NREL
NATIONAL RENEWABLE ENERGY LABORATORY

AN024

Effects of Technology Cost Parameters on Hydrogen Pathway Succession

2012 Annual Merit Review

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This presentation does not contain any proprietary, confidential, or otherwise restricted information

Overview

Analysis Timeline & Budget

Start date: Feb 2009

Status: Completed Oct 2011

100% DOE funded

- $150K DTI
- $75K NREL

MSM Timeline & Budget

Start date: Feb 2005

Status: ongoing

Percent complete: 80%

100% DOE funded

FY11 funding

- $250K NREL/Systems Integration
- $100K Sandia NL

FY12 funding

- $150K NREL/SIO
- $100K Sandia NL

Barriers

- Future market behavior (A)
- Inconsistent data, assumptions and guidelines (C)
- Suite of models and tools (D)

Partners

Sandia National Laboratories (SNL)

- Computational development

NREL

- H2A Production, HyDRA

Argonne National Laboratory (ANL)

- HDSAM, GREET

Directed Technologies, Inc. (DTI)

- HyPRO

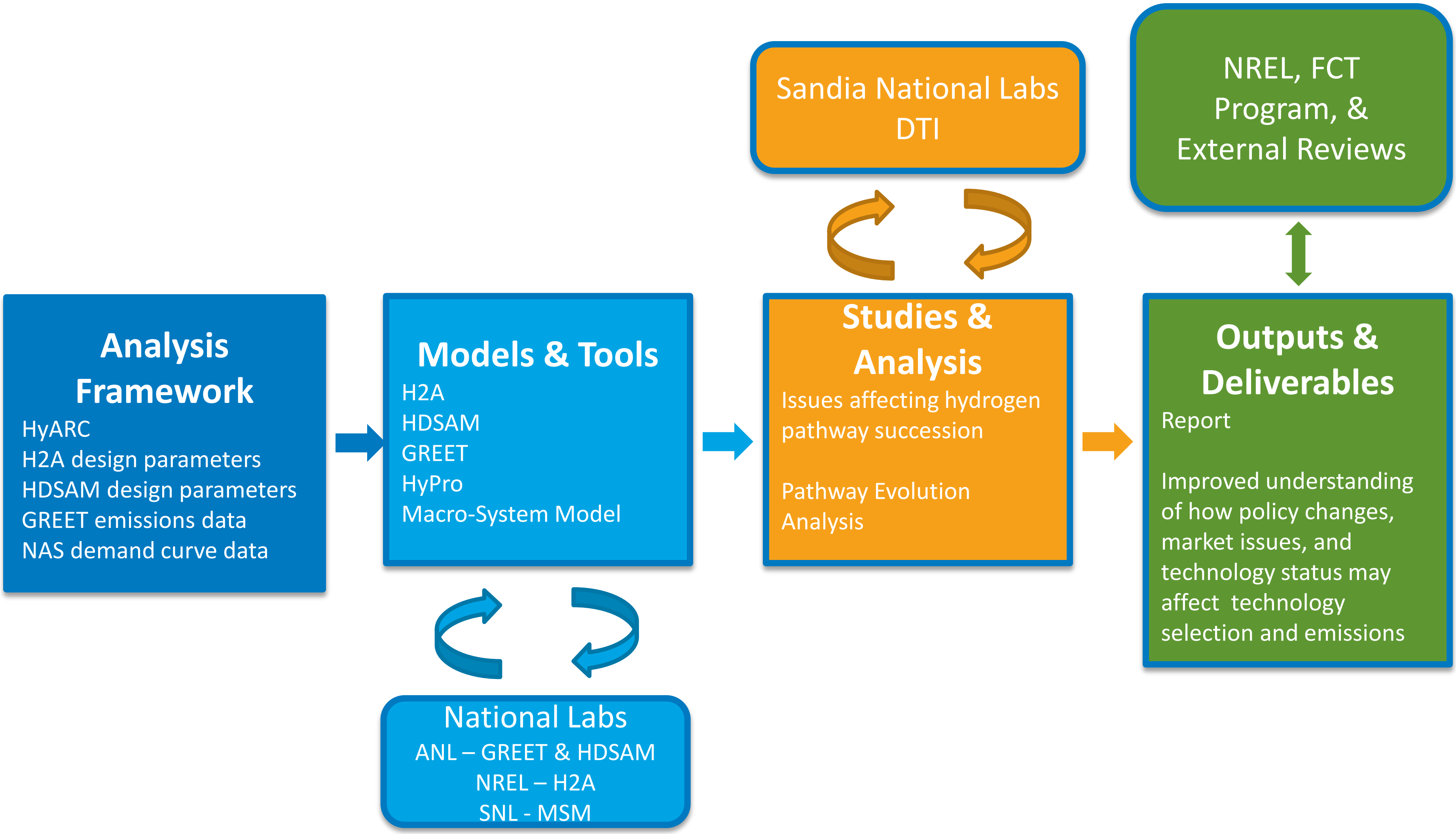
SENTECH (now SRA)

- MSM User Guide

Project Overview

Approach

Effects of Technology Cost Parameters on Hydrogen Pathway Succession



Analysis Objectives

Relevance

Improve understanding of options and tradeoffs in the evolution of hydrogen production and delivery infrastructure for transportation.

