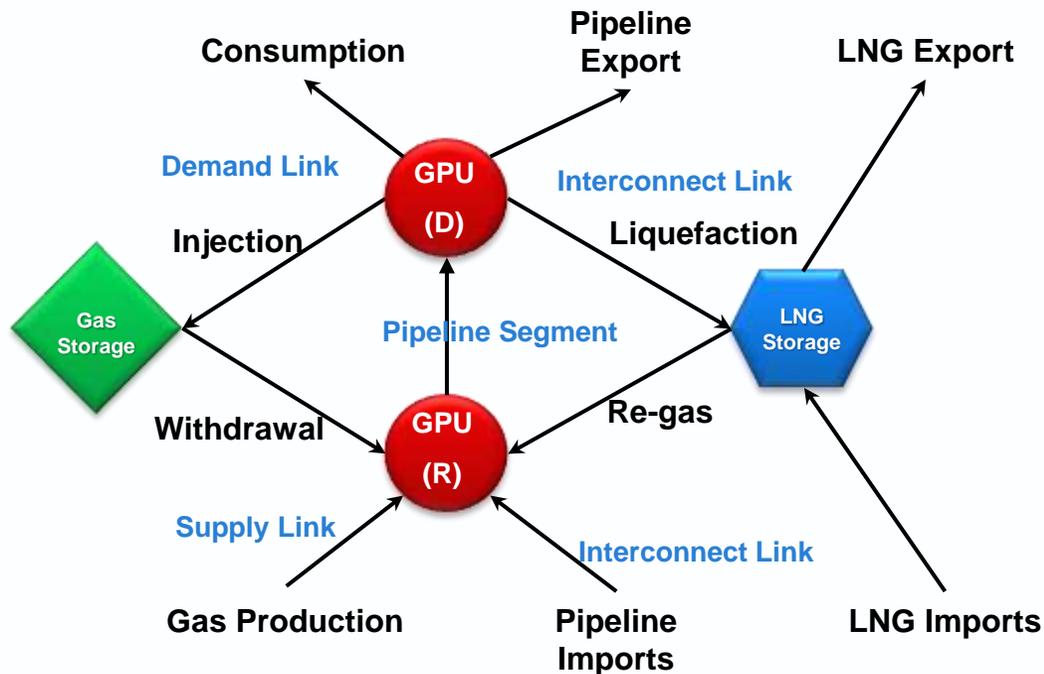
- **Each GPU may have production, consumption, storage, pipeline imports and/or exports, and LNG imports or exports.**

- **GPU's character can evolve over time.**

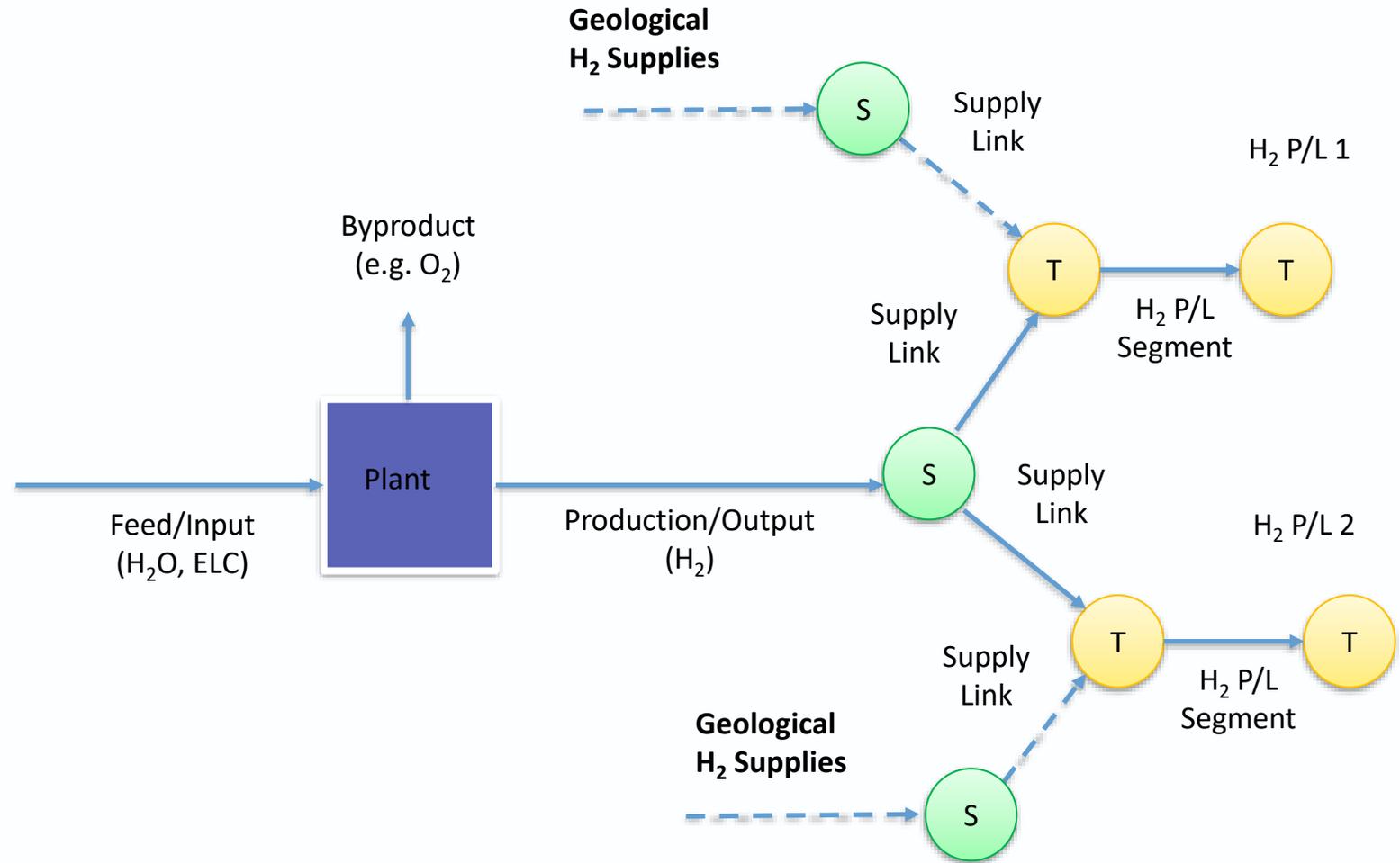# G2M2 capabilities works for H2 and NH3

- Global coverage: a ==good starting point for adding hydrogen and ammonia value chain, given it has some similar infrastructure that hydrogen would leverage==.

