Fifth Annual Conference on Carbon Capture & Sequestration

Steps Toward Deployment

Geological Storage Modeling

Optimal Design of a Fossil Fuel-Based Hydrogen Infrastructure with Carbon Capture and Sequestration

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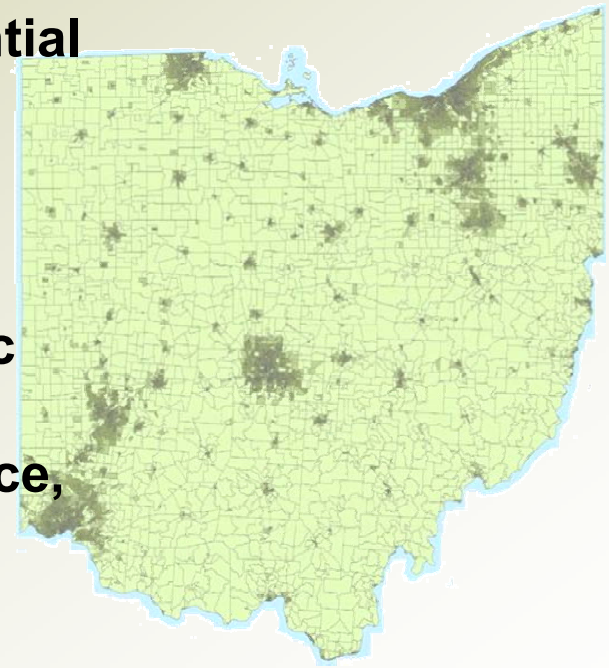
PROJECT OBJECTIVES

- Understand system design issues and economics for large-scale fossil energy system co-producing H_2 and electricity w/CO_2 sequestration.
- Conduct regional case studies of fossil H_2 systems with CO_2 capture & sequestration.
- Examine transition strategies
  today's energy system ➔ fossil H_2 & electricity w/CO_2 sequestration

Regional Case Study: Transition to a coal-based H_2 economy with CCS in Ohio

Technical Approach



- Build GIS data base, incl. H_2 demand, potential H_2 supply, existing infrastructure, CO_2 sequestration sites
- Combine spatial optimization tools and geographic data with engineering/economic models to design optimized H_2 and CO_2 infrastructures. Estimate costs, performance, emissions
- Assess "steady-state" and "dynamic scenarios" for building H2 system w/CCS

(These methods can be used anywhere in US)

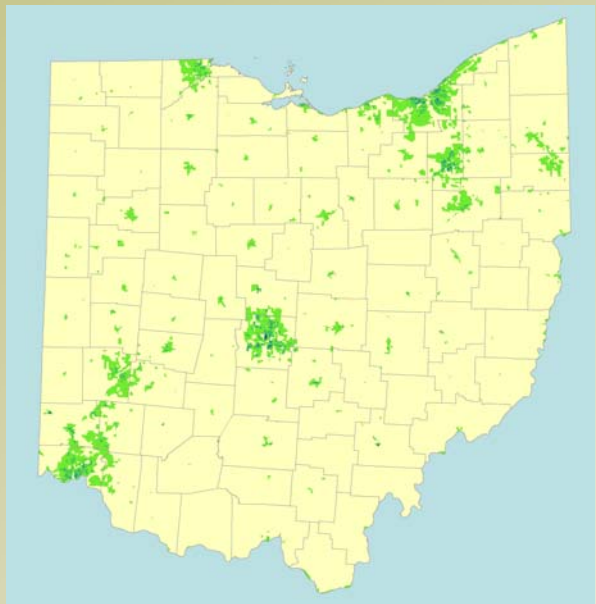
Hydrogen Scenarios Considered

Supply	Feedstock	Market Penetration	Distribution	CO_2 Sequestration
Centralized	Coal	5 - 75%	LH2 Truck	Yes
	Coal	5 - 75%	Pipeline	Yes
Onsite	Natural Gas	5 - 75%	N/A	No

- Natural Gas: $7/MMBtu
- Coal: $1.30/MMBtu
- Grid Electricity: $0.05/kWh

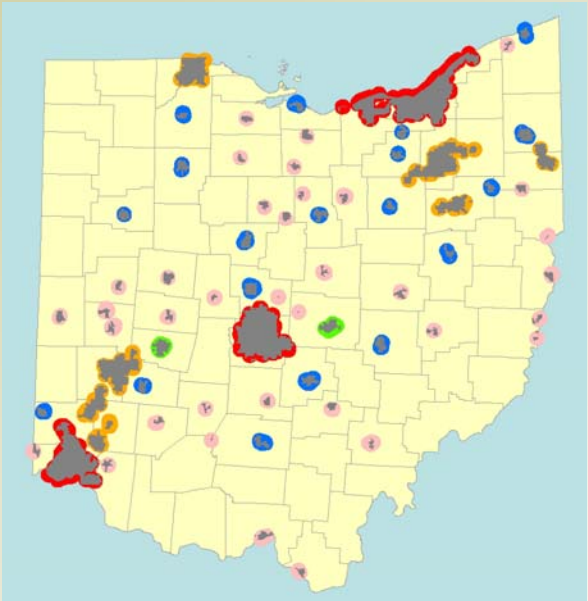
Modeling Hydrogen Demand

Population Density – US Census (people/km^2)



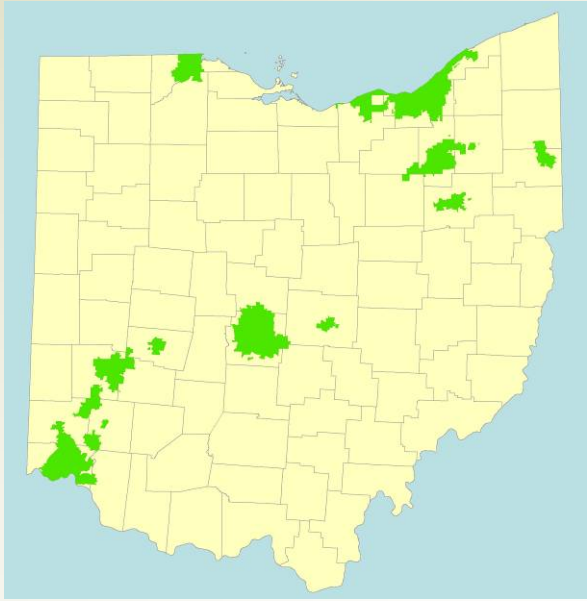
Legend
Population Density
0.00 - 500.00
500.01 - 2500.00
2500.01 - 5000.00
5000.01 - 10000.00
10000.01 - 17473.20
Counties

Estimate H_2 Demand and Aggregate



Legend
Counties
Demand Clusters
Aggregate H_2 Demand (kg/day)
85.2500 - 1000.0000
1000.0001 - 3000.0000
3000.0001 - 5000.0000
5000.0001 - 30000.0000
30000.0001 - 63235.4300

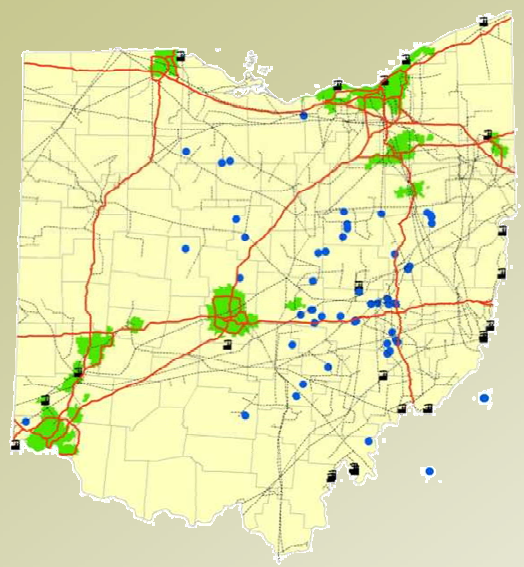
Select Demand Centers



Assumptions:
- Per Capita Vehicle Ownership: 0.7 vehicles/person
- Daily H2 Use/Vehicle: 0.6 kg/day

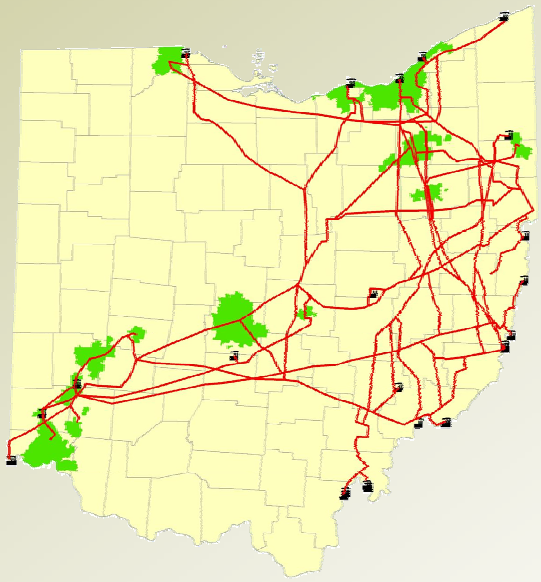
Hydrogen Supply Modeling
(10% Market Penetration)

