# Optimizing Hydrogen Integration in Natural Gas Pipeline Networks

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## The Leader in Energy Market Simulation Systems

**Providing energy companies, consultants, and regulators advanced tools to support:**

- Investment and M&A Strategy
- Environmental and Sustainability Goals
- Credible Risk Analysis
- Trading Strategy
- Policy Development and Assessment
- Energy Security

# Research Motive

**Collaborating between Bureau of Economic Geology and RBAC**

**Leveraging existing natural gas network modeling system (G2M2)**

**Will that be a realistic way to add hydrogen as a parallel value chain?**

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# Optimizing Hydrogen Integration in Natural Gas Pipeline Networks

1

## Network Modeling

Incorporating hydrogen into existing natural gas infrastructure requires sophisticated network flow modeling.

2

## Commodity Dimensions

The model must account for both natural gas and hydrogen as separate commodities commodities with unique supply, demand, and infrastructure. CO2 or other other coproducts can be considered as commodity as well with prices in the value the value chain.

3

## Plant Integration

Hydrogen production plants, with production pathways, must be integrated integrated into the network model with their input/output, including carbon including carbon tax and coproducts

4

## Demand Considerations

Hydrogen demand must be carefully modeled, accounting for its accounting for its lower energy density compared to natural gas. natural gas.

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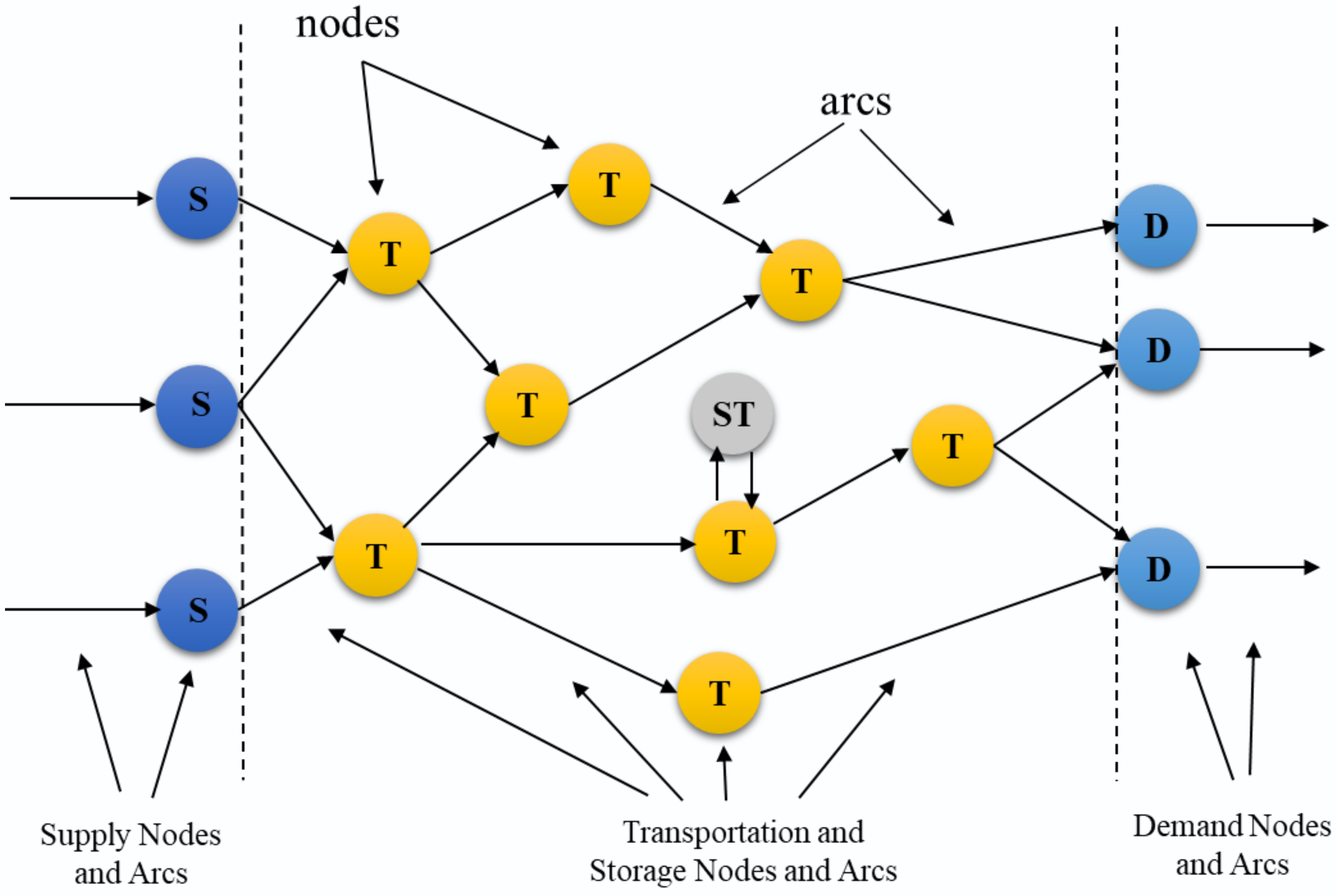
# Network Flow Model

- Basics of a partial equilibrium model for a single commodity (natural gas or hydrogen).
- 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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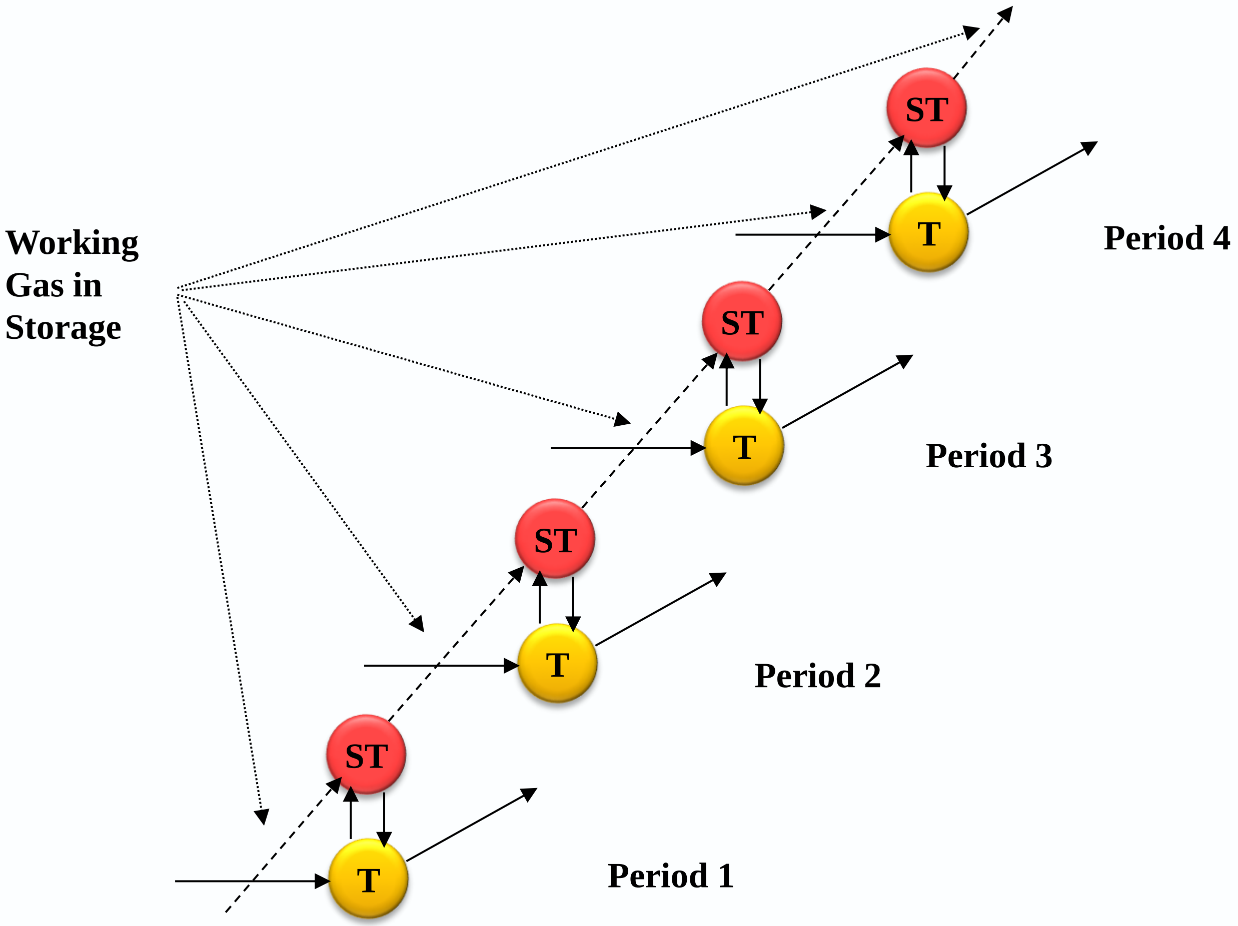
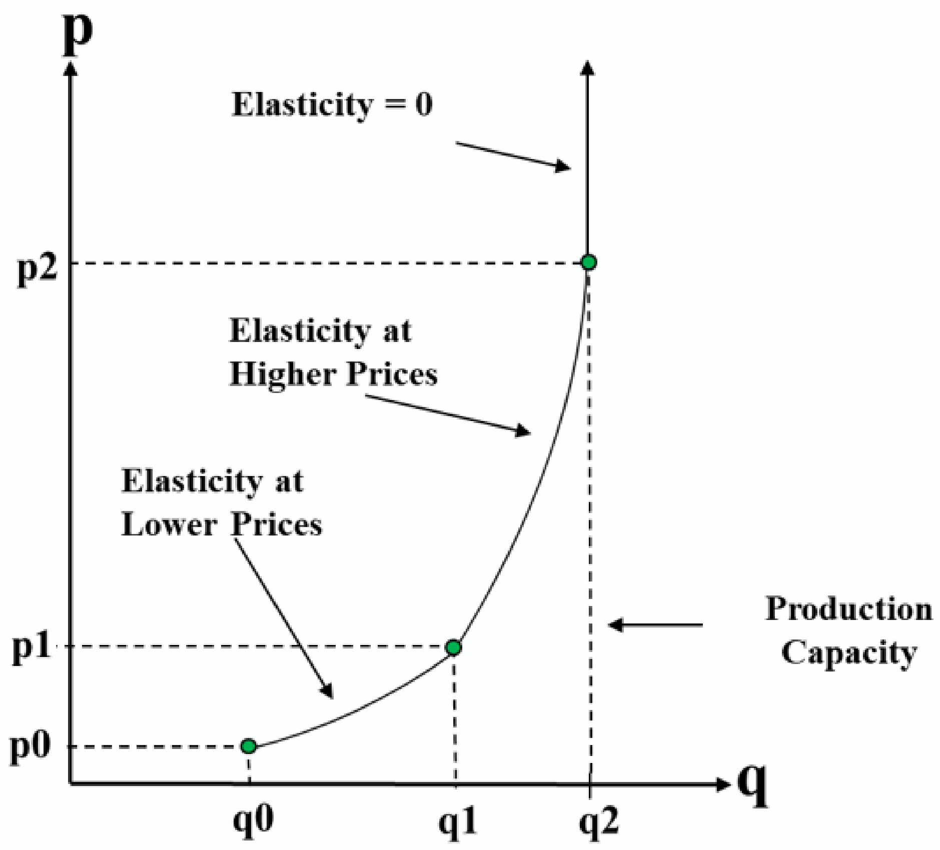
# Network Model – Multiple Periods – Linked by Storage