- Monthly resolution to 2050.

- Sector-level demand by region.

- Contracts, terminals, tankers, pipelines.

- CO_2 pricing and renewable gas.
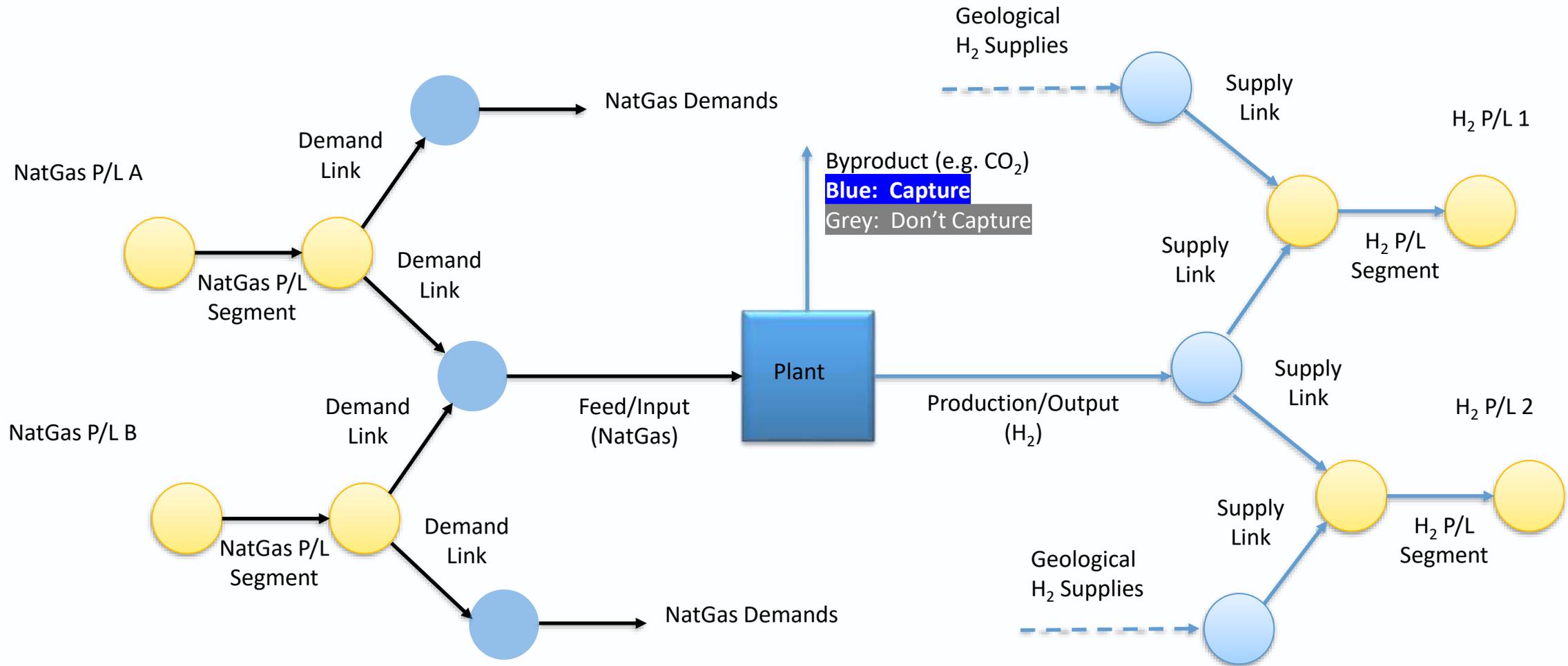
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Production Plant Object for H2 or NH3