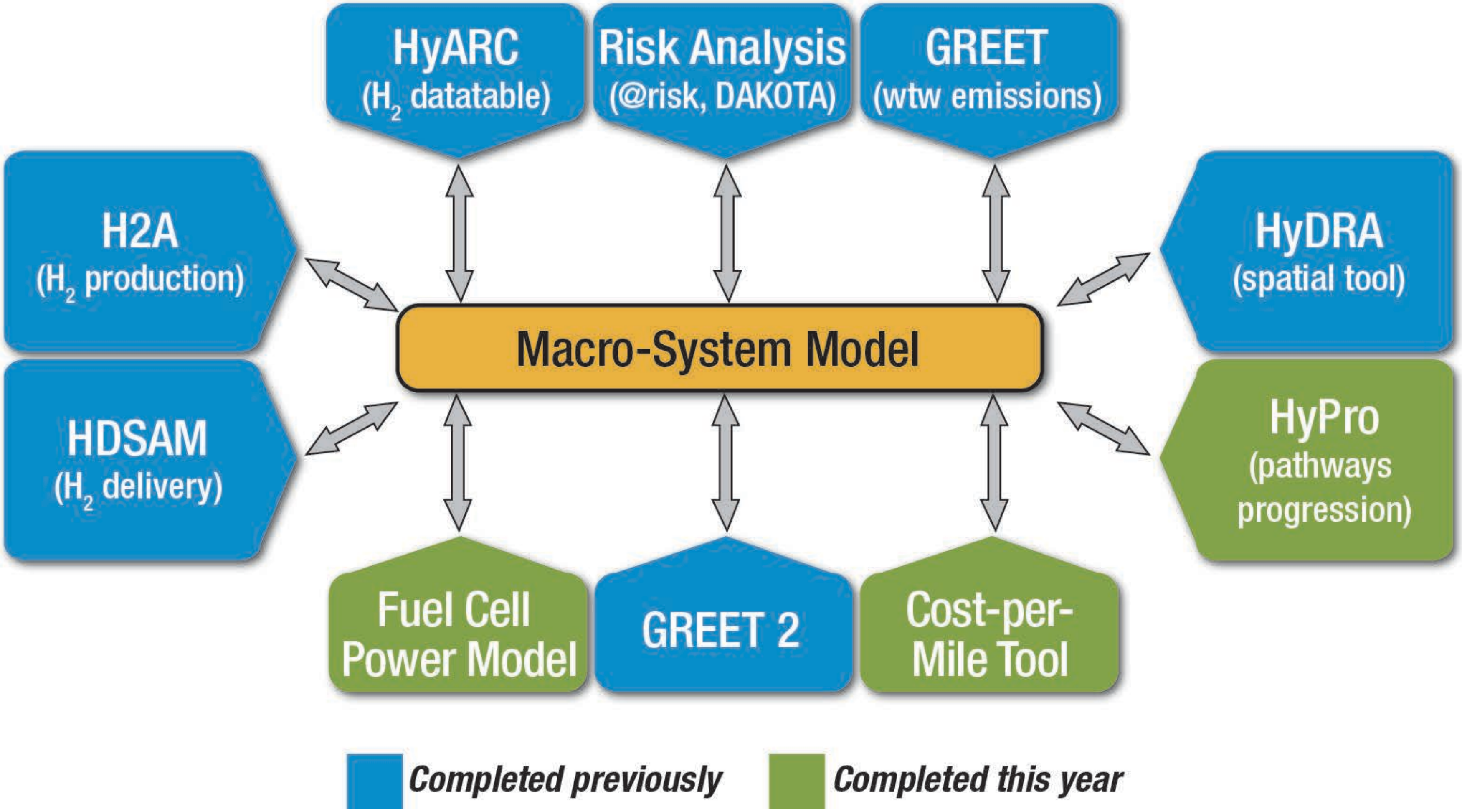
Specific focus on:

- **What is a likely succession of hydrogen pathways?**
- **How might major factors influence the sequence?**

Primary Analytical Tool: MSM

Approach

The Macro-System Model (MSM) provides a ***central transfer station*** to simplify communication across models and guarantee consistency in simulations that involve multiple models. A graphical user interface (GUI) allows users to easily use the models.