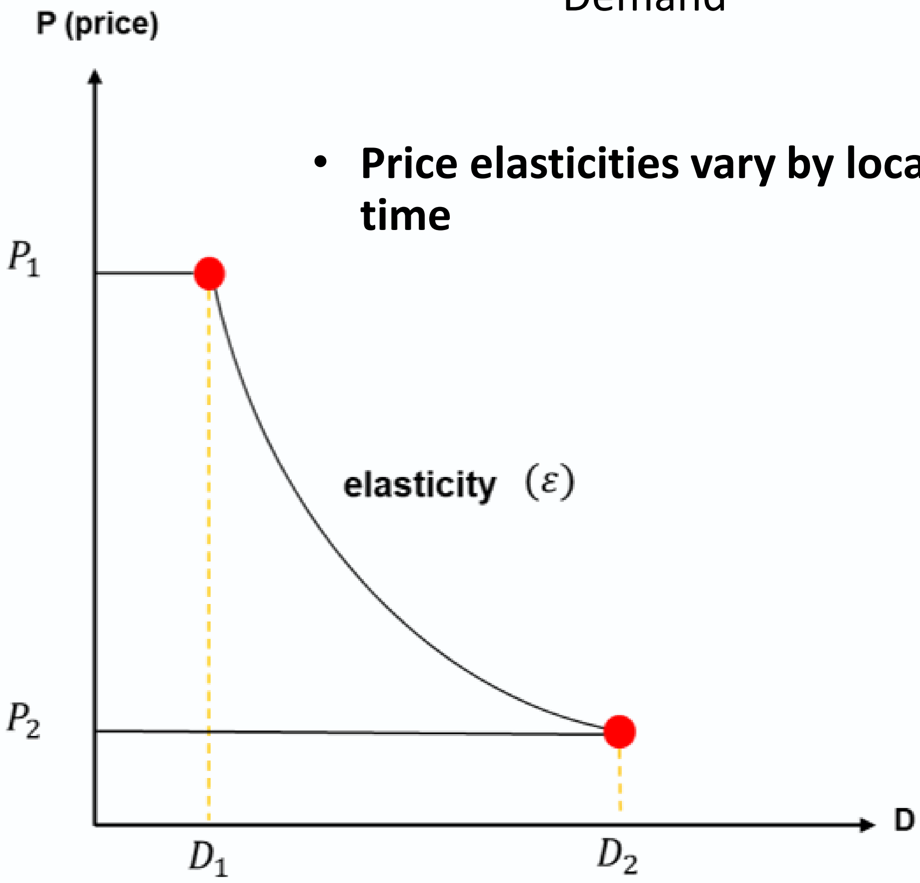


# Price Dependent Supply and Demand Models

Supply

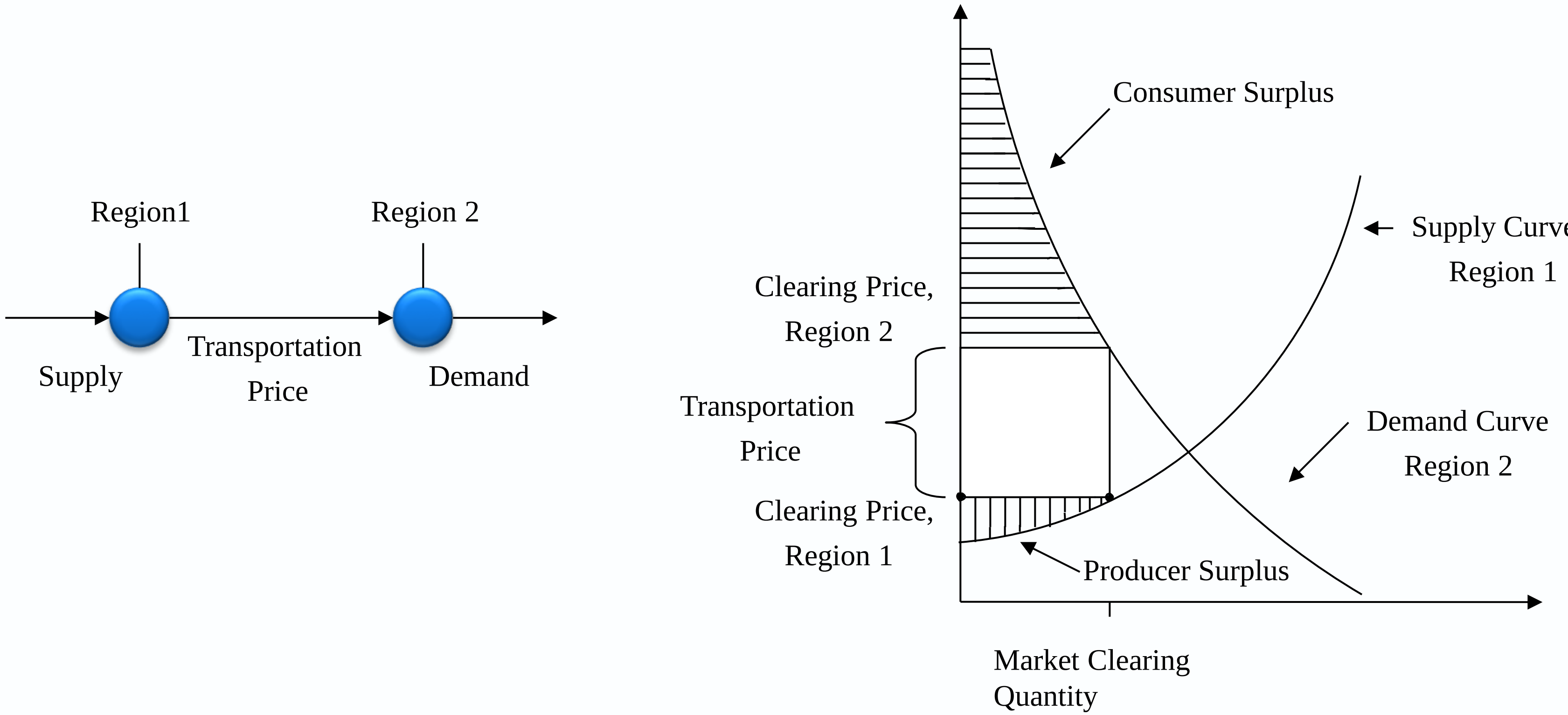



Demand




- **Price elasticities vary by location and time**

# Spatial Equilibrium




**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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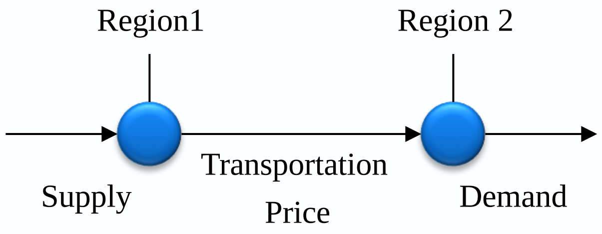
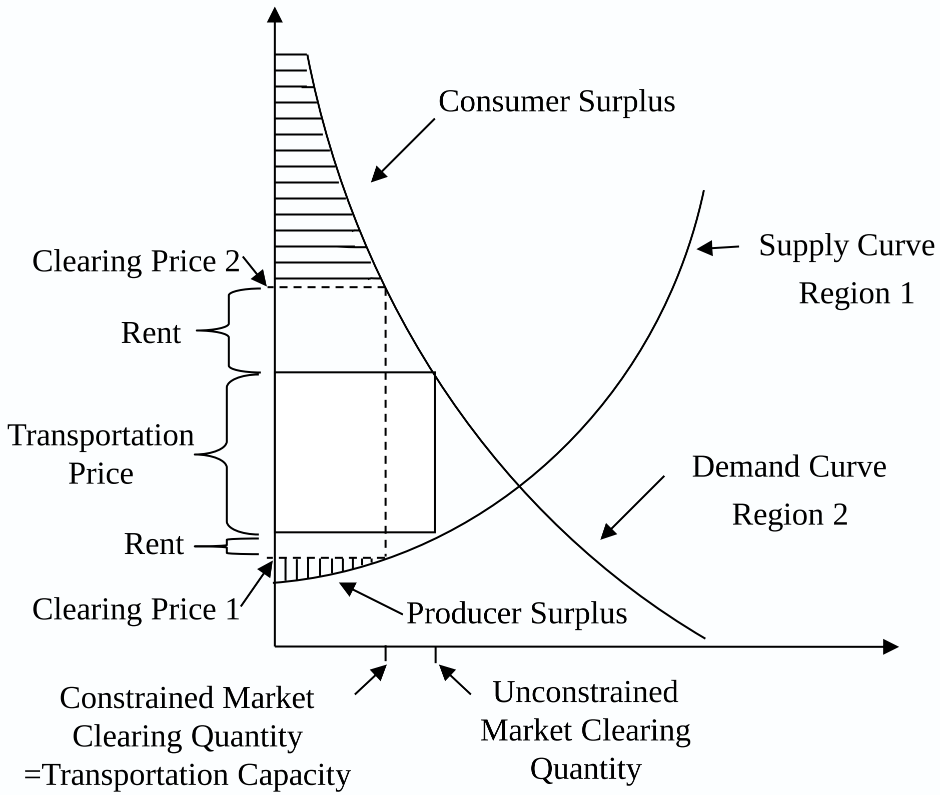
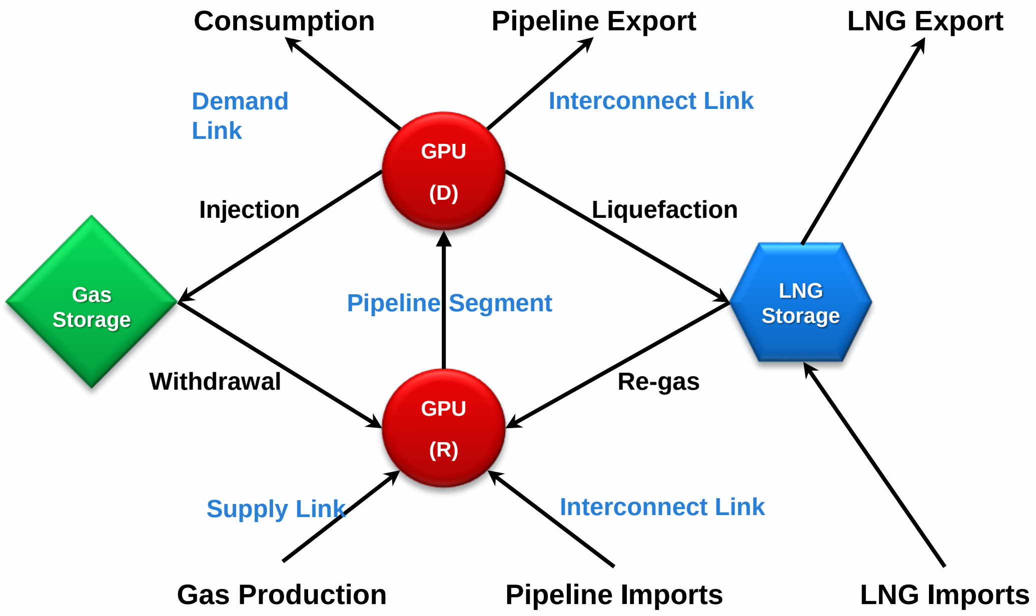
# Case Spatial Equilibrium with Constrained Transportation




**Transportation constraints raise prices in delivery areas and reduce prices in supply areas and lower both consumer and producer surplus.**