Byproduct (e.g. CO_2,), <0
or CoProdut (e.g. Oxygen)>0

Feed/Input
(e.g NatGas or H_2O)
Could connect from
a Demand Node

Plant

Transition to a different
value chain

Production/Output
(e.g. H_2 or NH_3)
Connecting to a Supply
Node

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Production Plant Input/Output Pipelines Green Hydrogen
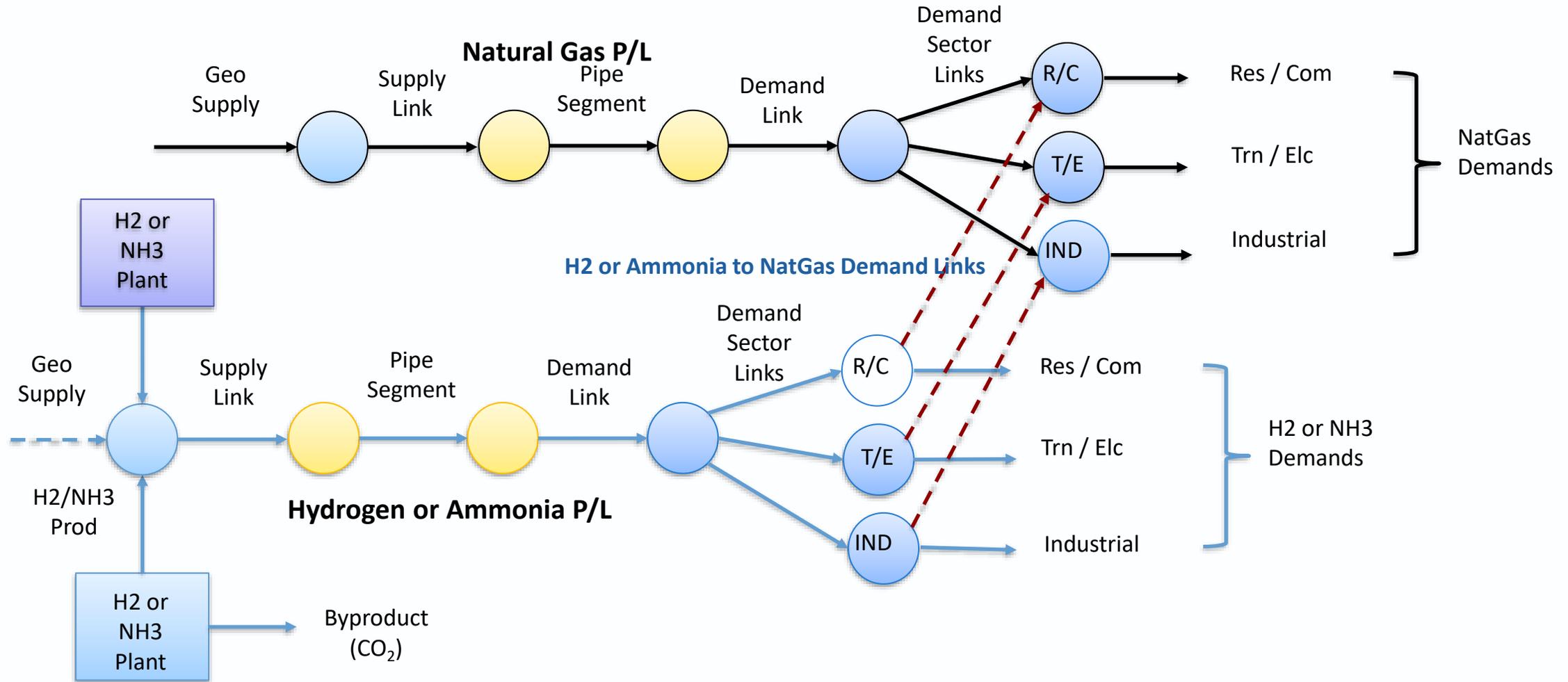
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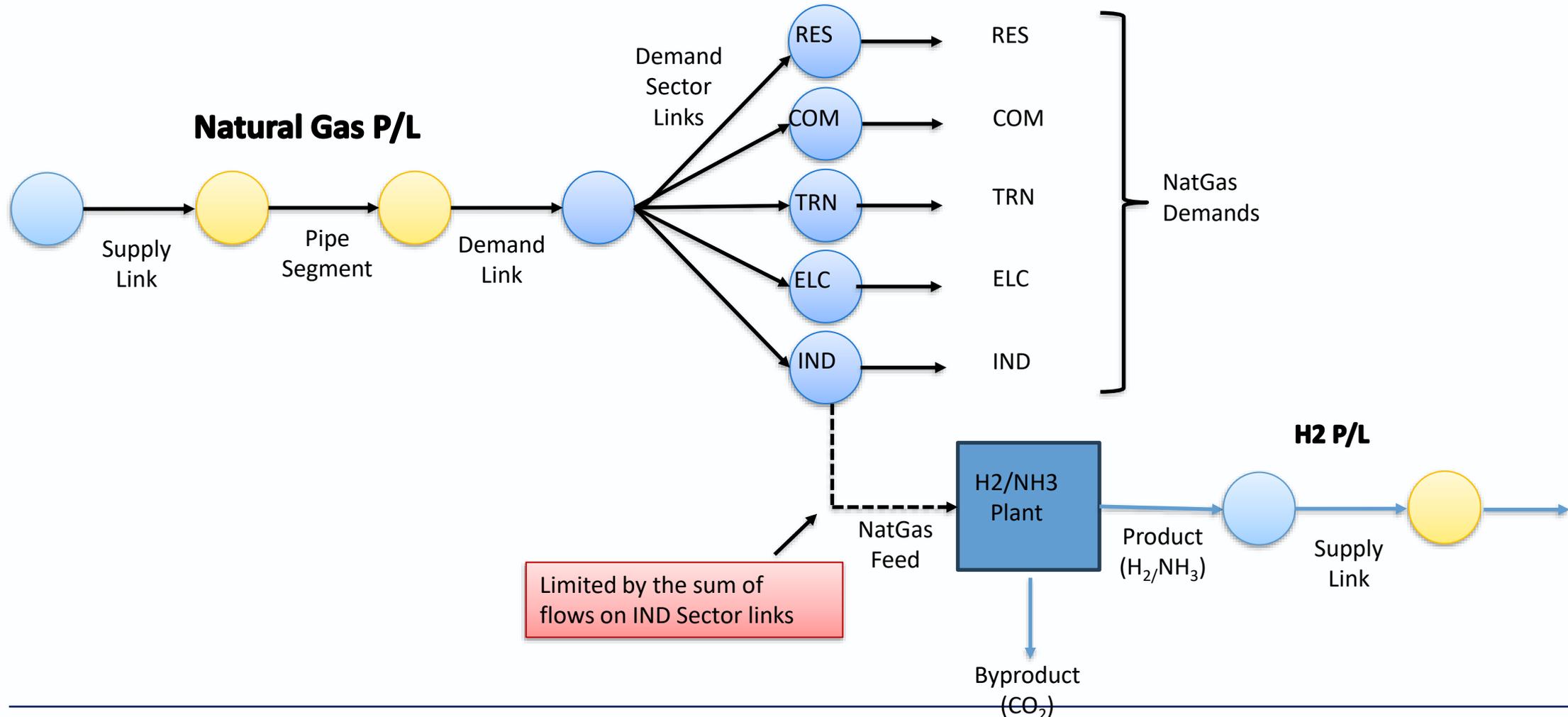
NH3 Production and Transport to NH3 Markets and to NH3 Cracker to H2 Markets