GIS Database



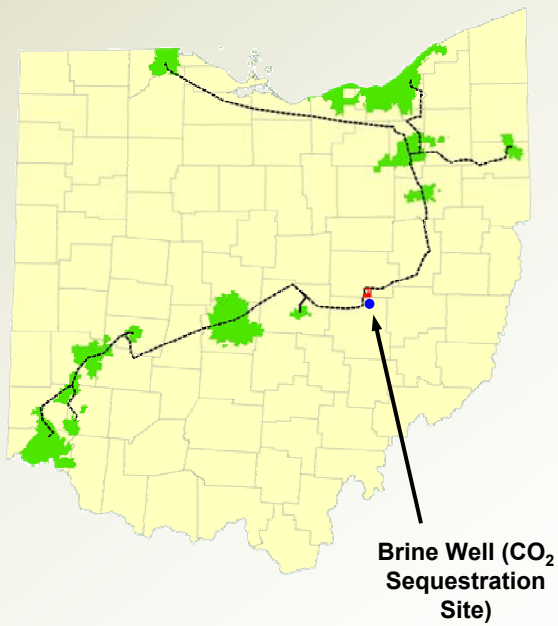
Legend
- Interstates
- Rights-of-Way
- Brine Wells
- Counties
- Demand Centers
- Coal Plants over 100mw

Identify Shortest Pathways Between Demand Centers and Coal Facilities



Legend
- Counties
- Demand Centers
- Coal Plants over 100mw
- Shortest Network Paths

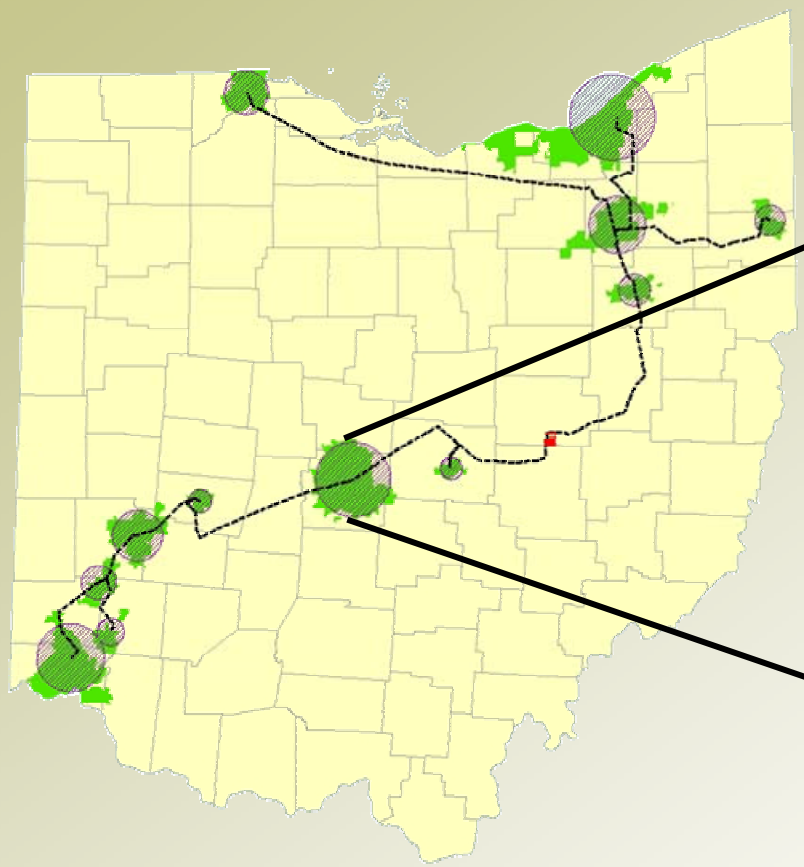
Optimal Supply Network



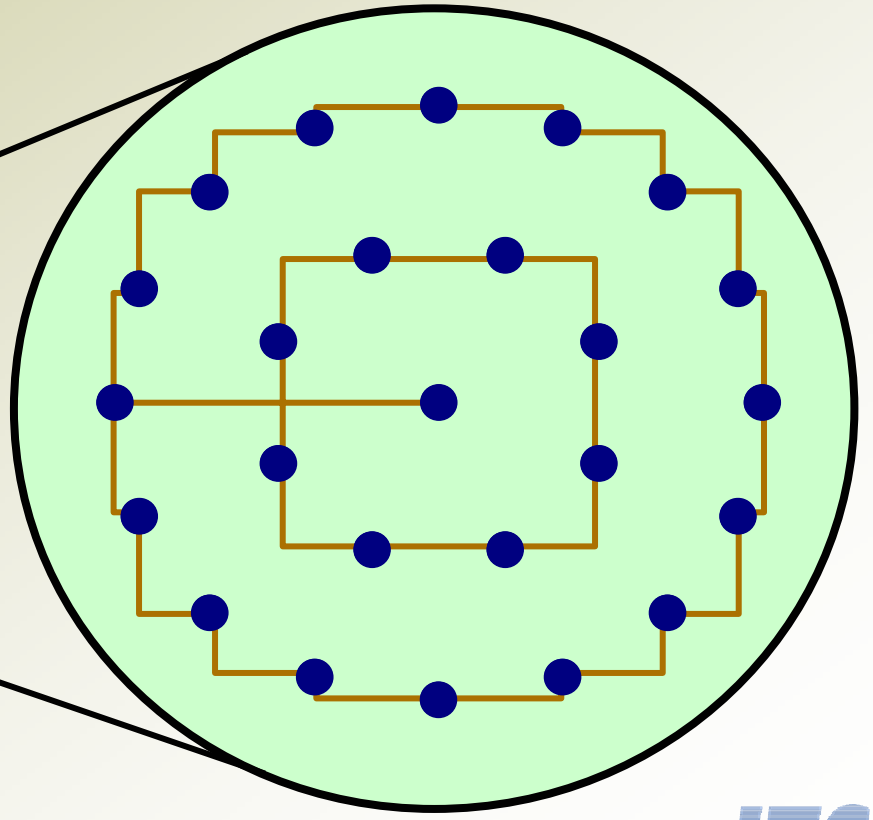
Urban H2 Distribution and Station Siting

UC Davis "Idealized City" Model

Equivalent Circle



Pipeline Design



Modeling Hydrogen Infrastructure:
Steady State Models v. Dynamic Models

Steady-state

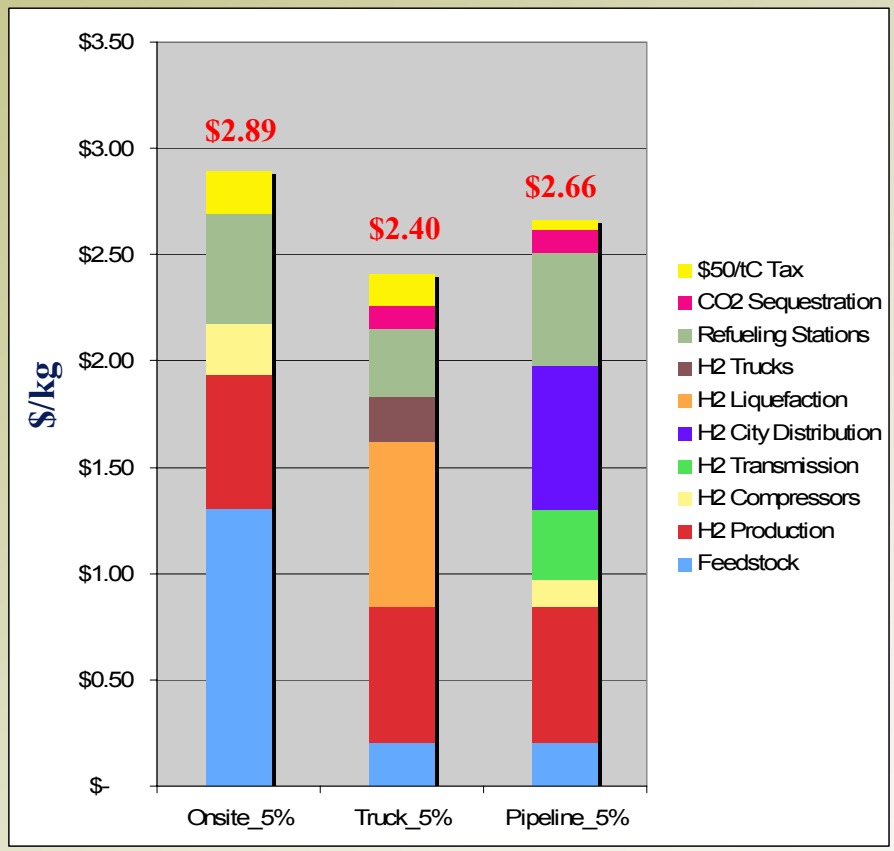
- Spatially optimized infrastructure is designed for one market penetration and is fully utilized
- Levelized cost of hydrogen is calculated for for a "snapshot" in time