# 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.**

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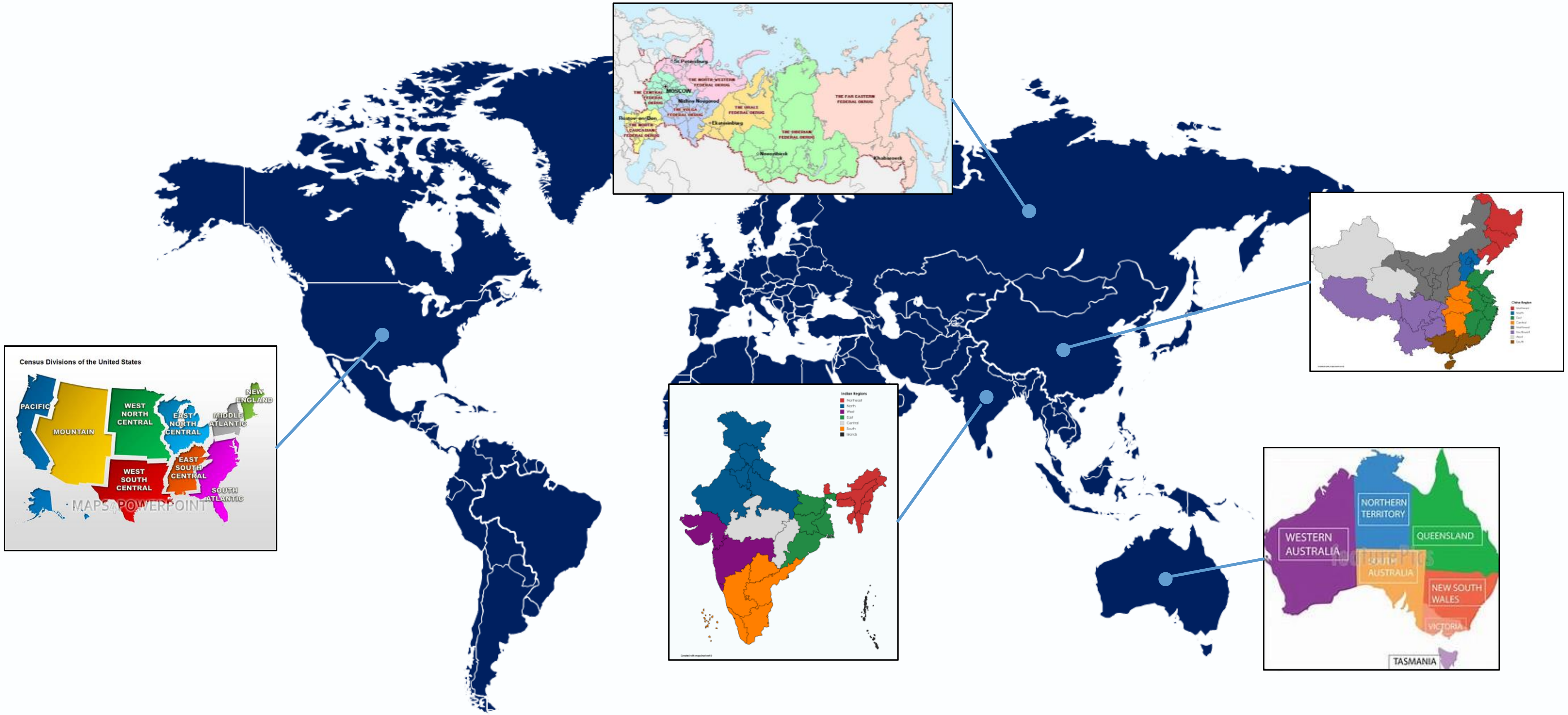
# Comprehensive Geographical Coverage




**G2M2 covers all areas and countries with natural gas consumption and production. Larger countries are split for greater modeling accuracy. This is a good starting point for adding hydrogen value chain given it has some similar infrastructure that hydrogen would leverage.**

# G2M2 Market Simulator for Global Gas and LNG

## Periodicity and Forecast Range

- **Monthly** (seasonal flows and prices)
- **Historical Backcasts from 2011**
- **Short, Mid, Long-term Forecasts out to 2050**

## LNG Contracts and Infrastructure

- **Liquefaction / Export Terminals**
- **Import / Regasification Terminals**
- **Contracts** (volume, duration, take-or-pay, dest restrictions)
  - Point-to-point, portfolio, spot

## Supply & Demand for 100+ Countries

- **Gas Production by Type** (Natural Gas, RNG)
  - Hydrogen and methane-hydrogen mixes in development
- **Gas Demand by Sector** (RES, COM, IND, ELC, TRN)

## Multiple LNG Tanker Classes

- **Q-Max / Q-Flex / Q-New**
- **ARC 7** (Arctic class)
- **Conventional** (5 different sizes)

## Pipelines and Storage

- **400+ Pipelines**
- **600+ Underground Storage Fields**
- Existing, Under Construction, Proposed and User Defined

## Energy Transition / CO2 Reduction

- **Renewable Natural Gas**
- **Carbon Emissions Prices, Taxes, and Limits**
- **Government Mandates re CO2 and Methane**
- **Developing H2 and Mixed H2-CH4 Capability**

**G2M2 unlocks potential for global gas opportunities**

**(supply-demand balancing network including pipeline systems & LNG infrastructure)**

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# Adding Hydrogen to the Network Flow Model

| Commodity | Commodity Name | Heating Value (BTU/M3) | Density (KG/M3) |
|---|---|---|---|
| CB | Carbon Black | 44,000.00 | 1.95 |
| CO2 | Carbon Dioxide | 0.00 | 1.98 |
| ELC | Electricity | 0.00 | 0.00 |
| H2 | Hydrogen | 11,477.20 | 0.09 |
| NatGas | Natural Gas | 36,303.25 | 0.72 |
| O2 | Oxygen | 0.00 | 1.43 |

To add hydrogen value chain, we also included multiple commodities, including CO2, ELC, O2, and others, as either feedstock/outputs.

- To add hydrogen to our natural gas network flow model, we must add a new dimension: **commodity**
- We had a "commodity": natural gas
- We can add more commodities
- We now add a new network model parallel to the original one, **for hydrogen**

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# H2 Plants Represented as Input/Output Models

- These input/output models are easily represented in a network flow model
  - For each **Plant Type**, define the inputs, outputs, and byproducts and how much of each input is needed and how much byproduct is produced per each unit of output H2
  - When the byproduct is CO2, one can charge a "carbon tax" per metric ton emitted
- Then define the set of **H2 Plants** with locations, types, capacities, and costs
- Provide **Pipeline Links** for natural gas input (if needed) and hydrogen output
- Create **Hydrogen Demand** functions for each consuming location
- Important notes on demand
  - Hydrogen only carries about 31% of the energy of natural gas per unit of volume
  - Reduce industrial demand for natural gas by the amount used in making hydrogen

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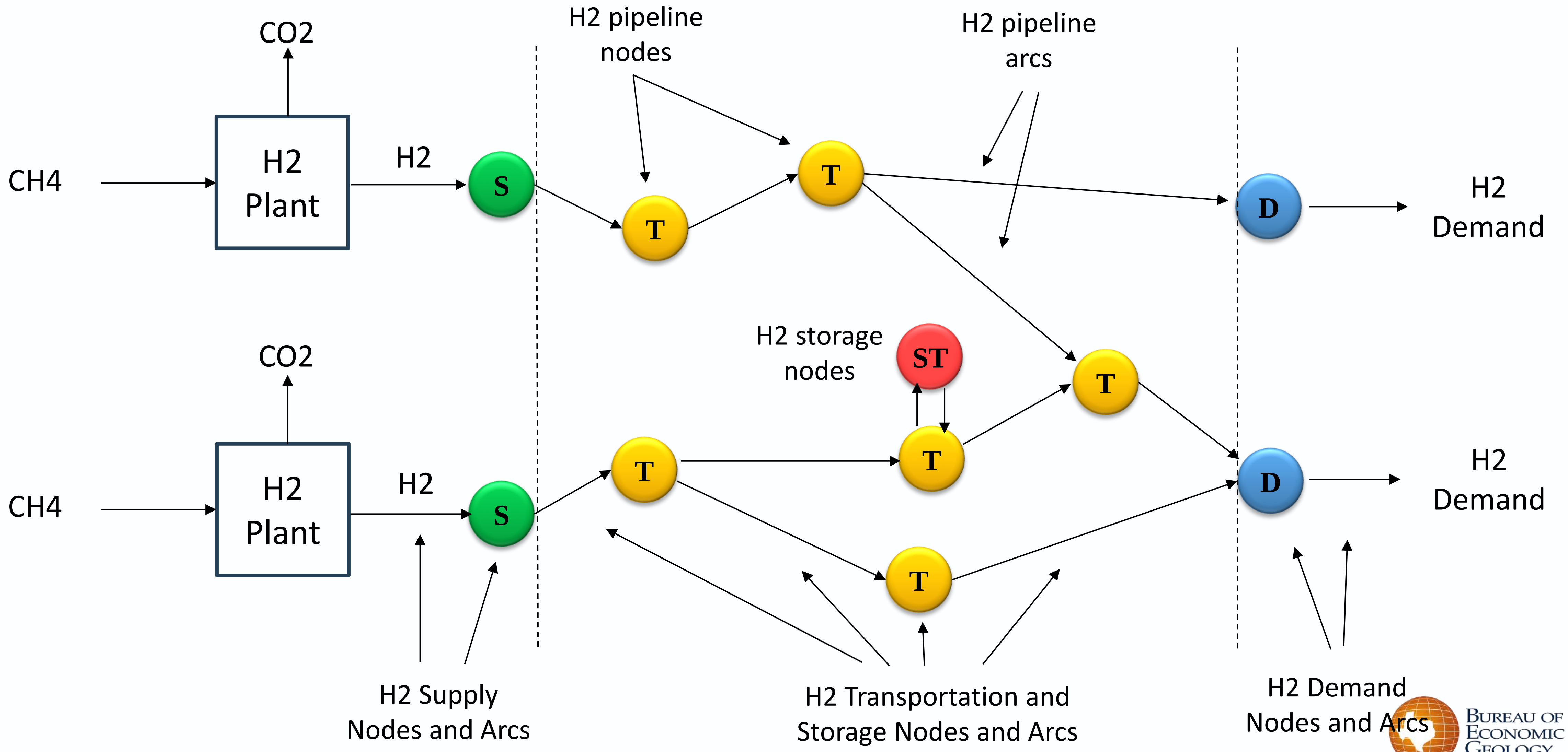
# Network Flow Model – Hydrogen from Natural Gas

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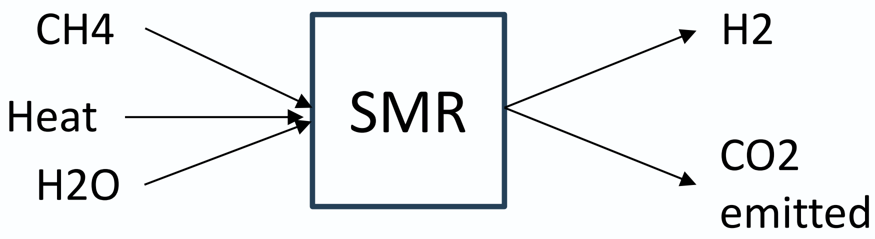
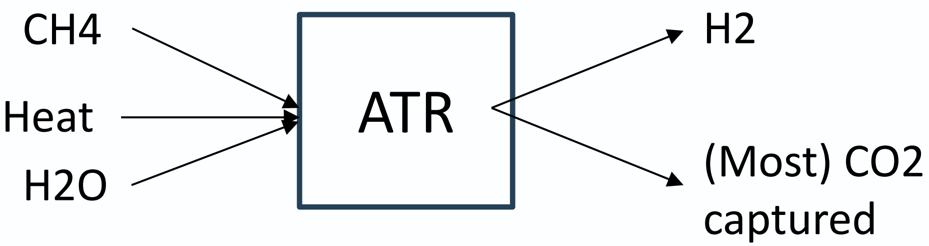
# H2 Production Plant Models