## Nat Gas to ammonia is modeled directly

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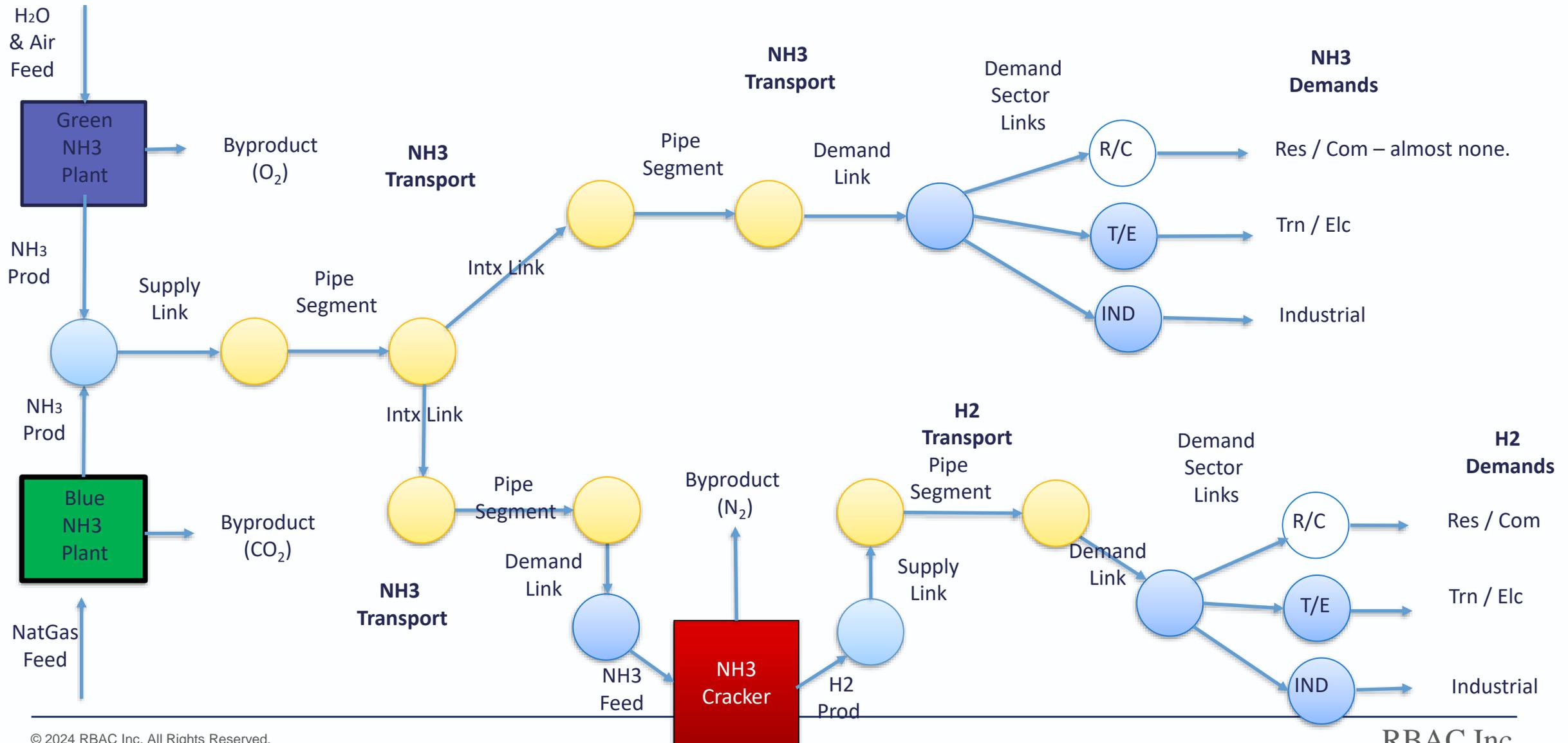
H2/NH3 Production and Pipeline Flow including Substitution for Nat Gas

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Clean Hydrogen Production

- Hydrogen production is only for domestic demand. Liquefied hydrogen transportation can be easily integrated.

- <mark>No hydrogen demand here is for clean ammonia production – otherwise we will double count here.</mark>

- 1400 plants are included as inputs.

- Here is showing the production, not the capacity of the plants.

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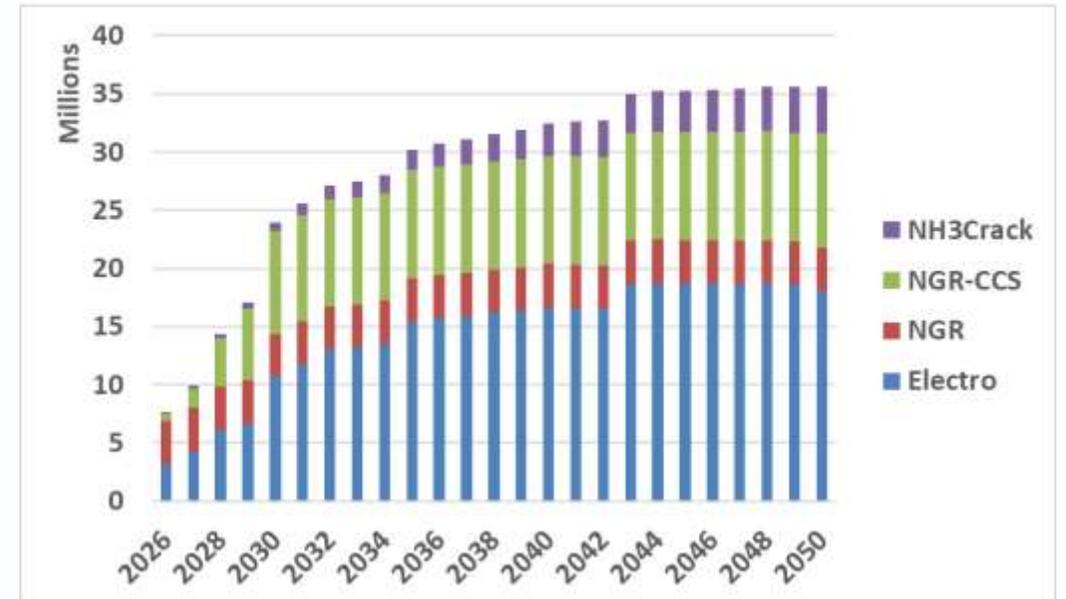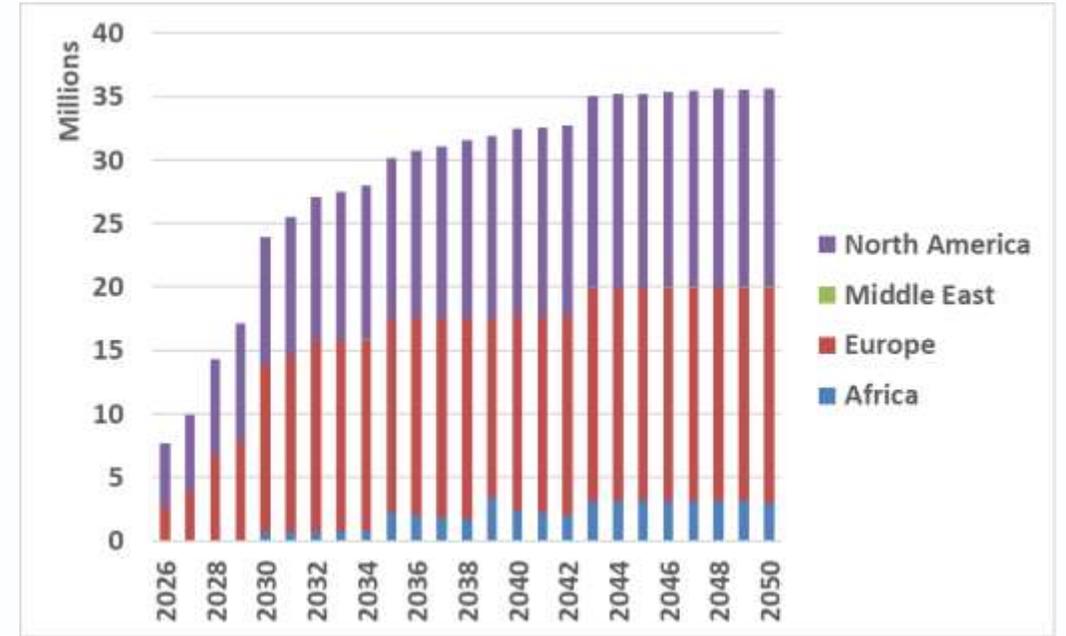
Clean Hydrogen Demand vs Deliveries by Region