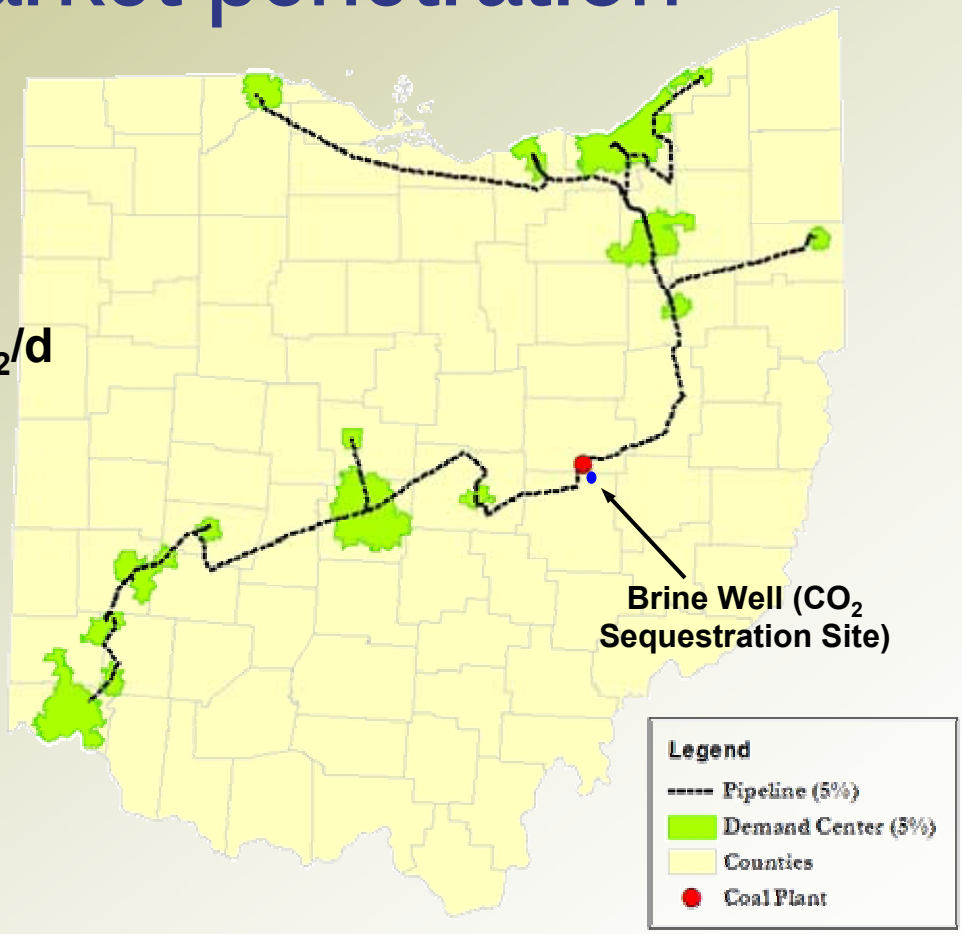
Dynamic

- Develop scenarios for infrastructure build up
- Calculate levelized cost of H2 over time
- Captures underutilization of capital as market grows

Steady state – 5% market penetration

- One coal plant - 266 tons H_2/day
- 15 demand centers
- 131 H2 refueling stations (2000 kg/d)
- CO_2 sequestration system: 4,600 tCO_2/d

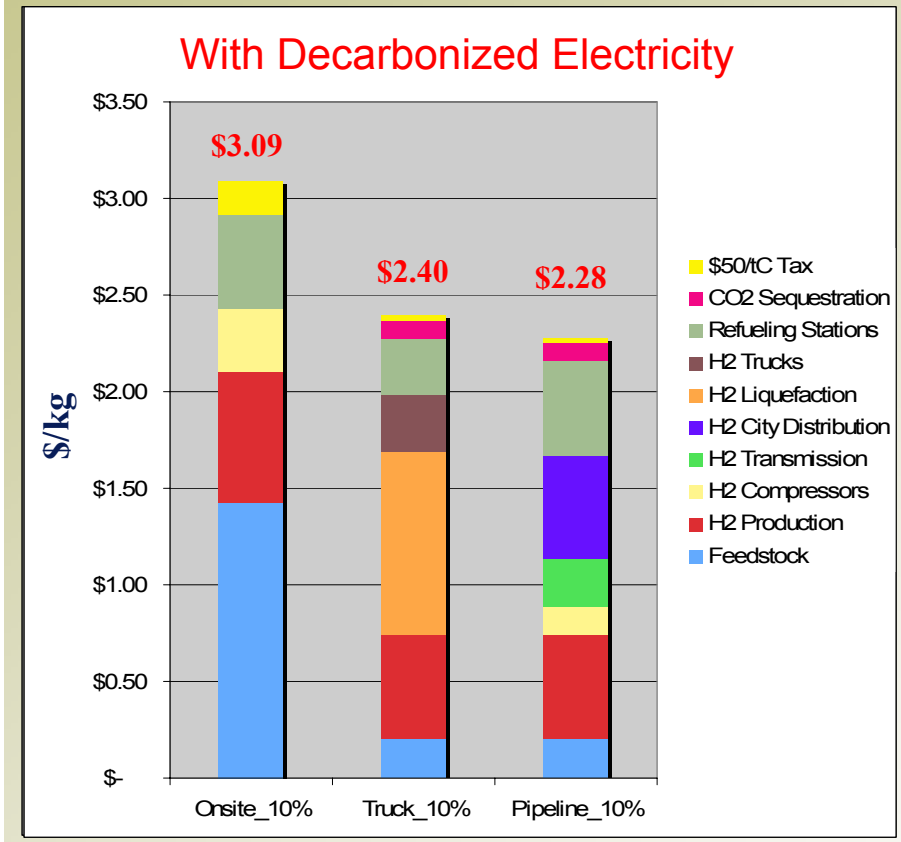


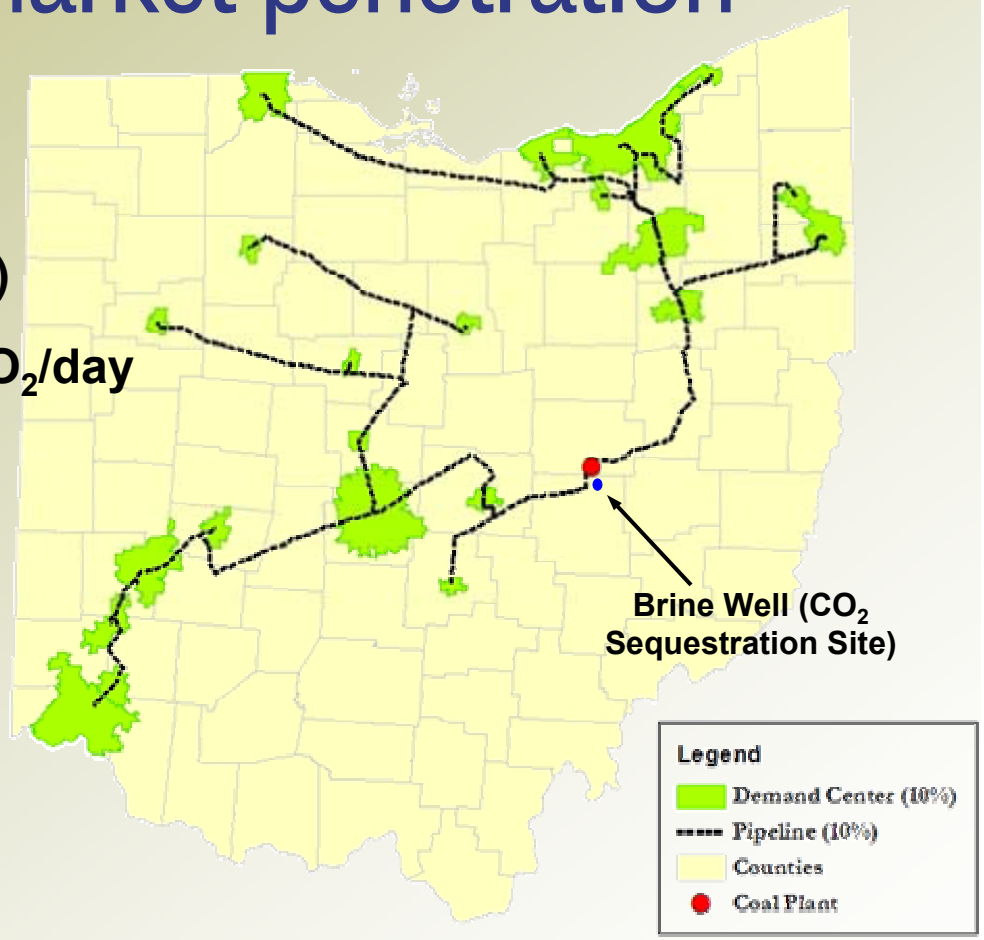


- Total capital cost: $0.7 Billion (Truck); $1.3 Billion (Pipeline)
- $1,600/vehicle (Truck); $2,800/vehicle (Pipeline)

Steady state – 10% market penetration

- One coal plant - 509 tons H_2/day
- 22 demand centers
- 182 H_2 refueling stations (2600 kg/d)
- CO_2 sequestration system:8,800 tCO_2/day