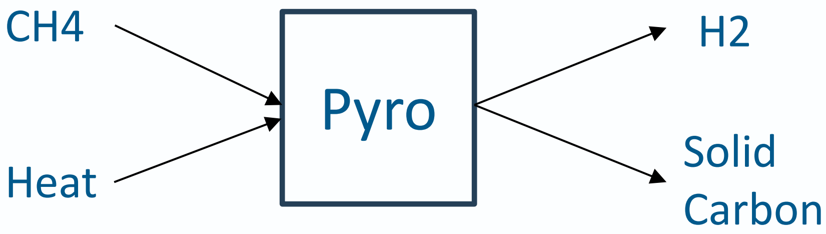
- SMR (no CCUS) = **NGR**



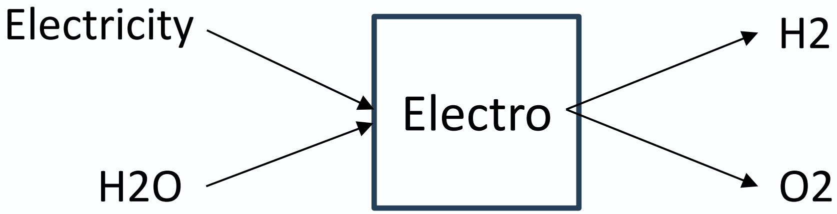

- SMR / ATR with CCUS = **NGR-CCS**




- Pyrolysis




- Electrolysis

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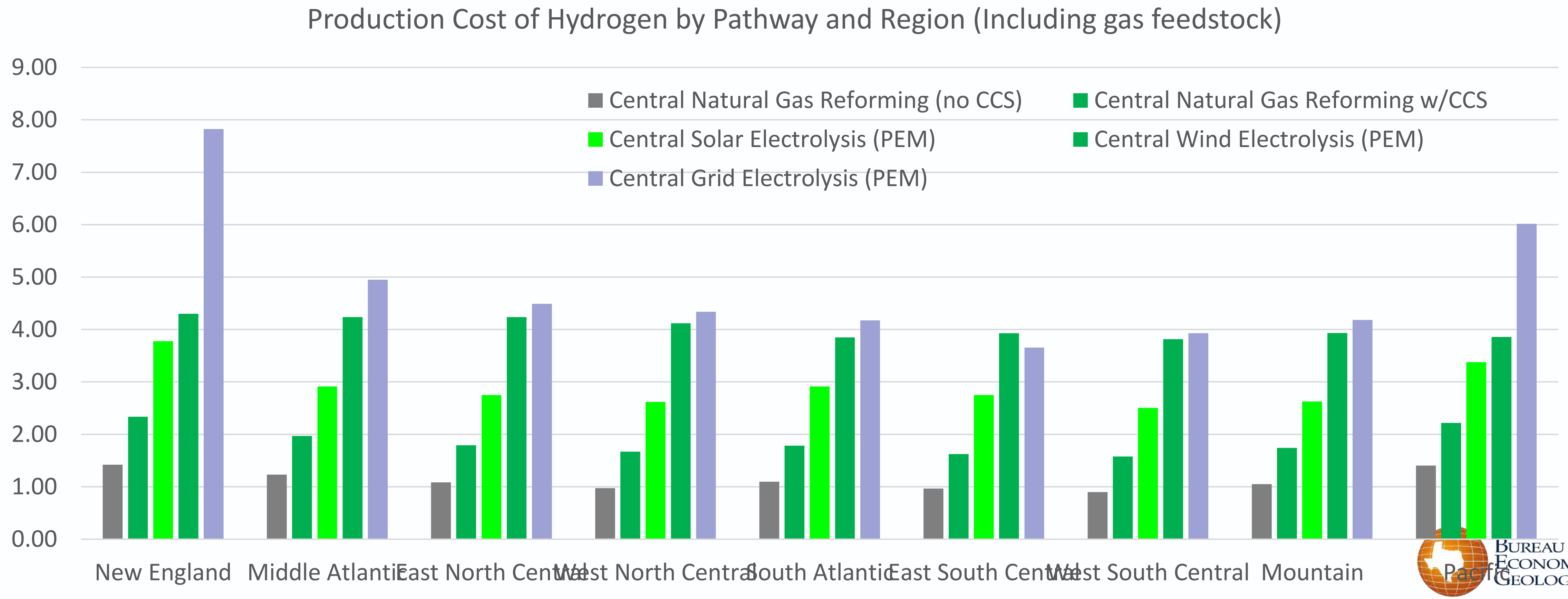
# Production Cost of Hydrogen

- Incentive of 45v or 45Q if applied separately.
- Feedstock of natural gas are separated out in the model to reflect different gas feedstock prices



# CCS Costs and Retrofitting

- CCS costs are calculated in two separate parts:
  - Facility-level costs of carbon capture equipment and processes.
  - Carbon Transportation and Storage
  - Retrofitting existing hydrogen production facilities
    - Each plant could choose its own schedule and strategy for retrofitting.

| Region | $CO_2$ T&S Cost ($/kg $H_2$) |
|---|---|
| Gulf Coast | 0.1 |
| Great Lakes | 0.15 |
| Appalachia, West | 0.18 |
| Mid-Atlantic | 0.22 |
| Northeast | 0.33 |
| Central, Mountain | 0.1 |
| Northwest | 0.18 |
| Alaska, Hawaii | 0.22 |

**Source: NPC study 2024**

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# Modeling Hydrogen Demand

### Industrial (IND)

Hydrogen demand from industries like manufacturing and chemical production.

### Electricity Generation (ELC) (ELC)

Hydrogen used for power generation generation in homes, businesses, businesses, and the grid.

### Commercial/Residential (COM/RES)

Hydrogen powering homes, commercial buildings, and appliances.

### Transportation (TRN)

Hydrogen fuel for vehicles like cars, cars, trucks, buses, trains, and ships. ships.

### Export (EXP)

Exporting hydrogen (in the form of Ammonia) to meet growing global demand.

**The model must also account for the elasticity of hydrogen demand - how demand - how sensitive consumers are to changes in hydrogen price and price and availability.**

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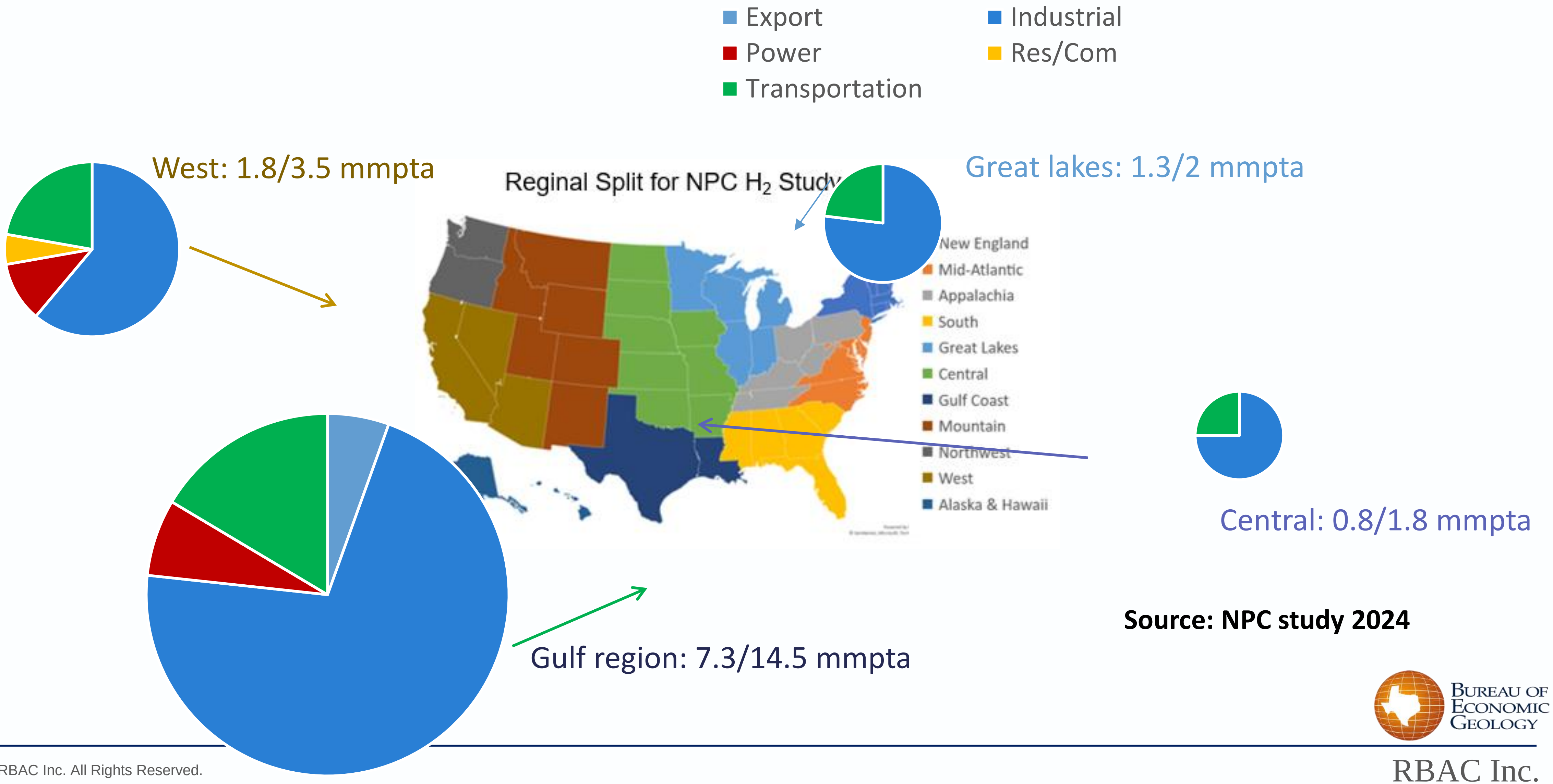
# Regional Demand Target by Sector (2030/2050)




**Source: NPC study 2024**

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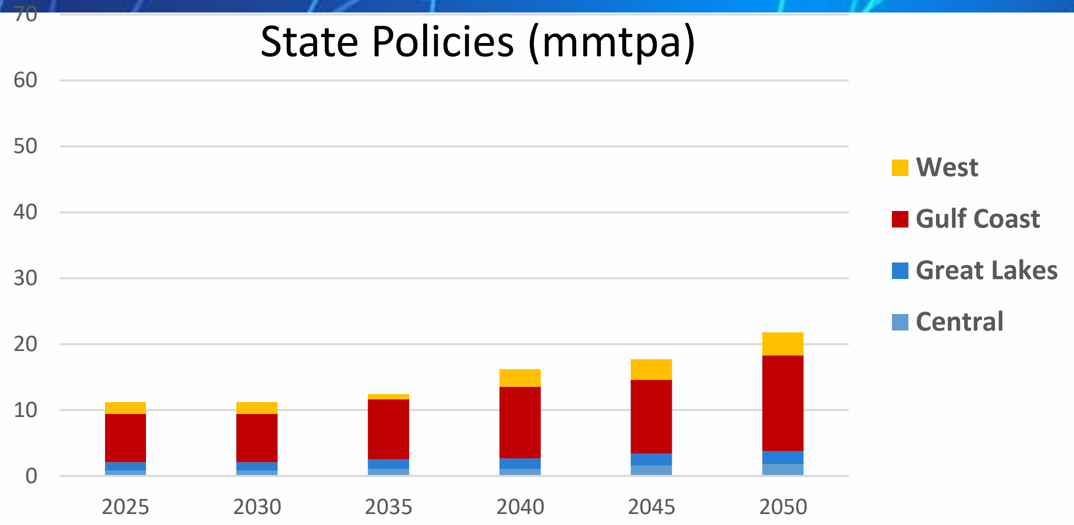
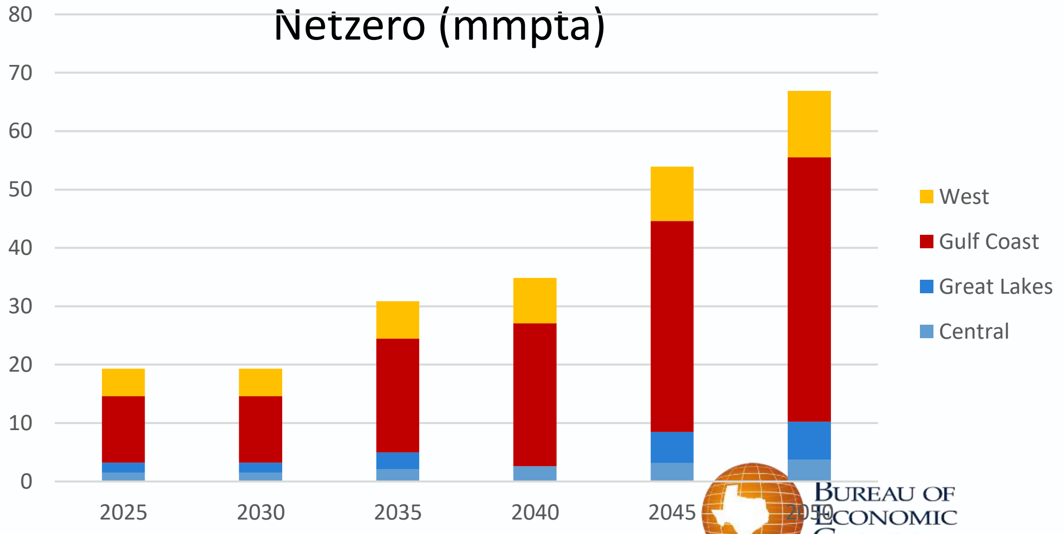
# Demand by Region and Scenario