Assuming no cross-regional hydrogen trade in this scenario. Hydrogen is produced and used in the region.

Here we could choose to model either captive demand for hydrogen and ammonia or not. Here, showing a captive demand case, not directly competing with natural gas on costs, but there is competition between domestic hydrogen and imported ammonia

The shortfall could be due to insufficient production or competition from imported ammonia filling the same demand.

Note that the scale of North America and Europe is 100 times bigger than the Middle East and Africa here.

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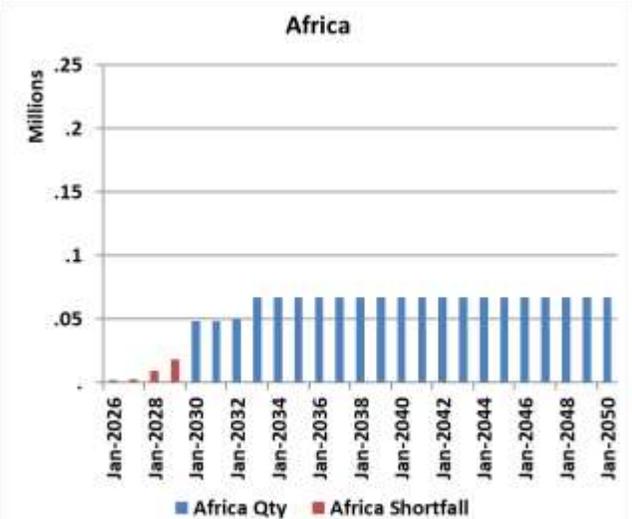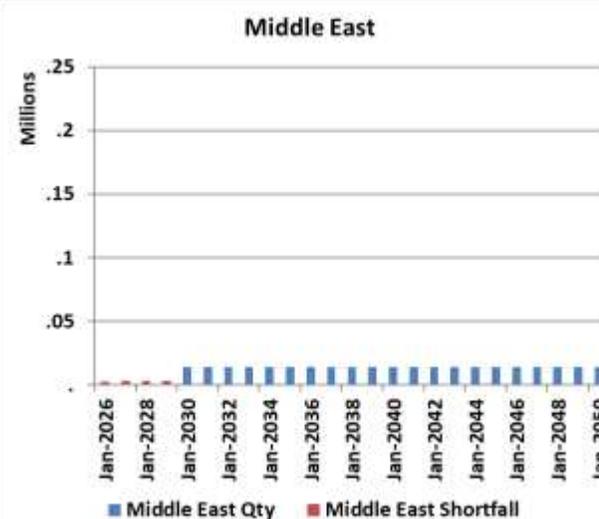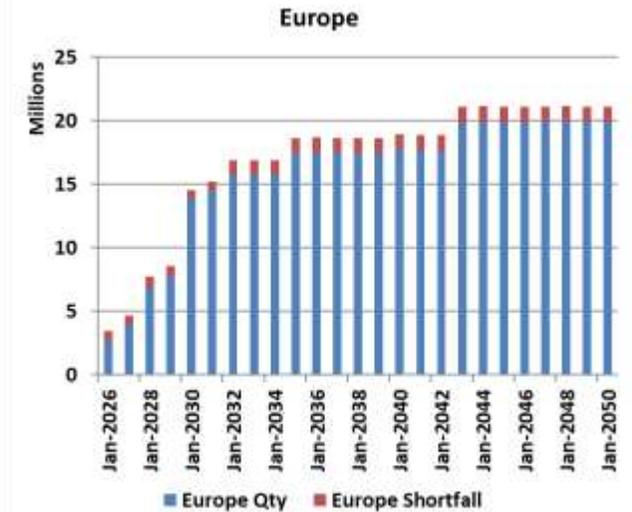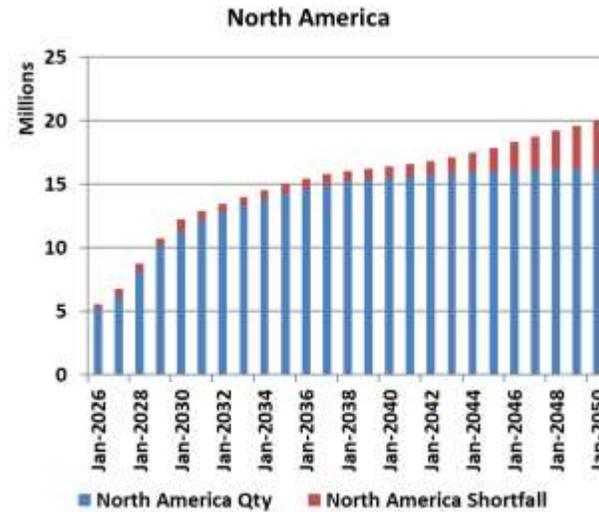
Clean Ammonia Production

- Clean ammonia production is only for energy and fuel applications, not including traditional agriculture or industrial applications.