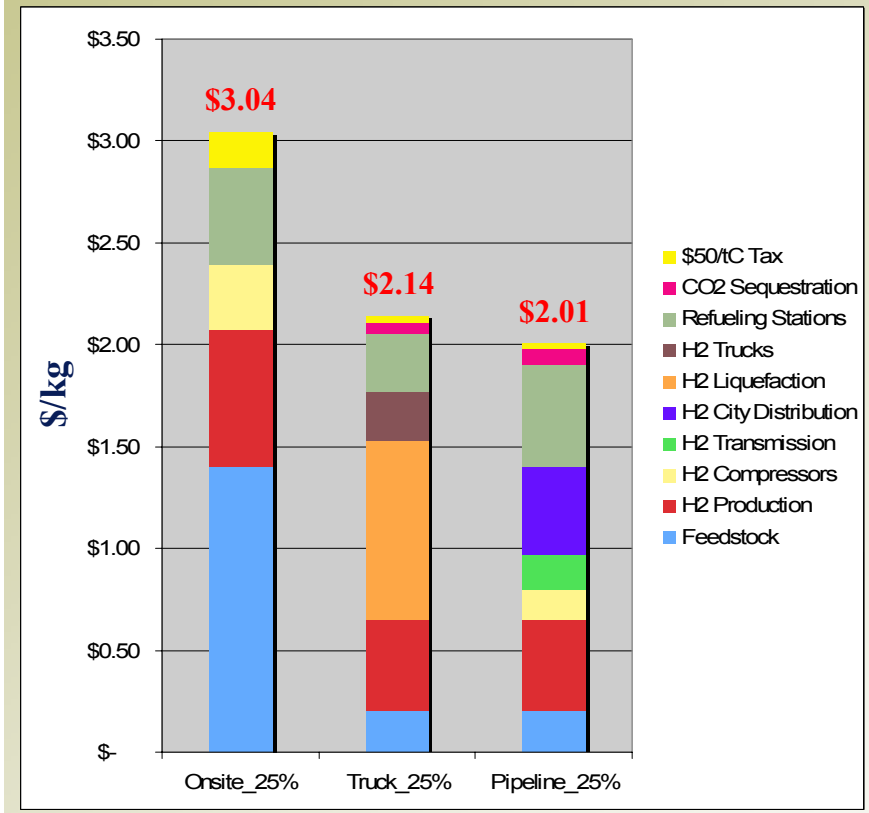


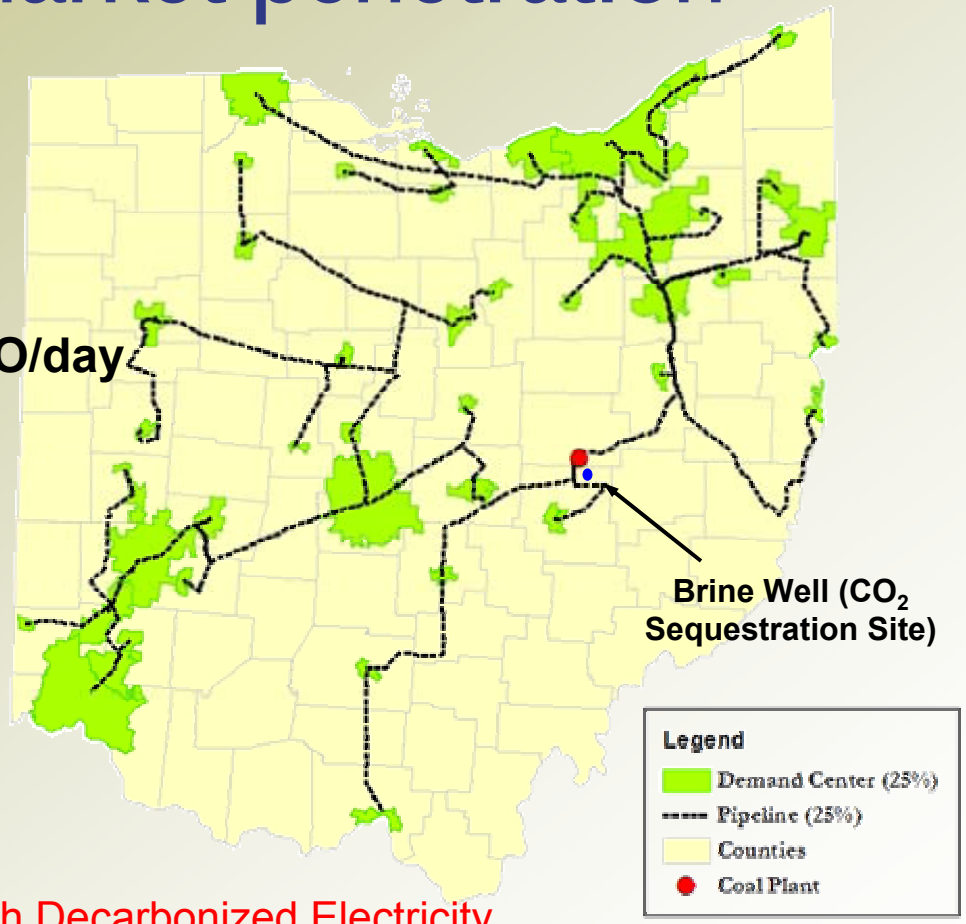


- Total capital cost: $1.2 Billion (Truck); $2.0 Billion (Pipeline)
- $1,400/vehicle (Truck); $2,400/vehicle (Pipeline)

Steady state – 25% market penetration

- One coal plant – 1,337 tons H_2/day
- 46 demand centers
- 471 H2 refueling stations (2700 kg/d)
- CO_2 sequestration system: 23,000 t CO/day



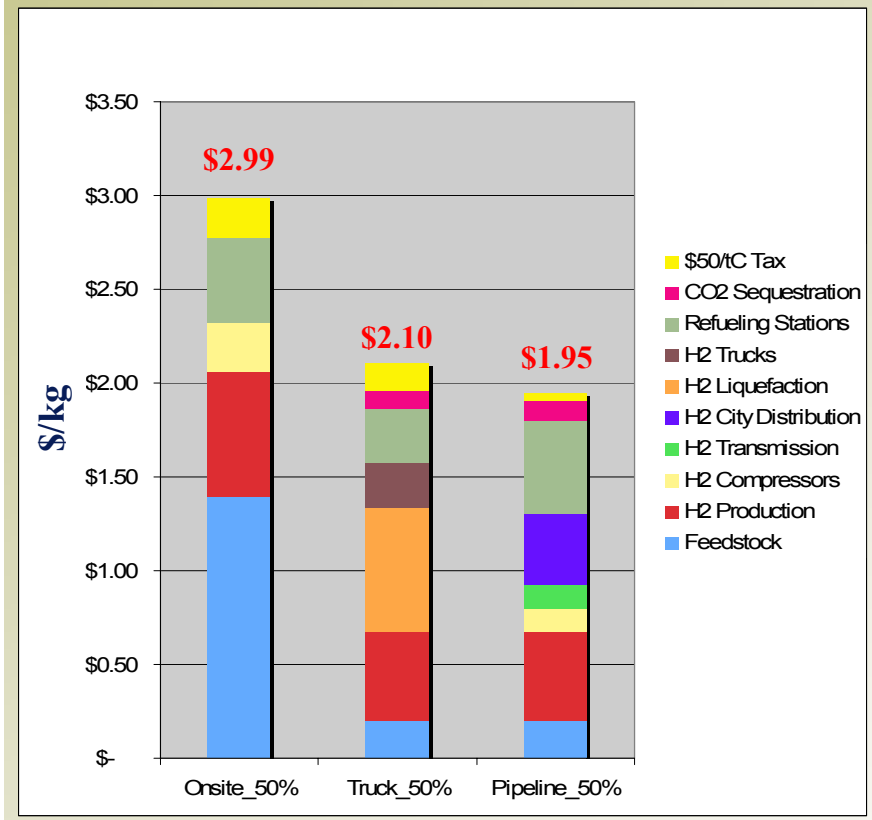


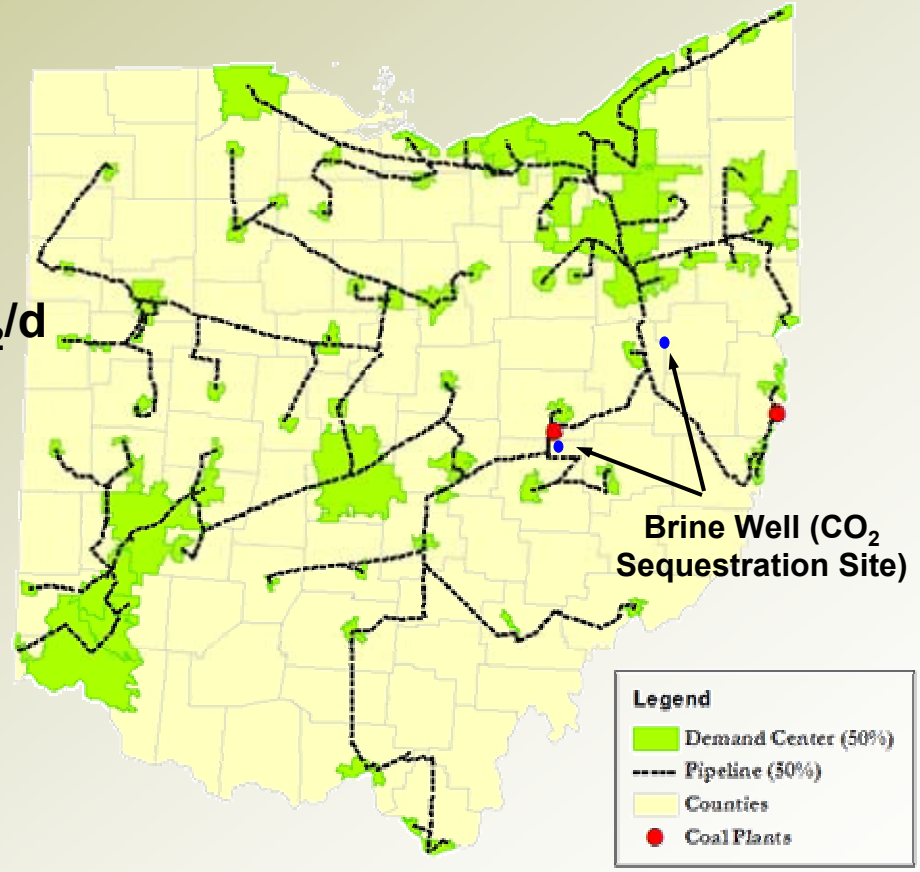
With Decarbonized Electricity

- Total capital cost: $2.6 Billion (Truck); $4.5 Billion (Pipeline)
- $1,200/vehicle (Truck); $2,000/vehicle (Pipeline)