**Source: NPC study 2024**

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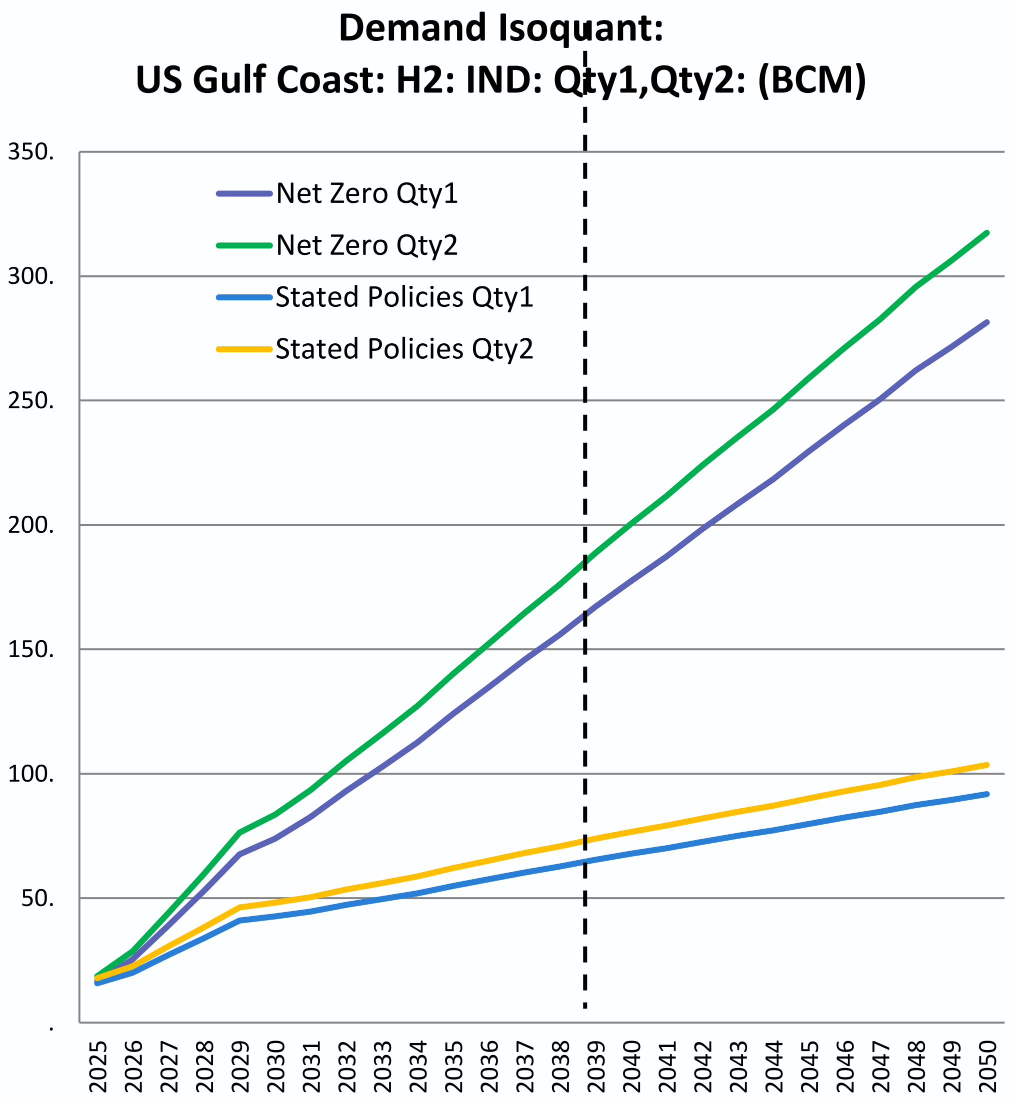
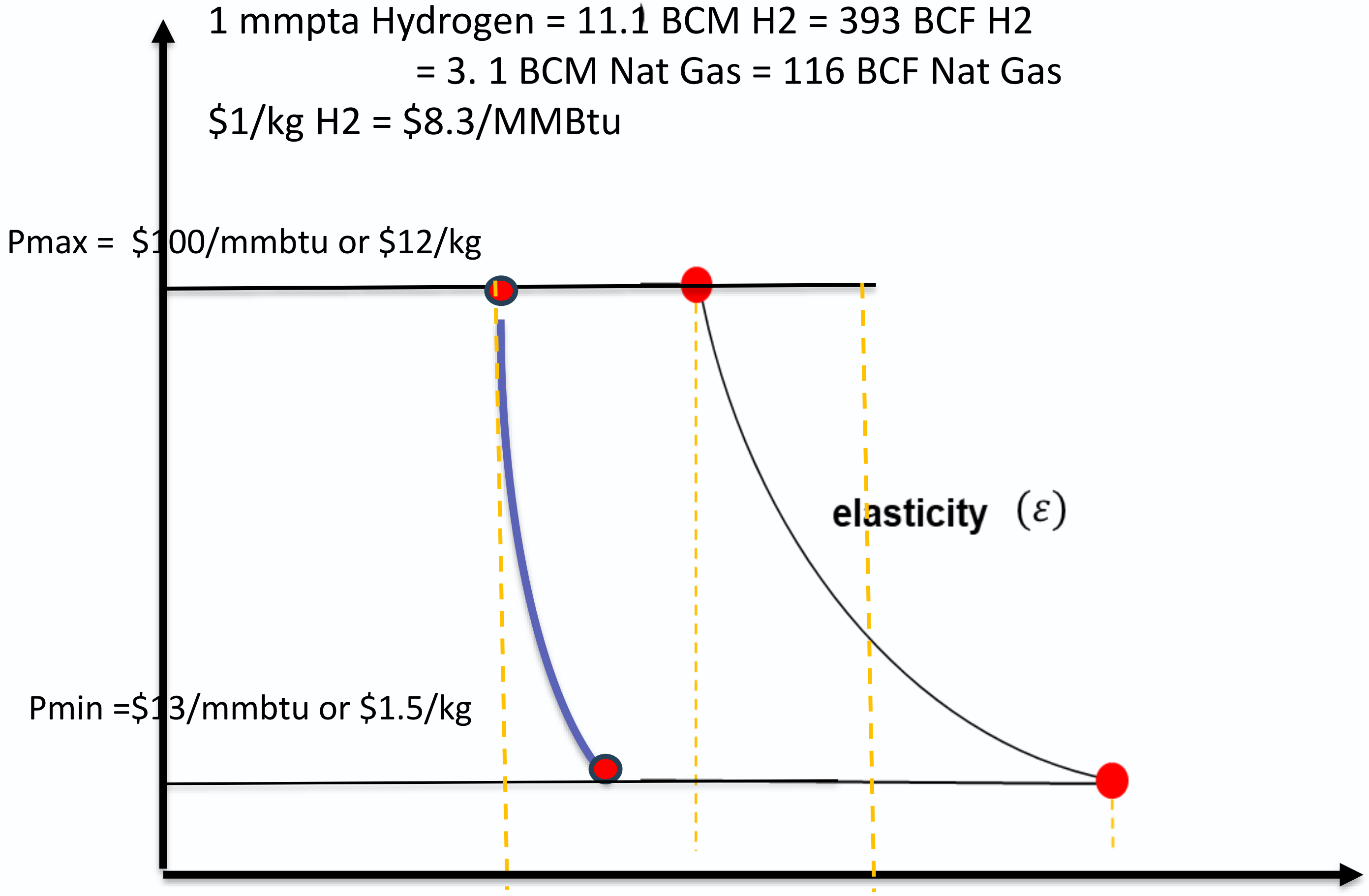
# 1) Converting equivalent gas units 2) Construct demand curves




1 mmpta Hydrogen = 11.1 BCM H2 = 393 BCF H2
= 3. 1 BCM Nat Gas = 116 BCF Nat Gas
$1/kg H2 = $8.3/MMBtu



# Hydrogen Pipeline and Storage Setup

| Pipeline | Underground Storage |
| --- | --- |
| Dedicated hydrogen pipelines will be essential for essential for transporting hydrogen from production sites to demand centers. | Storing hydrogen underground in salt caverns or or depleted gas fields can help balance supply and supply and demand. This storage capacity will be will be critical for managing seasonal variations in variations in hydrogen usage. |

Flexible data granularity across different regions, which does not impact the optimization

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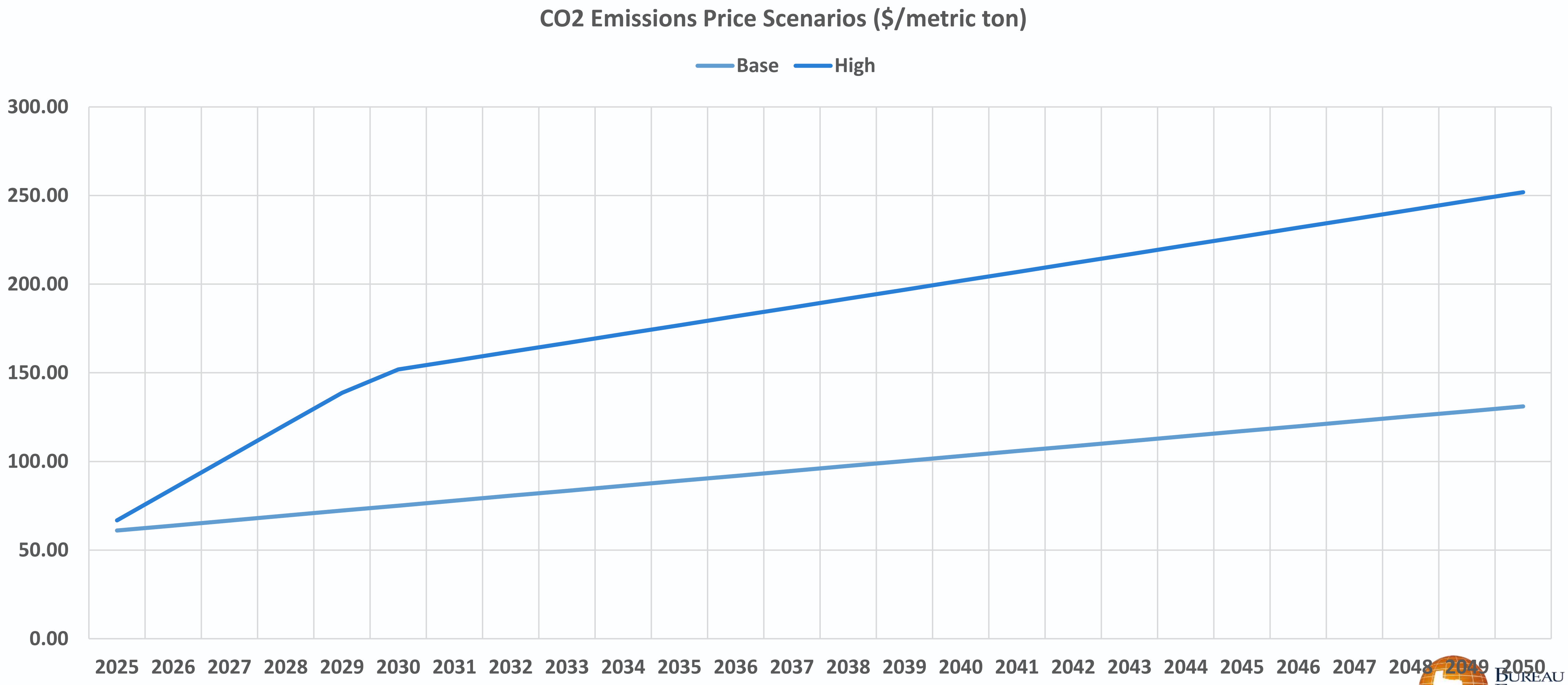
# CO2 Price Assumptions