- Clean ammonia can be exported at $0.02 per ton per mile as the transportation costs.

- **Besides the previously added over close to 1400 hydrogen plants, we added another 99 plants of clean ammonia**
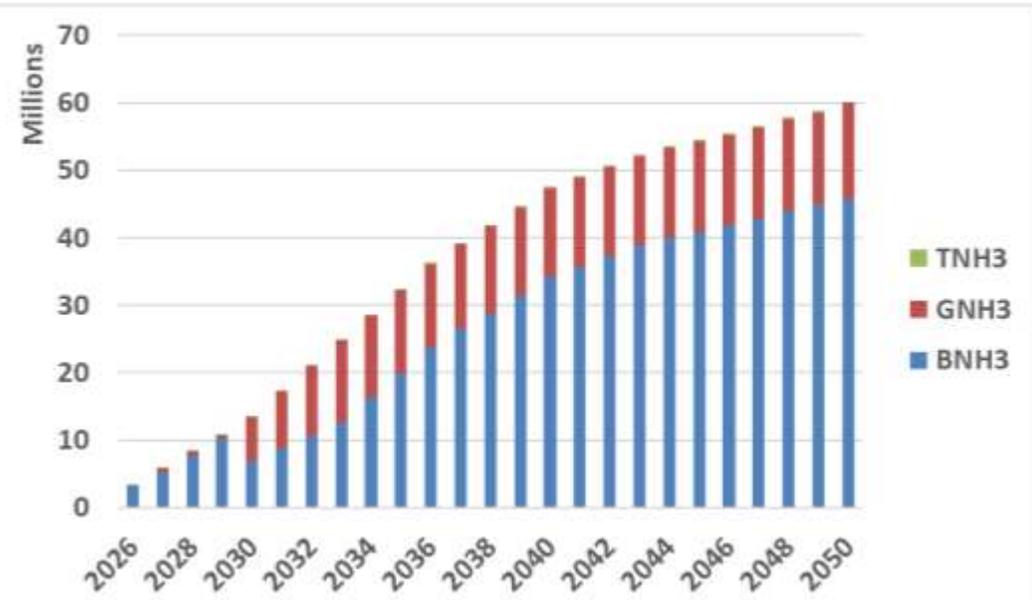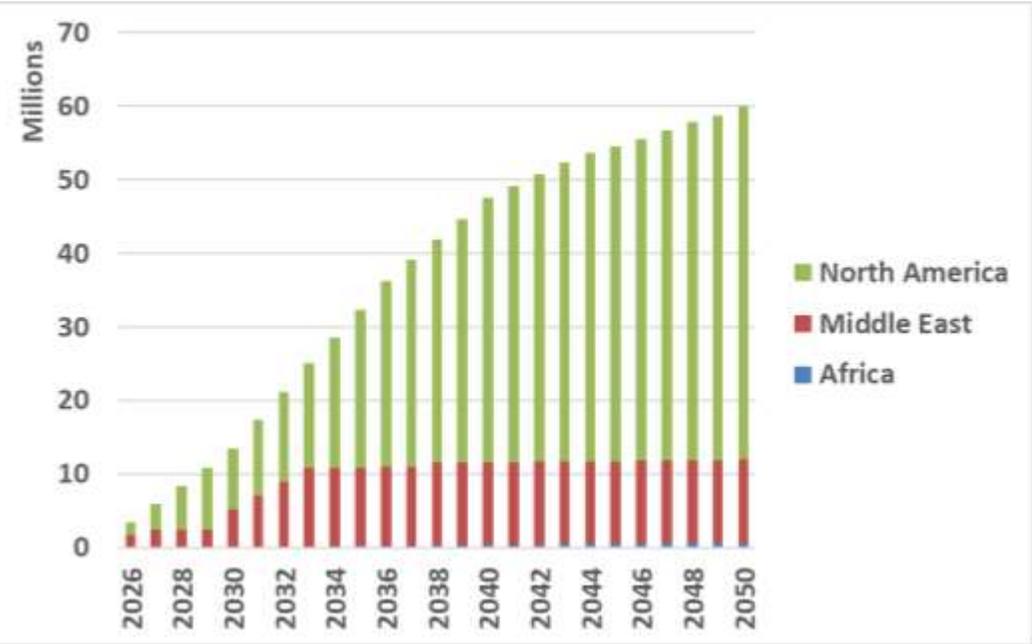
Clean Ammonia Demand versus Deliveries by Region

North America
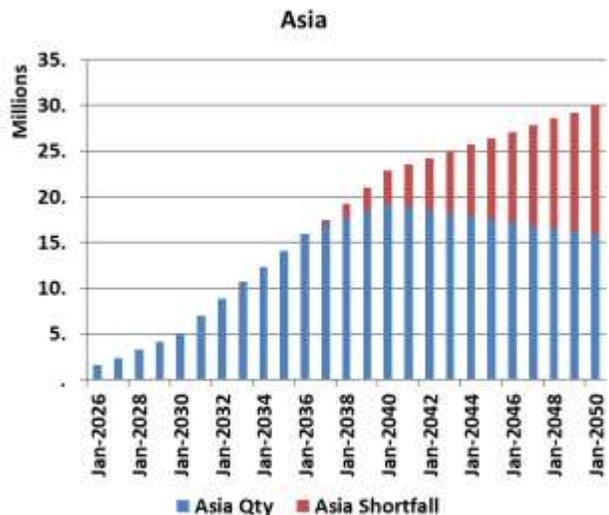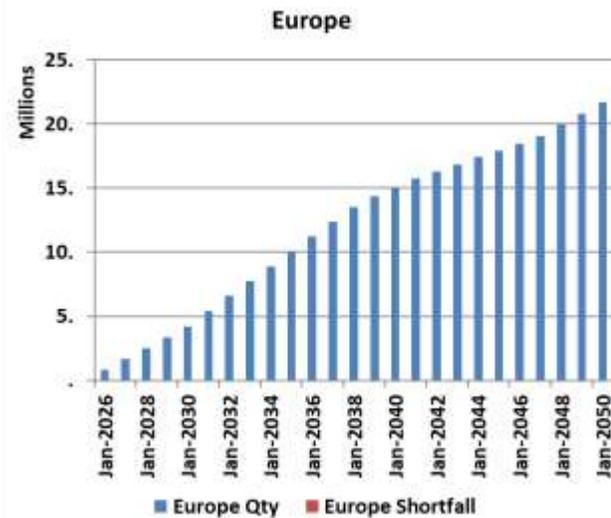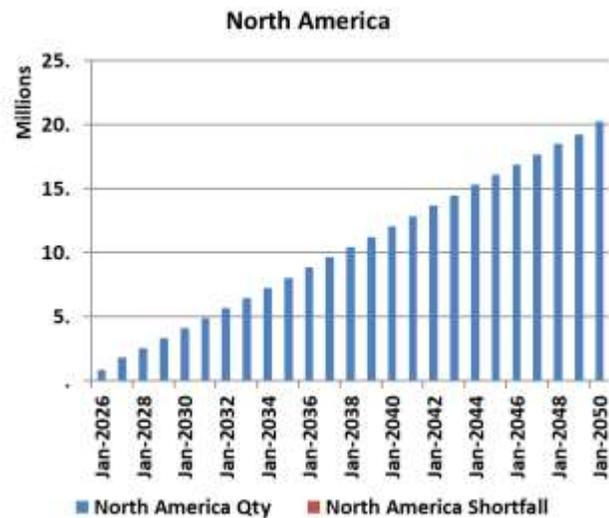
Europe