Steady state – 50% market penetration

- Two coal plants – 2,600 tons H_2/day
- 78 demand centers
- 926 H2 refueling stations (2800 kg/d)
- CO_2 sequestration system: 46,000 tCO_2/d

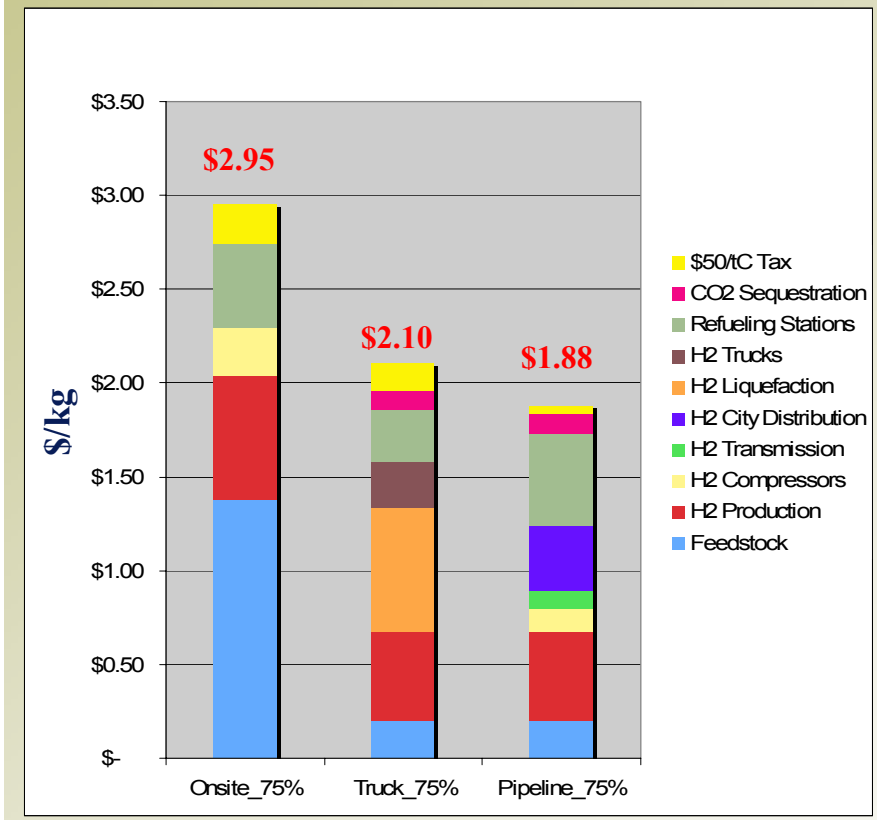


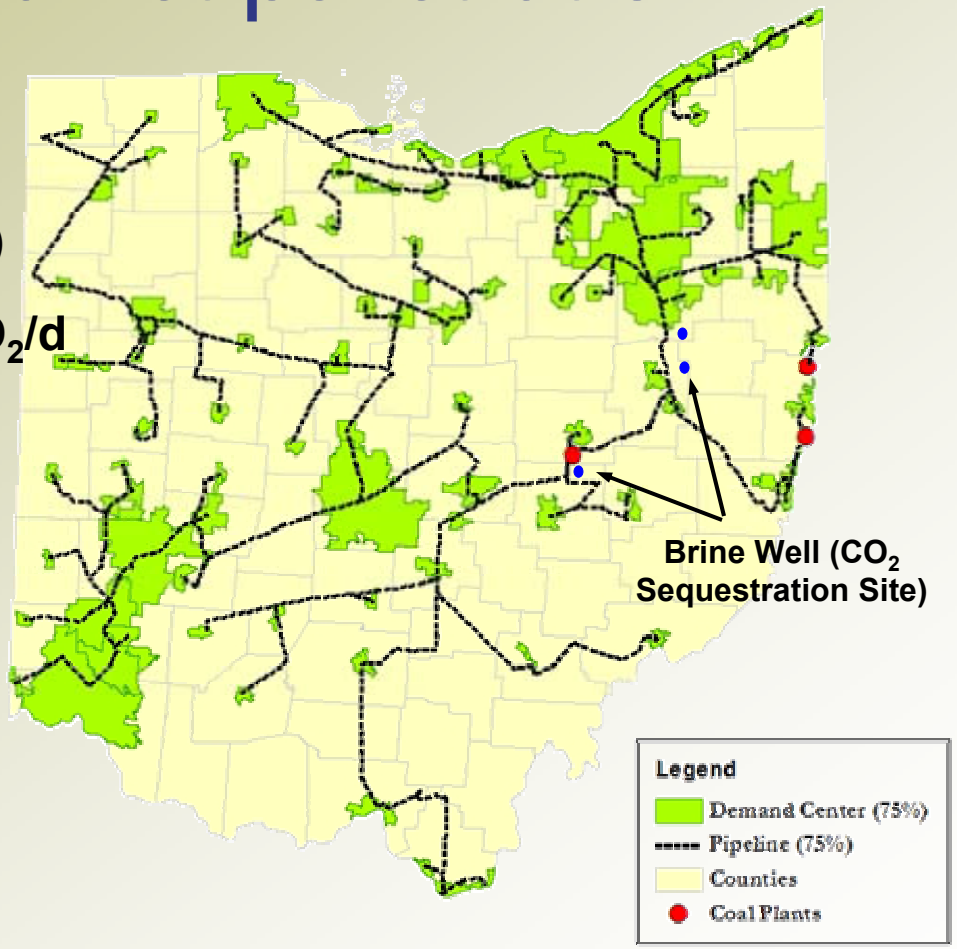


- Total capital cost: $5.3 Billion (Truck); $8.4 Billion (Pipeline)
- $1,200/vehicle (Truck); $1,900/vehicle (Pipeline)

Steady state – 75% market penetration

- **Three coal plants – 4,000 tons H_2/day**
- **96 demand centers**
- **1,380 H2 refueling stations (2900 kg/d)**
- **CO_2 sequestration system: 69,000 tCO_2/d**