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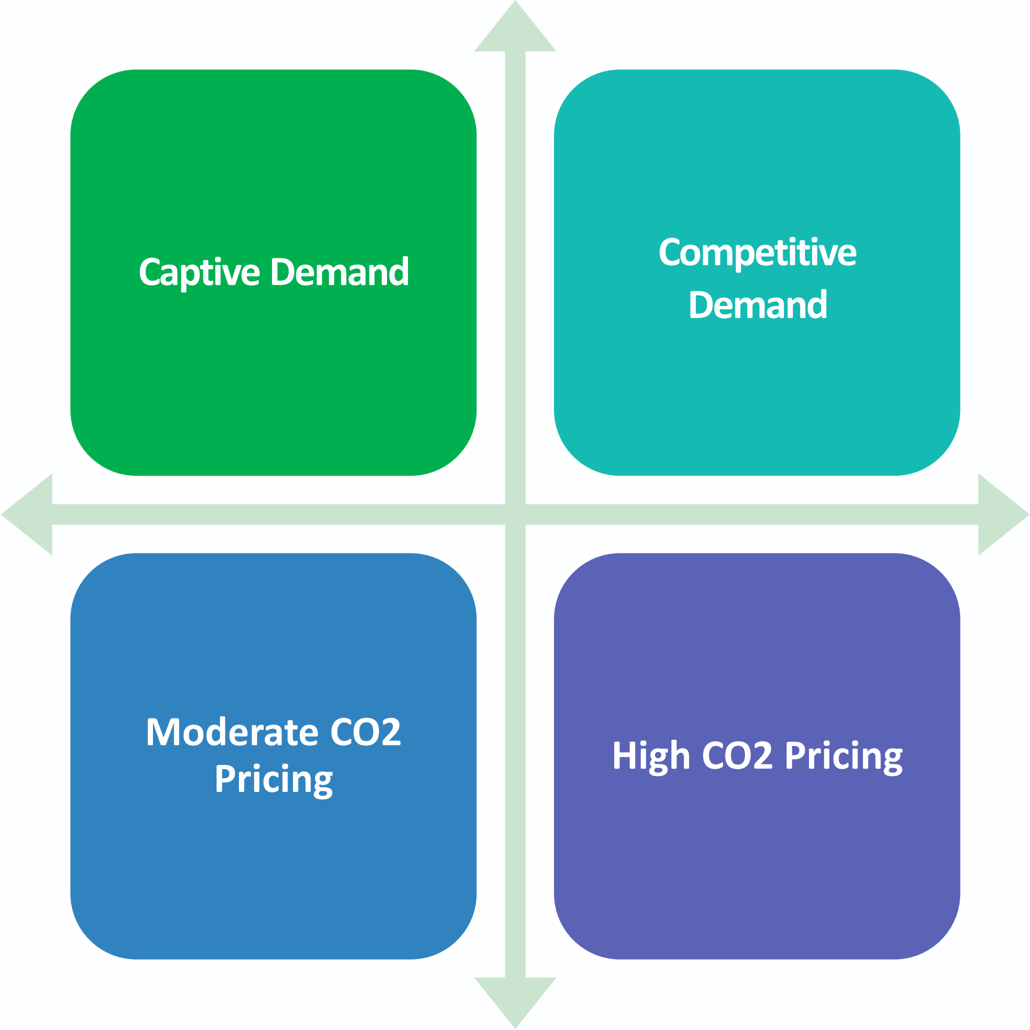
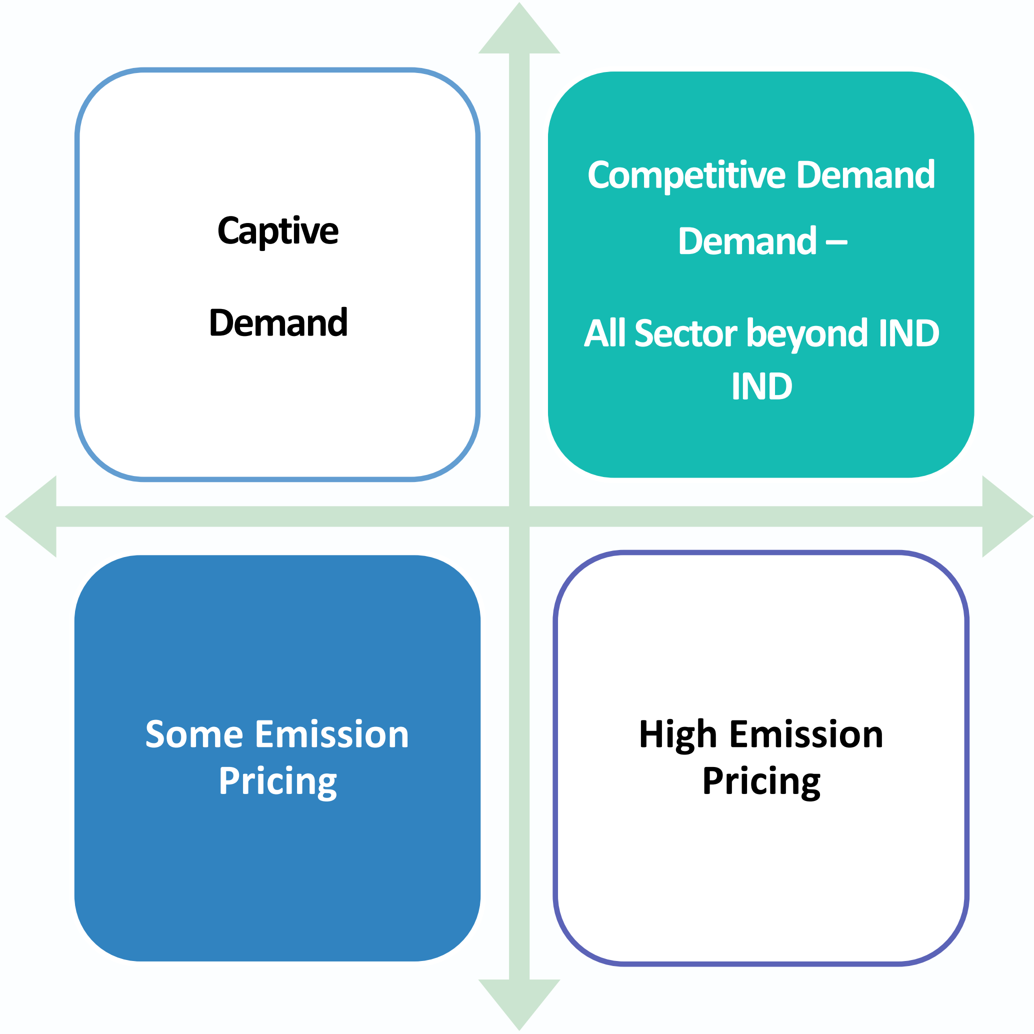
# Scenario Selection



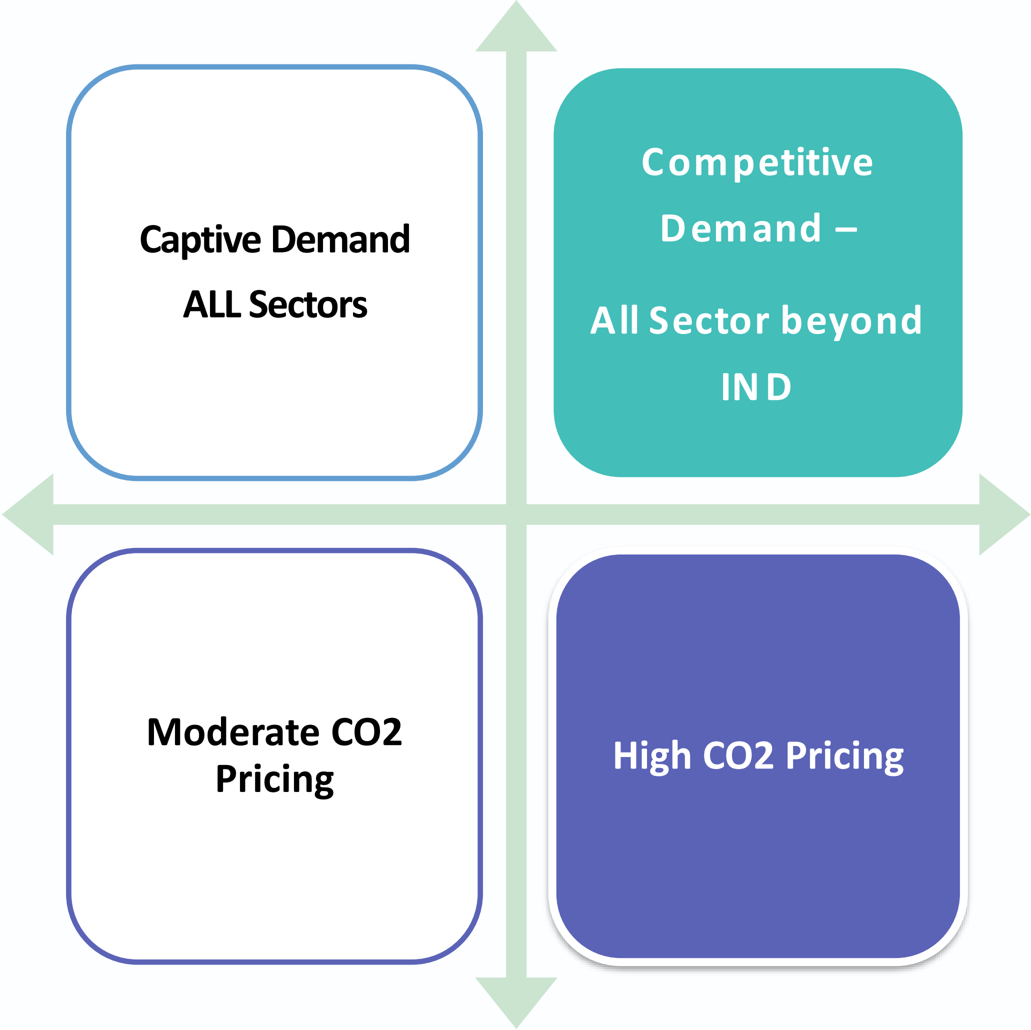
# Competitive Demand + Moderate CO2 Pricing




- Captive Demand IND ONLY; Competitive for other sectors
- Up to $132/ton Emission Pricing

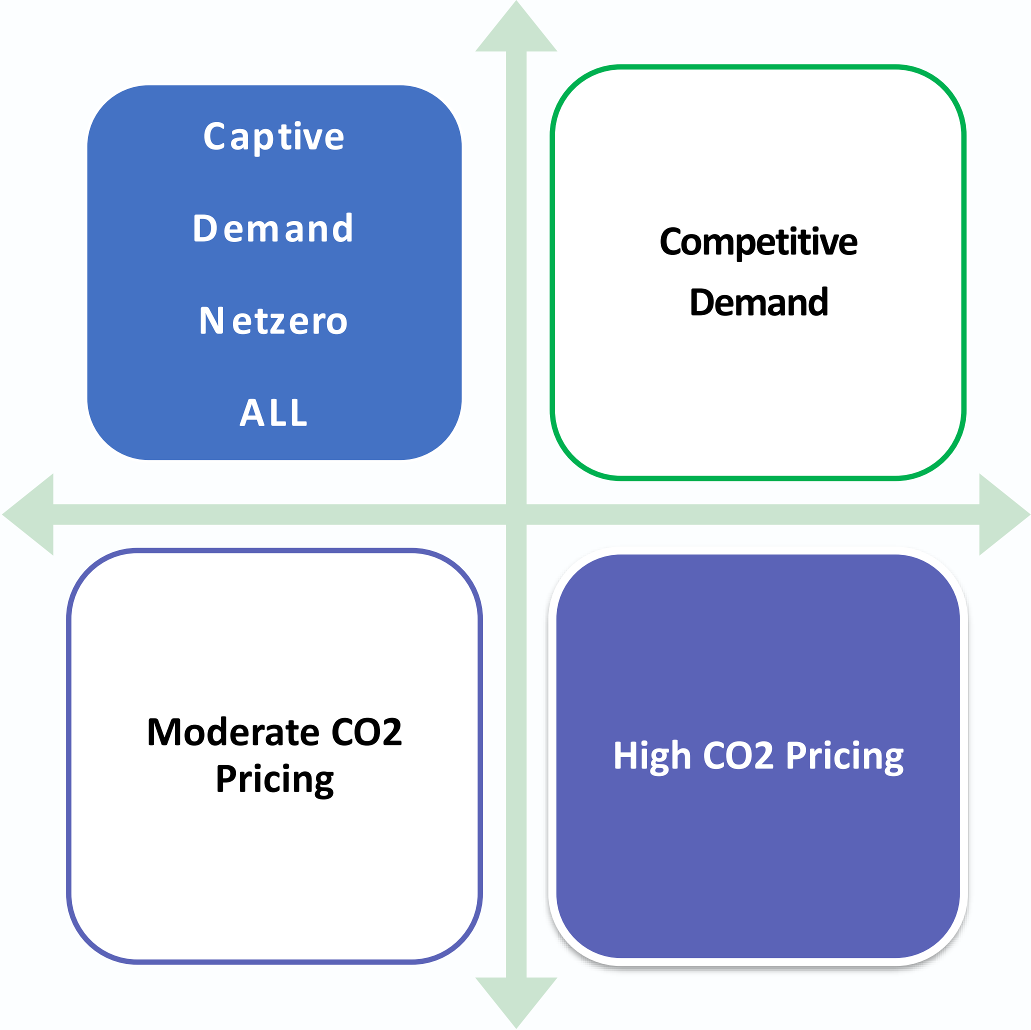
# Competitive Demand + High CO2 Pricing






- Competitive Scenario High CO2 Pricing
  - Captive Demand IND ONLY; Competitive for other sectors
  - Up to $250/ton Emission Pricing