Asia

- Asia and Europe are both relying 100% on ammonia imports.

- Asia still has great demand potential, with some existing shortfall.

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Trade Flow and Balances

- Europe has three options for imports:
- the Middle East, North America (Texas or LA), or North Africa.

- Asia has two options for imports:
- the Middle East, North America.

- These trade paths are shaped by modeled costs, production capacity, and transport infrastructure
- **Asia and Europe compete for the Ammonia trade.**
- **Long term contracts can be integrated besides spot trade.**

Europe NH3 imports by Source
(North America -> Europe; Africa -> Europe)

Asia NH3 imports by Source
(North America -> Asia; Middle East-> Asia)

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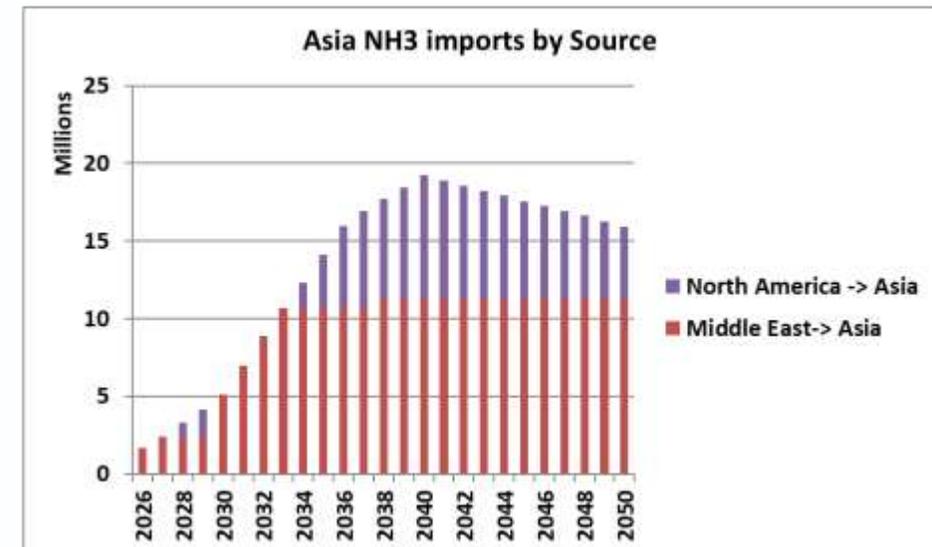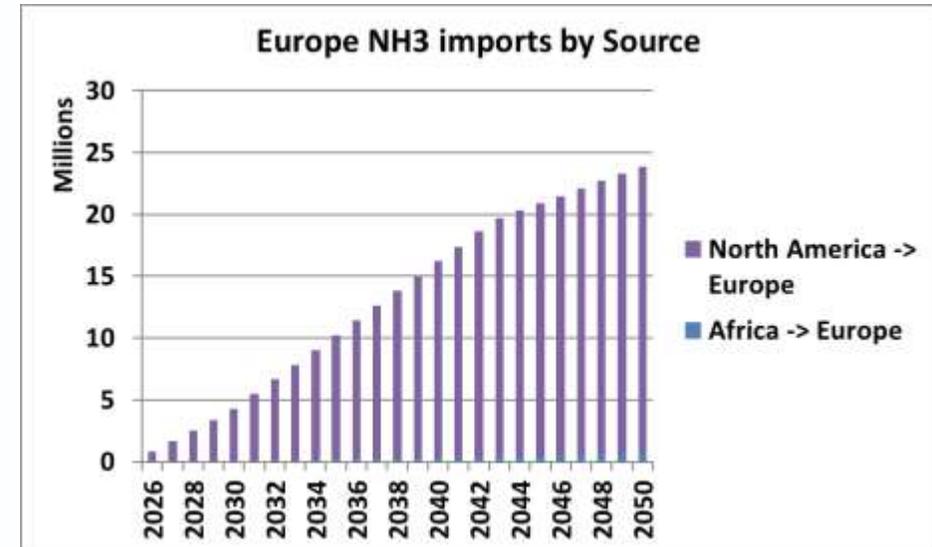
Average Delivery Prices of Ammonia