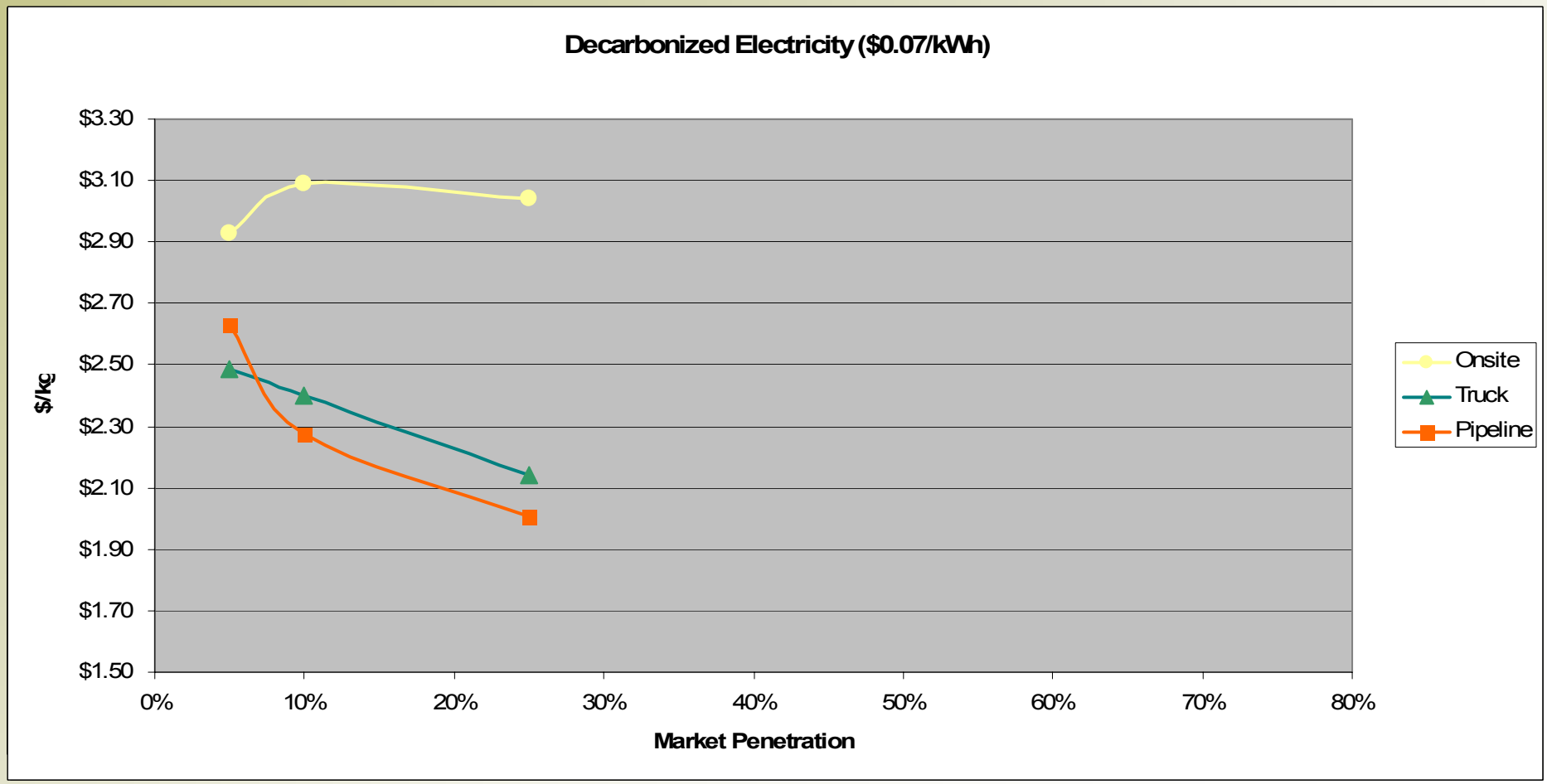


- **Total capital cost: $8.0 Billion (Truck); $12.0 Billion (Pipeline)**
- **$1,200/vehicle (Truck); $1,800/vehicle (Pipeline)**

Steady-State Summary

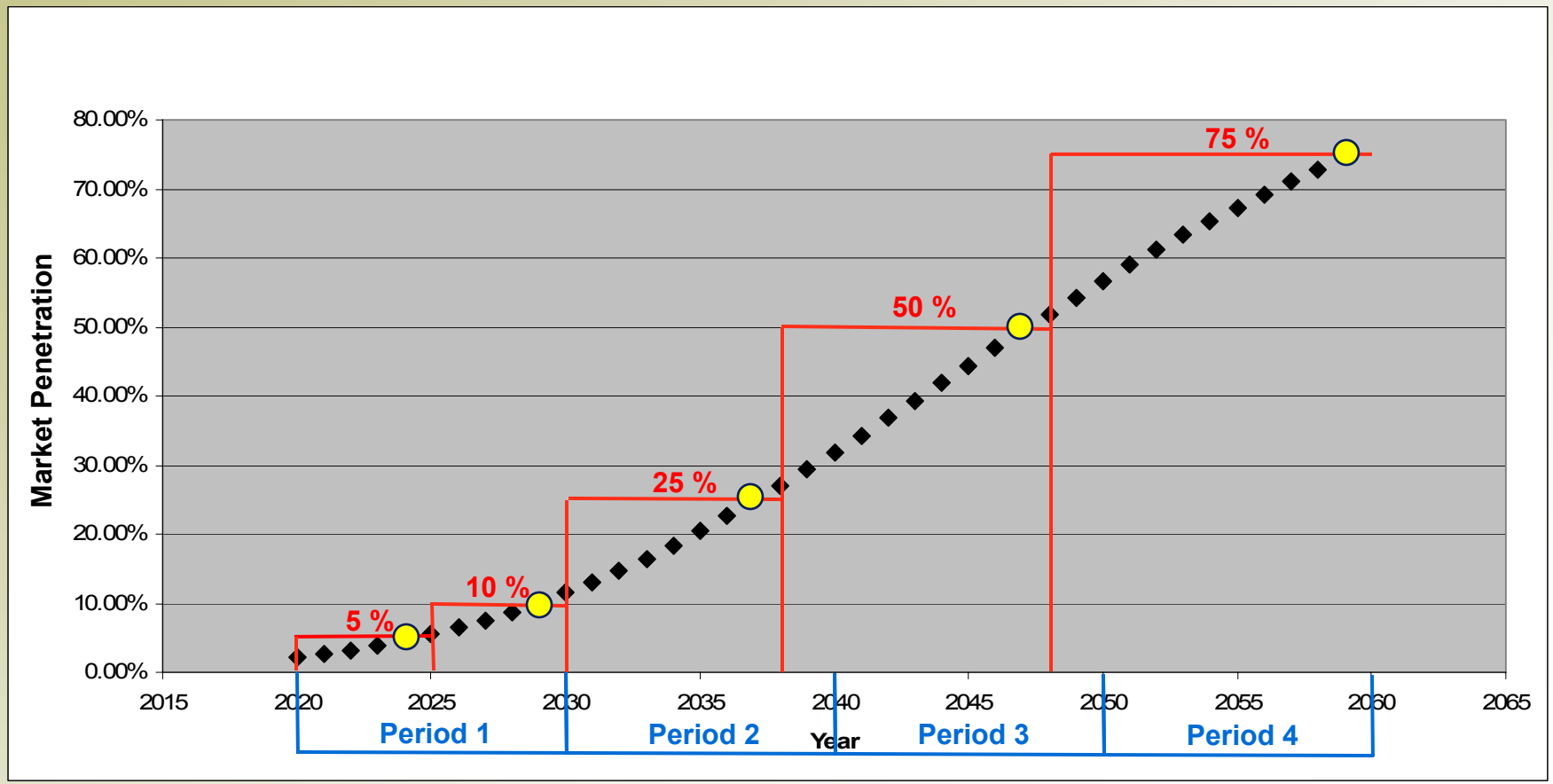
Base Case: No carbon tax; $0.05/kWh electricity

Decarbonized Electricity: $0.07/kWh
$50/ton Carbon Tax



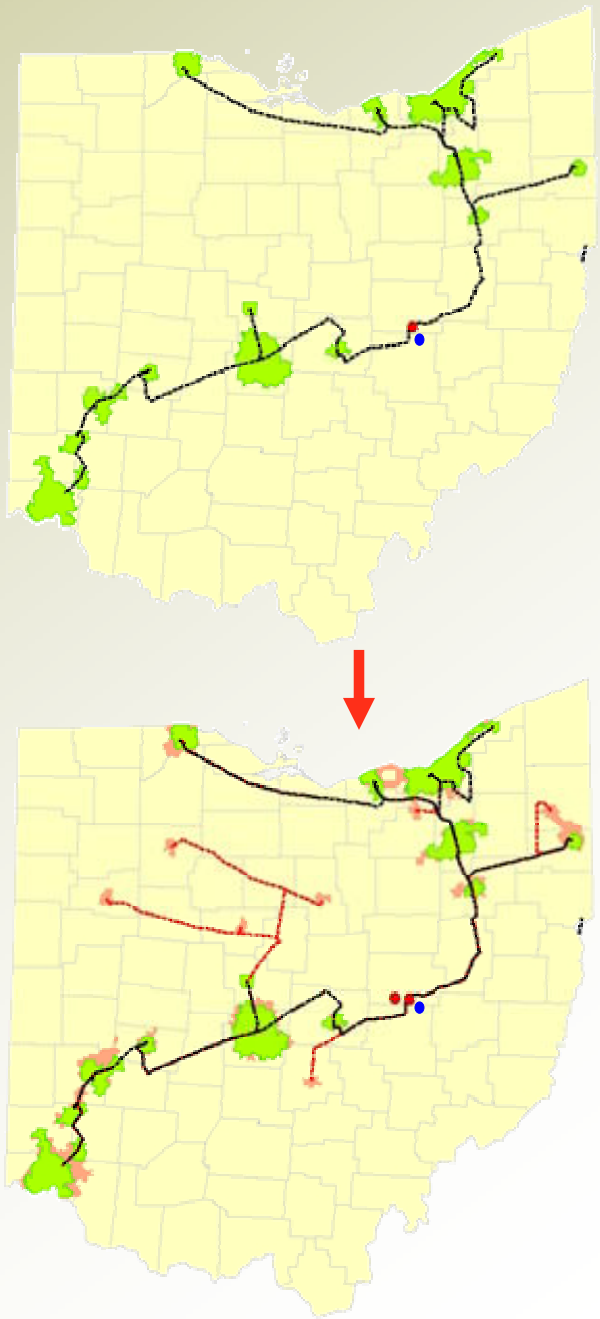
Dynamics: H_2 Infrastructure Build-Out Scenarios