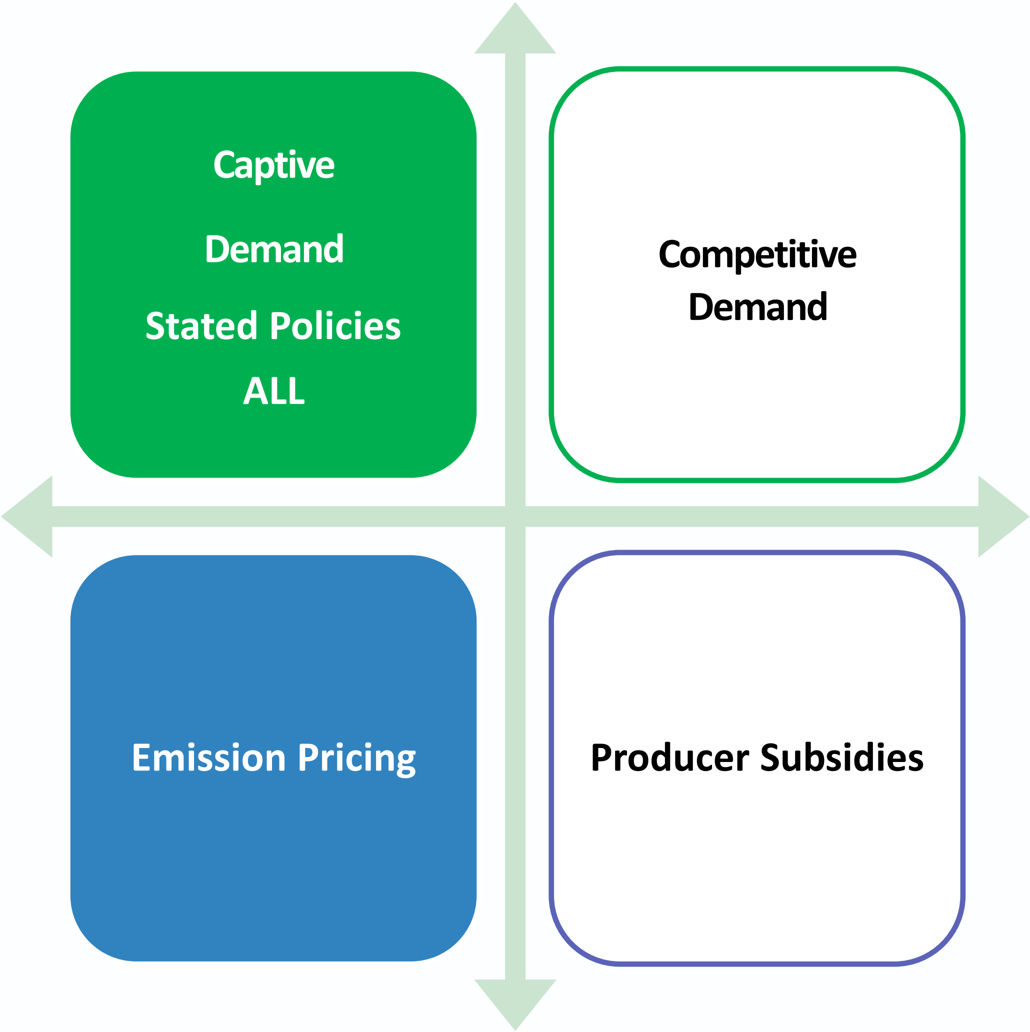
# Captive ALL Netzero + High CO2 Pricing




– Captive Demand ALL sector (higher in quantity)

– Up to $250/ton Emission Pricing

# Captive ALL State Policies + Moderate CO2 Pricing




- State Policies Captive
  - Captive Demand ALL sectors
  - Up to $132/ton Emission Pricing

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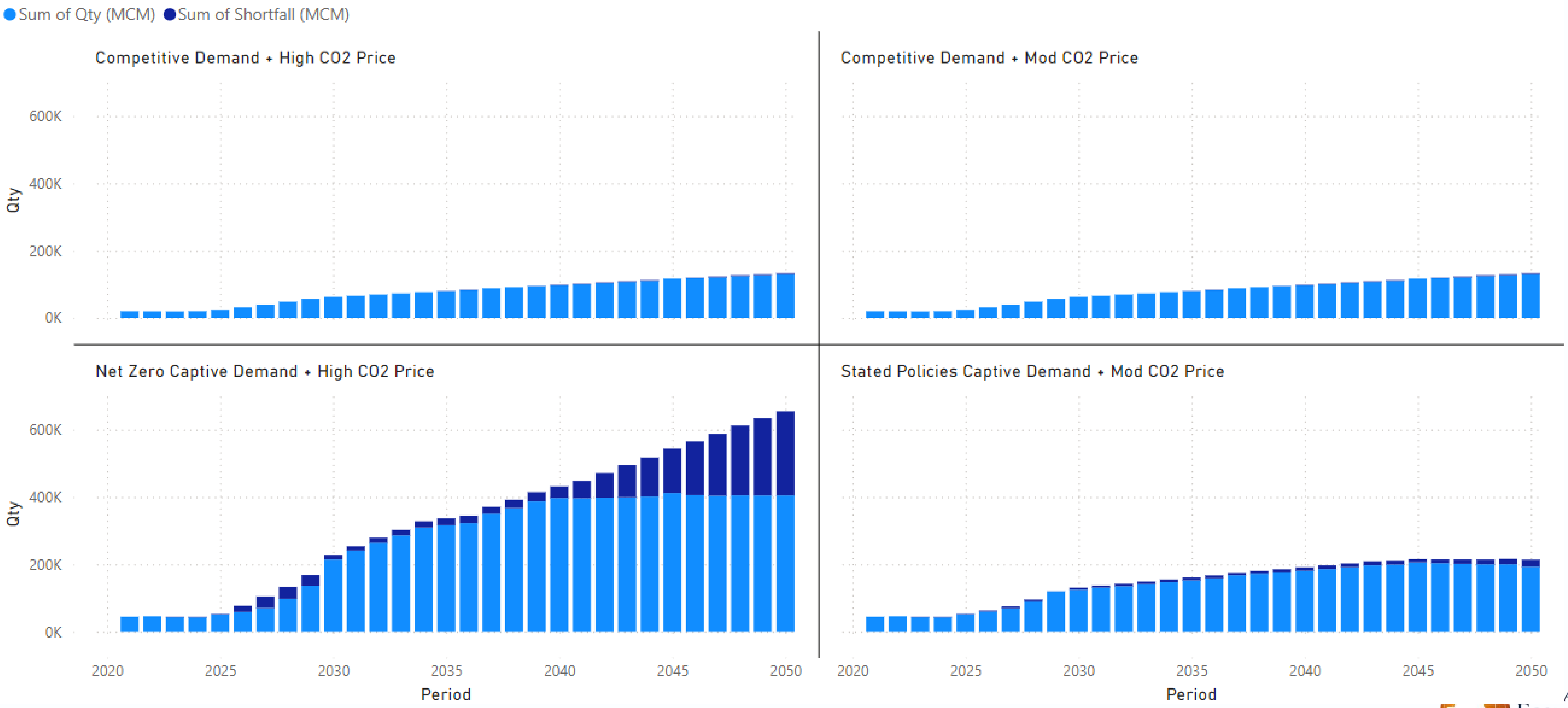
# Delivery Quantity of Hydrogen for U.S. Aggregated

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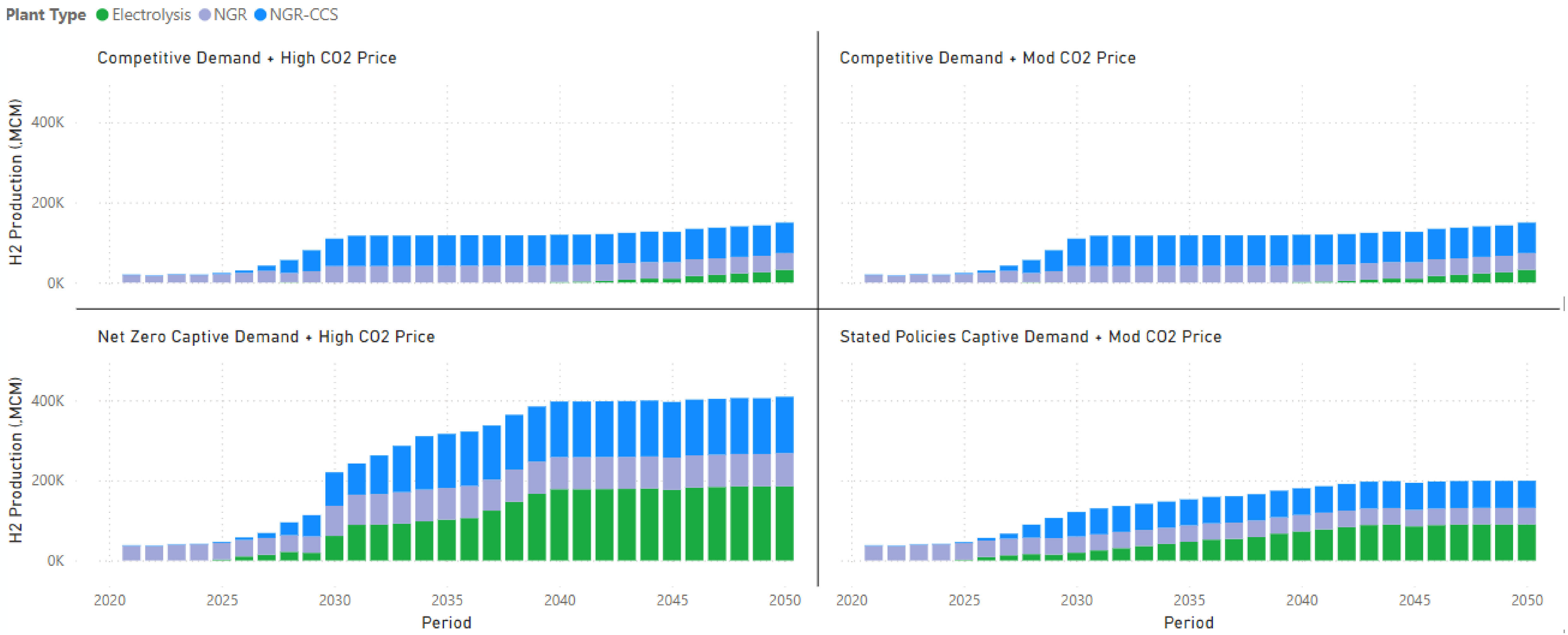
# Production Pathway of Hydrogen