NH3
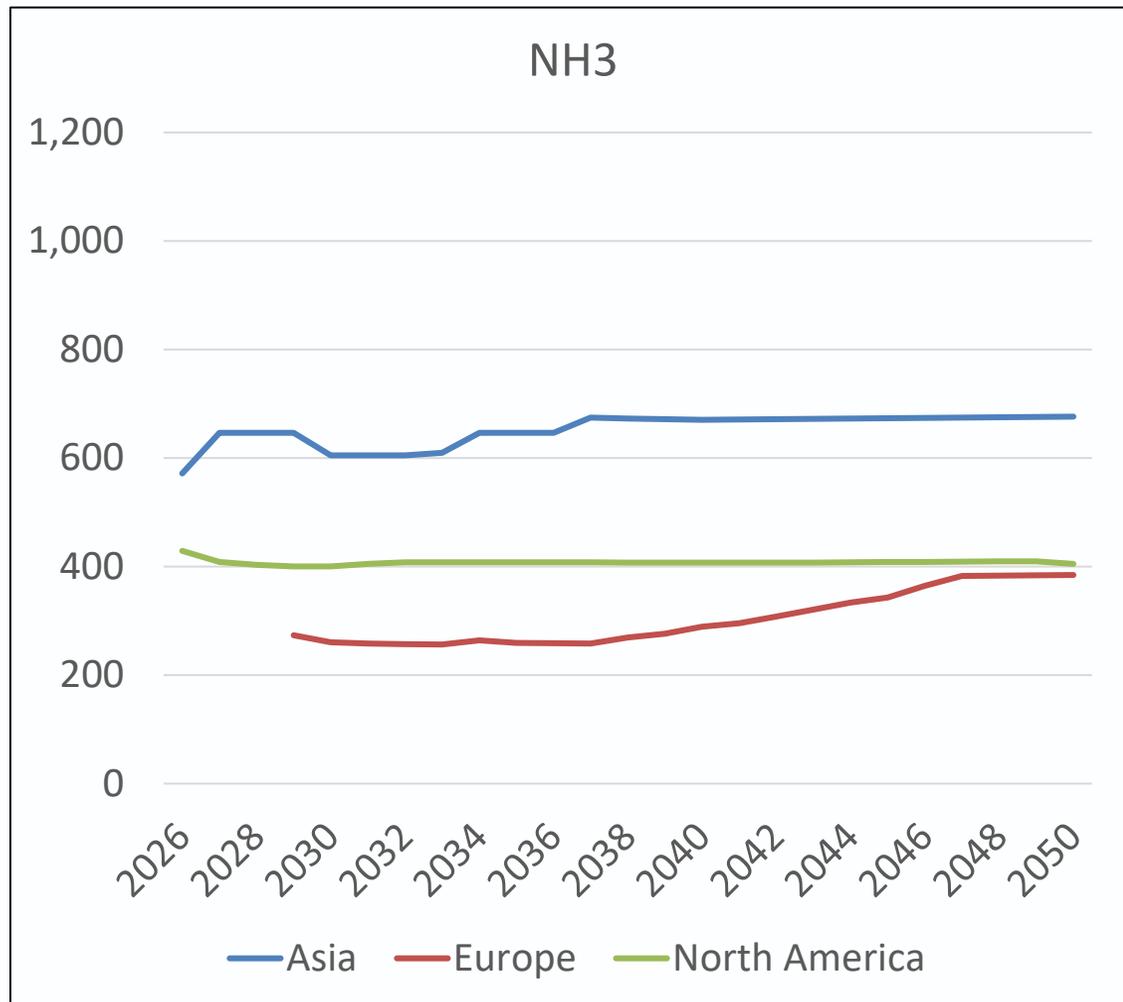
- Asia's NH3 delivery cost is higher due to longer transport and constrained supply, while Europe delivery price is the average between Middle East / Africa and North America.

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Findings

- The natural gas network model can accommodate hydrogen and ammonia with great technical accuracy and robustness.

- Ammonia emerges as the practical vector for global hydrogen trade.
  - Local granularity is available. We currently model European countries separately for hydrogen, ammonia, and the natural gas network.

- This framework is commercially ready to support strategic planning for a global clean fuel market.
  - Considering the cost-competitive positions of the US and Saudi Arabia, it has already started working with South Korea.

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RBAC Inc.

RBAC, Inc.

www.rbac.com

(281) 506-0588

contact@rbac.com

RBAC leads the market in global and regional gas and LNG market simulation and predictive analytics in support of corporate investment and M&A strategy, ESG, risk analysis, planning, and commodity trading. Our products and expertise help companies go beyond the narratives and hype to identify the opportunities and define the risks inherent in the uncertainties of energy transition using reality and fact-based fundamentals and analysis.

We continuously enhance our market simulation systems with the latest software and computer technology while applying the best of mathematical economics to assist our clients achieve their goals. This is especially needed as we see fundamental shifts taking place in the energy industry to achieve energy transition goals and meet increasingly demanding requirements of ESG. We provide regularly scheduled updates of our simulation systems and databases to keep our clients up-to-date with the most current market information. We enhance the functionality of our systems to enable our customers to simulate the effect of new regulations or industry requirements.

Our aim is to continue to lead the market in best practices which raise the standard of market simulation, enabling rapid and flexible scenario generation, sensitivity analysis, risk-assessment and forecasting, giving clients the edge in the rapidly changing energy market.

Those using RBAC's products and services include energy industry firms and consultants, as well as government agencies involved with energy, transportation, and the environment.

RBAC's principal products include:

- **GPCM® Market Simulator for North American Gas and LNG™** focused on the North American gas & LNG markets. GPCM is the industry standard market simulator for North American gas.
- **G2M2® Market Simulator for Global Gas and LNG™** for simulating increasingly integrated gas and LNG markets worldwide.
- **Gas4Power®** for integrating gas and power market fundamentals to produce credible forecasts for both.
- **NGL-NA®** Market Simulator for North American Natural Gas Liquids

With RBAC's advanced simulation systems, licensees can create and run scenarios involving bio-methane (Renewable Natural Gas – RNG) mixed with natural gas and to assess the implications of carbon taxes and markets on supply, demand, and prices. Future enhancements will include the ability to simulate the advent of a future hydrogen market with both pure hydrogen pipelines as well as mixtures with methane. The Energy Analyst of today and the future needs these kinds of tools to conduct realistic assessments and help develop realistic strategies and plans to achieve the goals of the energy transition.

Dr. Robert Brooks founded RBAC in 1987 based on experience developing several well-respected predictive models for government and industry. He designed the first gas transportation model while getting his PhD at MIT and has led the industry ever since.

RBAC's staff includes industry-trained experts in natural gas supply and demand, transportation, storage, marketing, and trading. Our team applies its world-class expertise in mathematical modeling, statistical analysis, mathematical algorithm development, software engineering, and database design to current and future challenges, risks and opportunities in energy.