Hydrogen Vehicle Market Penetration



Build-Out Scenario 1: Period 1

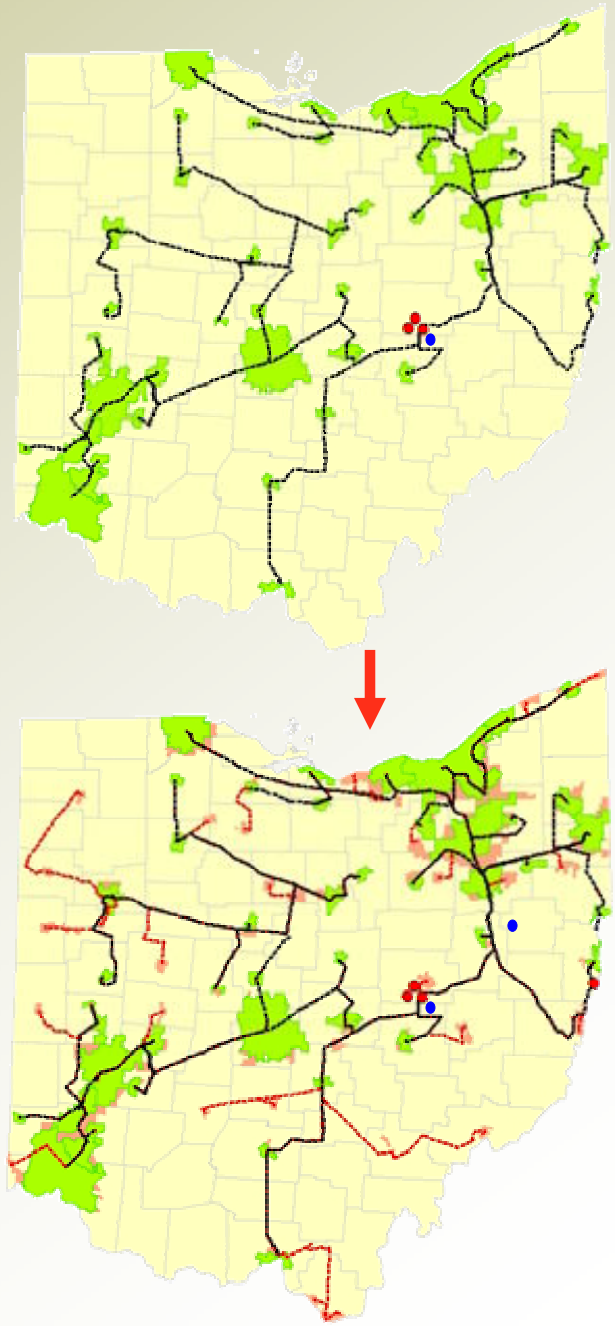
PERIOD 1	Year 1 (2020)	Year 6 (2025)	Year 10 (2029)
Market Penetration	2.1%	5.5%	9.6%
H2 Demand (tons H2/day)	113	292	509
H2 System	**Initial Capacity**	**New Capacity**	**Cumulative Capacity**
Coal Plant (tons H2/day)	296	270	565
H2 Transmission Pipelines (km)	931	43%	1,327
H2 Distribution Pipelines (km)	854	46%	1,251
Refueling Stations	131	70%	223
Sequestration System			
CO2 Pipeline (km)	14	0%	14
Injection Wells	2	100%	4



Levelized Cost of Hydrogen: $3.34/kg

Build-Out Scenario 1: Period 2

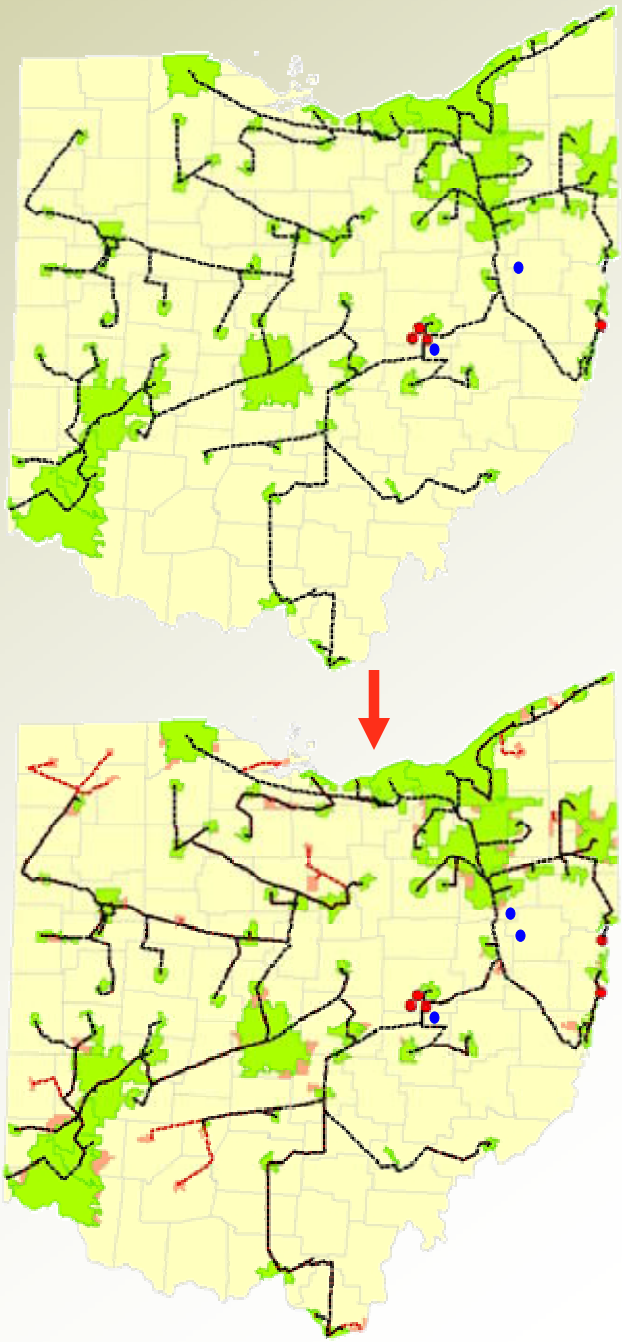
PERIOD 2	Year 11 (2030)	Year 19 (2038)	Year 20 (2039)
Market Penetration	11.5%	27.0%	29.4%
H2 Demand (tons H2/day)	611	1,440	1,566
H2 System	**New Capacity**	**New Capacity**	**Cumulative Capacity**
Coal Plant (tons H2/day)	920	1,452	2,938
H2 Transmission Pipelines (km)	75%	140%	5,588
H2 Distribution Pipelines (km)	110%	65%	4,334
Refueling Stations	135%	91%	1,004
Sequestration System			
CO2 Pipeline (km)	0%	793%	125
Injection Wells	150%	110%	21



Levelized Cost of Hydrogen: $2.96/kg

Build-Out Scenario 1: Period 3

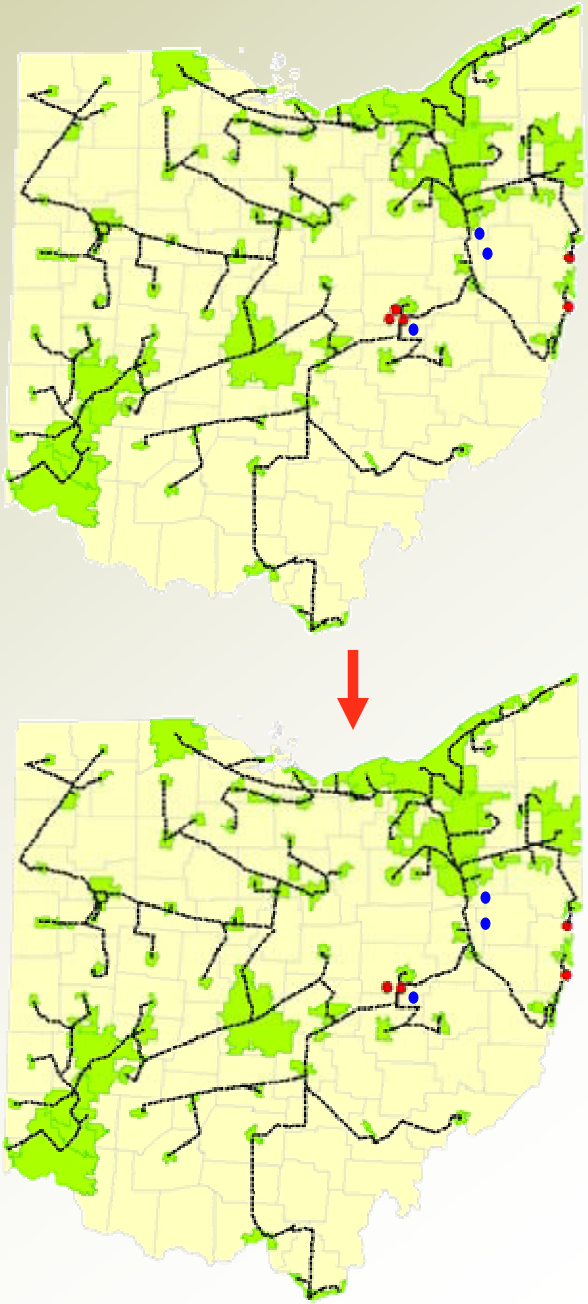
PERIOD 3	Year 29 (2048)	Year 30 (2049)
Market Penetration	51.9%	54.3%
H2 Demand (tons H2/day)	2,764	2,892
H2 System	**New Capacity**	**Cumulative Capacity**
Coal Plant (tons H2/day)	1,491	4,428
H2 Transmission Pipelines (km)	65%	9,192
H2 Distribution Pipelines (km)	32%	5,695
Refueling Stations	49%	1,503
Sequestration System		
CO2 Pipeline (km)	58%	197
Injection Wells	52%	32



Levelized Cost of Hydrogen: $2.46/kg

Build-Out Scenario 1: Period 4

PERIOD 4	Year 31 (2050		Year 40 (2059)
Market Penetration	56.7%		74.9%
H2 Demand (tons H2/day)	3,017		3,985
H2 System	**New Capacity**	***Retired Capacity***	**Cumulative Capacity**
Coal Plant (tons H2/day)	565	*565*	4,428
H2 Transmission Pipelines (km)	0	*0*	9,192
H2 Distribution Pipelines (km)	0	*0*	5,695
Refueling Stations	0	*0*	1,503
Sequestration System			
CO2 Pipeline (km)	0	*0*	197
Injection Wells	0	*0*	32