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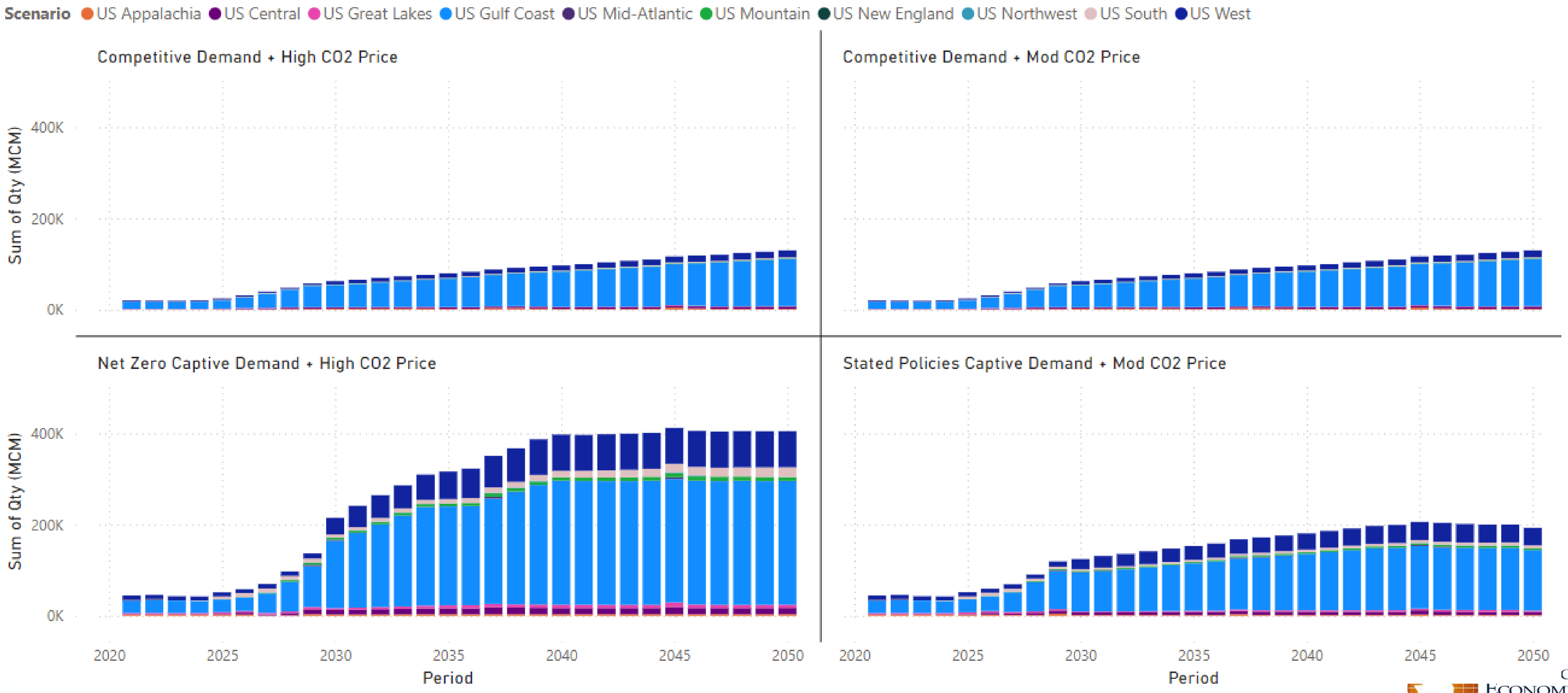
# US Hydrogen Production by Region

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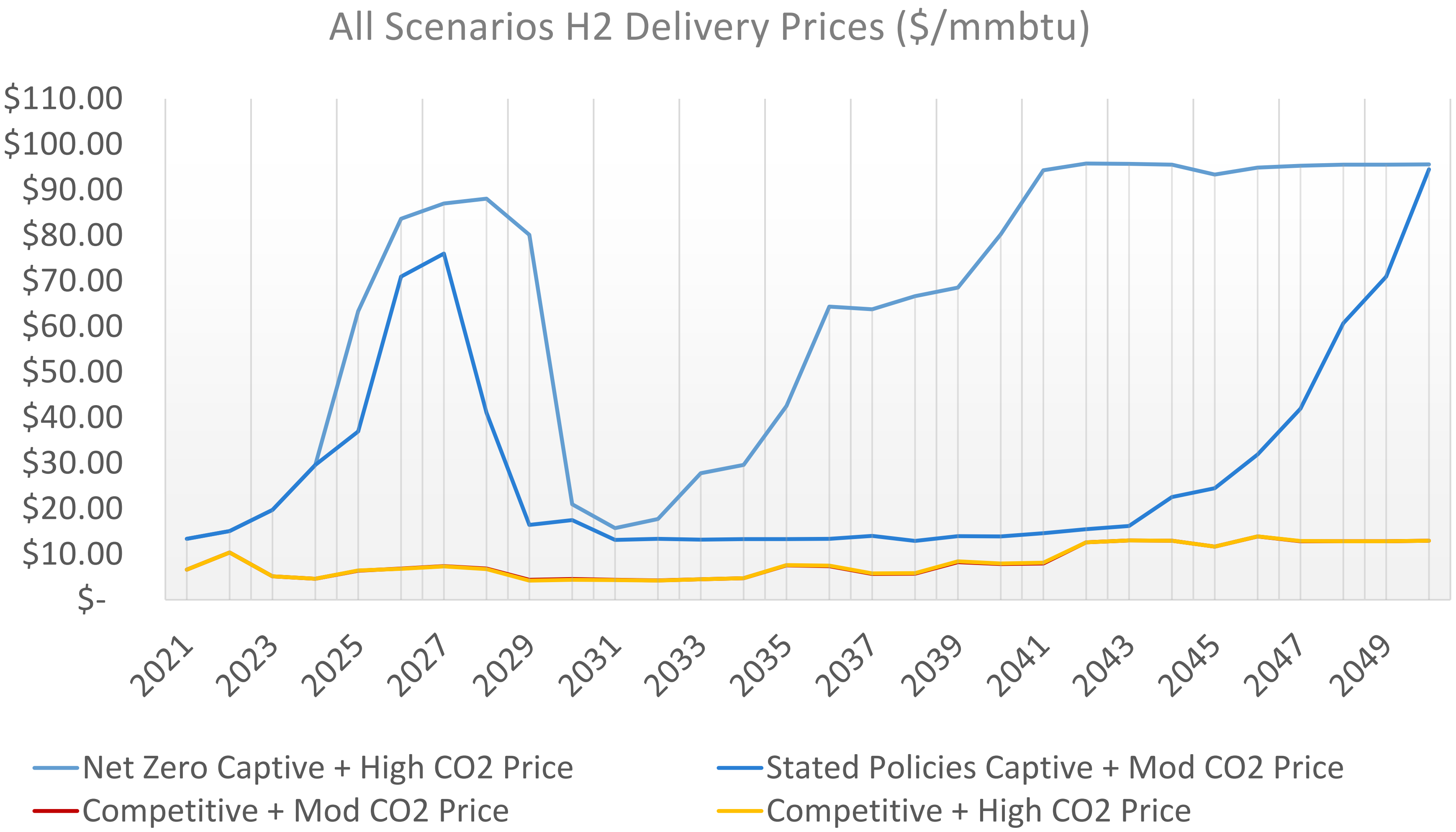
# Delivery Price of Hydrogen

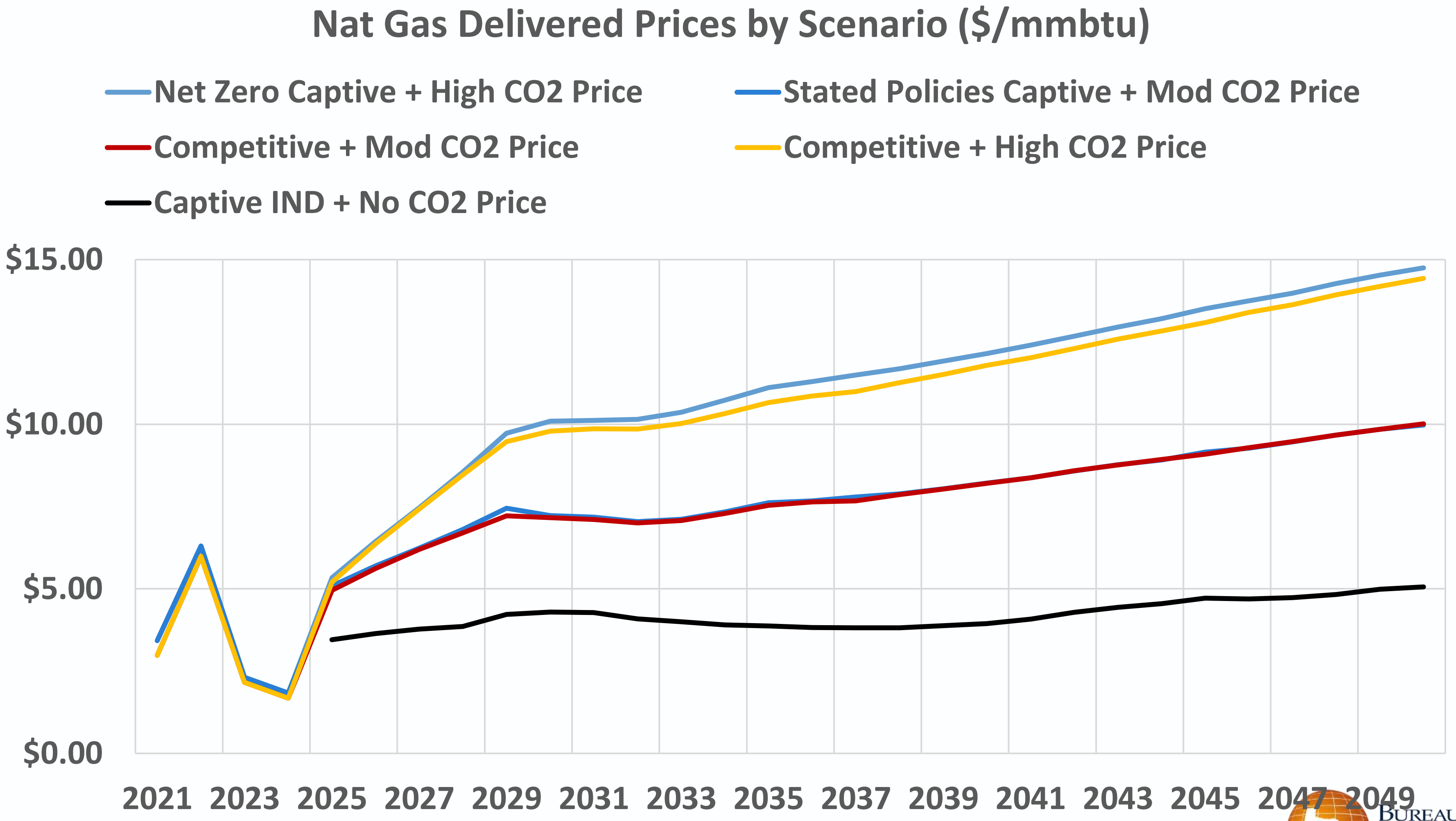
- High price before 2030: capacity at utilization of low carbon H2 is at 100% and the price is set with economic rent.
- Starting closer to 2030, carbon pricing needs to be high enough for the retrofitting capacity of existing SMR capacity for CCS upgrade.
- Captive demand is forcing the market to procure the supply: inelastic demand




**$8.3/mmbtu = $1/kg H2**

# Delivery Price of Nat Gas

- The No CO2 Price: Current Market Outlook
- Hydrogen has little impact on gas price – it does not matter if it is captive or not.
- However, CO2 Price has much greater impact for Nat Gas Price

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# Working in progress:

– Key messages:
  - Dual commodity network model works!
  - Captive demand are required for scaling up hydrogen
  - Additional policies/incentives are required for hitting netzero targets
  - Additional carbon pricing or tax will hurt natural gas market, but will benefit for CCS upgrade for SMR plants, but not demand penetration

– Next steps:
  - Demand can be divided into more granular nodes.
  - Pipeline / trunklines can be specified with more granular demand
  - The transportation and storage tariff can be structured, similar to current gas practice for hydrogen

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