Levelized Cost of Hydrogen: $2.22/kg

H2 Infrastructure Build-Out Scenarios

	Feedstock	Market Penetration	Distribution
1. Oversize Transmission Pipelines for 25% MP	Coal	5 – 75%	Pipeline
2. Oversize Transmission Pipelines for 75% MP	Coal	5 - 75%	Pipeline
3. Oversize Initial Hydrogen Production Plant for 25% MP	Coal	5 - 75%	Pipeline

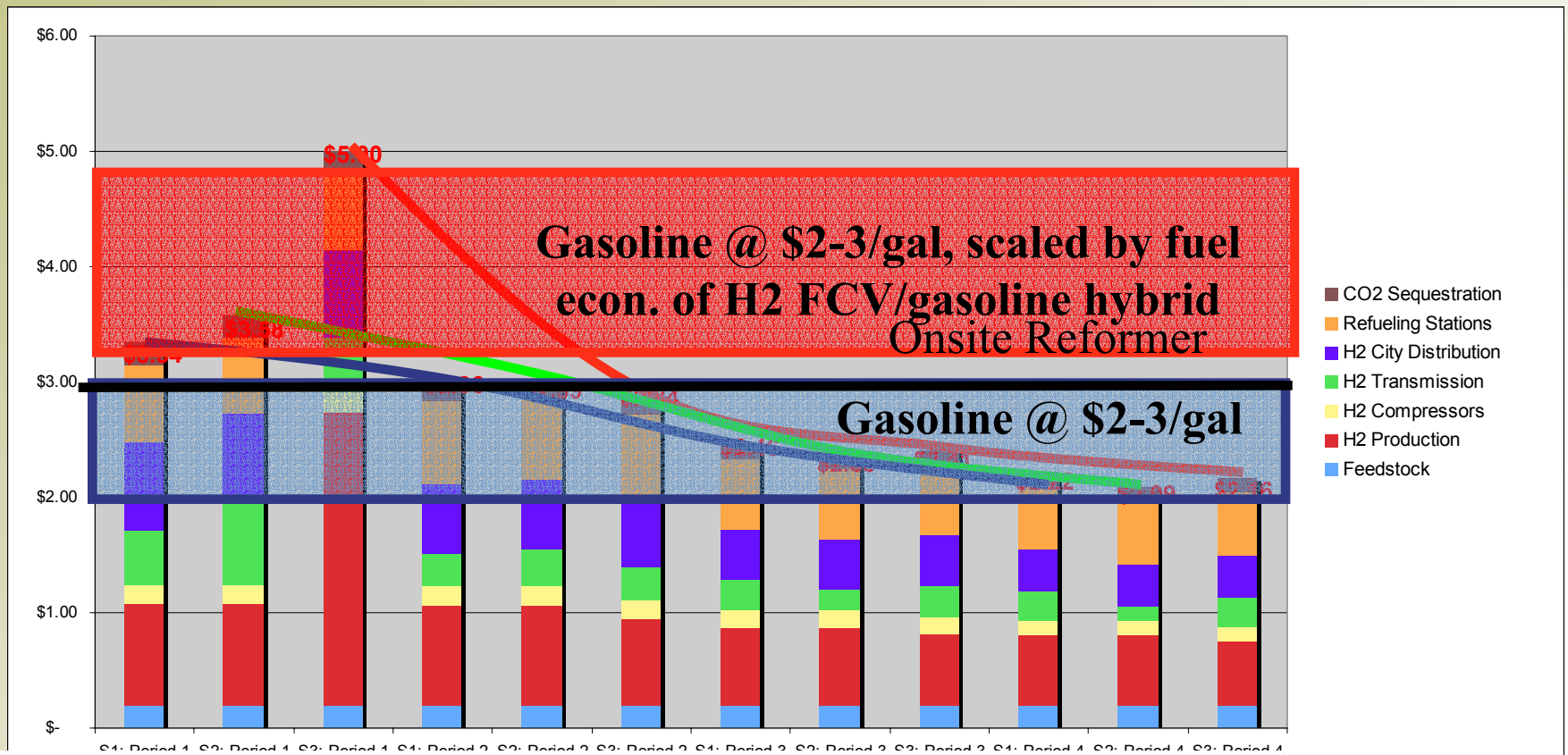
Build-Out Scenarios

Summary of Results

Scenario 1: Oversize Transmission Pipelines for 25% MP

Scenario 2: Oversize Transmission Pipelines for 75% MP

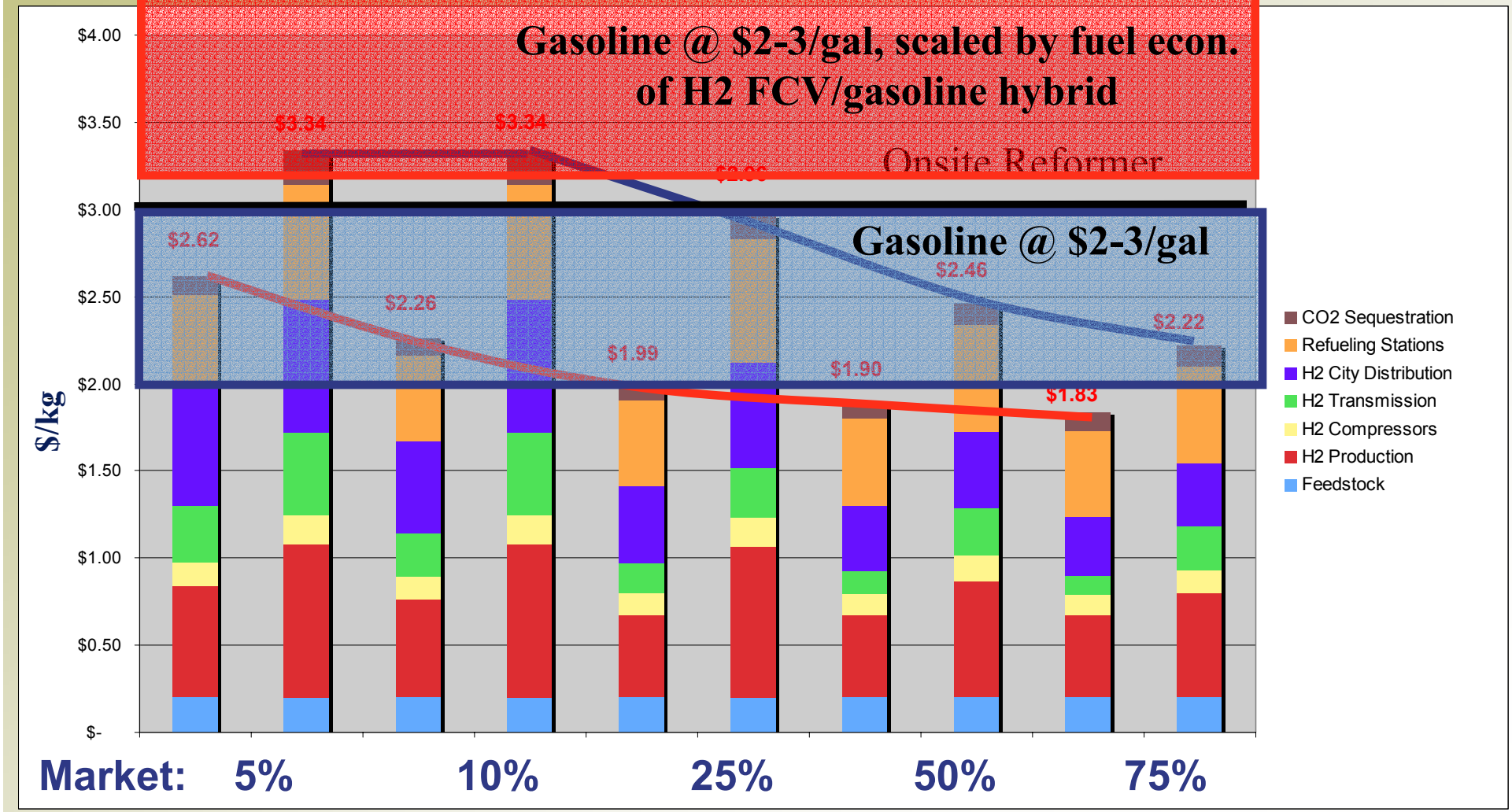
Scenario 3: Oversize Initial Hydrogen Plant for 25% MP



Period: ← 1 → ← 2 → ← 3 → ← 4 →

Comparison of Steady-State and Build-Out Scenarios

Levelized costs associated with steady-state scenarios are consistently lower (underutilization and legacy effects)



Conclusions

Steady-State

- Steady-State models underestimate future costs as a result of underutilization and legacy effects
- Pipelines can become competitive very early if carbon emissions are regulated (~10% MP); ~40% MP if not regulated
- Liquid truck delivery is sensitive to electricity prices

Build-Out

- Oversizing early infrastructure results in much higher initial hydrogen costs and only slightly lower costs in the longer term
- Despite steady-state results, onsite may remain competitive with pipelines until ~25% MP because utilization can be kept high (if natural gas prices increase, central coal w/ CCS becomes competitive sooner).

Acknowledgments

Sponsors

- NETL
- DOE
- H2 Pathways Program at UC Davis

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