HyPro: Original Structure

Approach

HyPro was originally built as a stand-alone tool with three major pieces

Research

Assumptions
Costs
Technologies

UC Davis
H2A Production
HDSAM
FPITT
Transition Team
HYTRANS

Cost Database

Capital cost
Efficiency
Feedstock prices
Plant location

DTI Model (Tool)

Determine Net Demand

Calculate Cost Function for All Available Options at This Demand

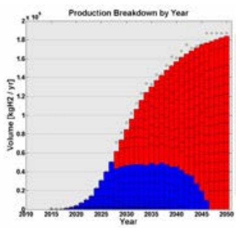
Select & Build Lowest Cost Option

Update Installed Capacity

Iterate Next Year

Results & Sensitivity

Cheapest Build
H_2 Profited Cost
Stranded Assets
Capital Costs
Infrastructure



Modify parameters

Cost Database

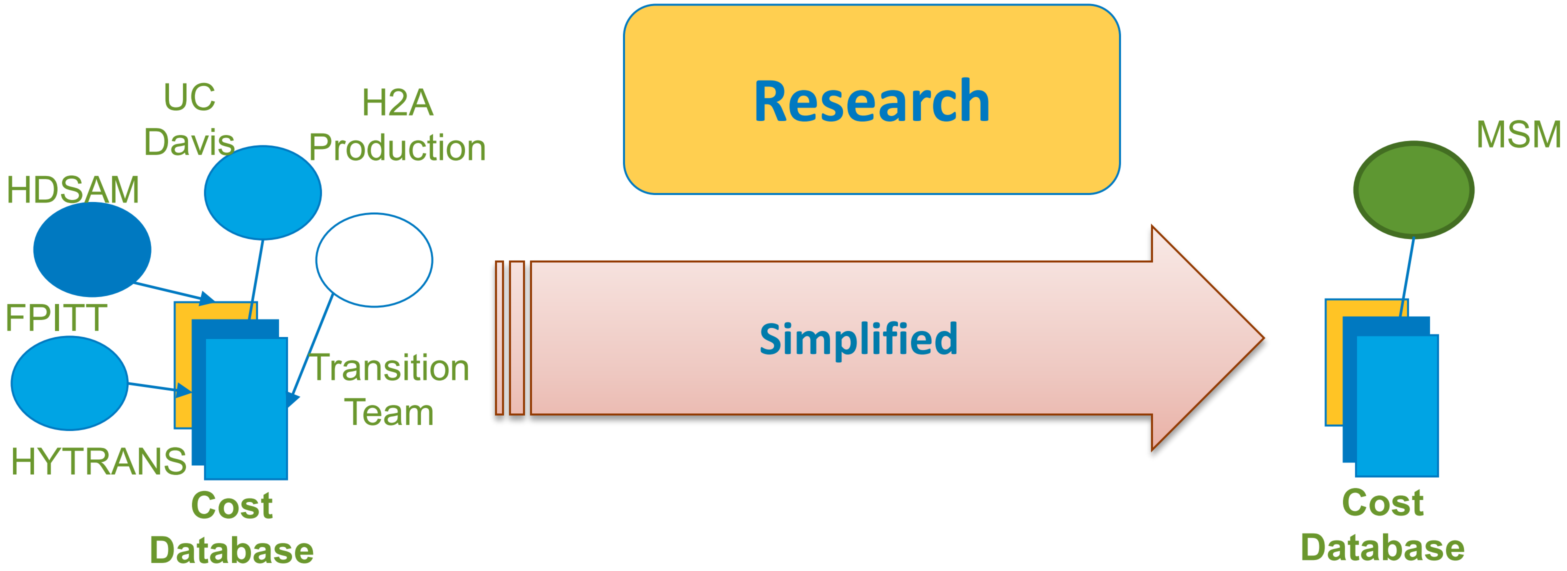
Re-run model to assess impact

Integration of HyPro to MSM

Accomplishment

HyPro was linked to the MSM for this analysis. Linking

- **Simplifies update of H2A & HDSAM input parameters**
- **Automates incorporation of GREET emissions data**
- **Simplifies performance of sensitivities that affect cost and emissions**
- **Allows new technologies to be characterized and implemented into the HyPro tool easily**



Analysis Production & Delivery Options

Approach

H2A V2 and HDSAM V2.2 costs were used for this analysis. Advanced costs implemented in 2025. Technology combinations shown below.

Central Production	Delivery
Coal	Liquid truck or pipeline
Coal with CCS	Liquid truck or pipeline
Natural Gas	Liquid truck or pipeline
Natural Gas w/ CCS	Liquid truck or pipeline
Biomass	Liquid truck or pipeline
Central Electrolysis	Liquid truck or pipeline
Nuclear High Temp. Electrolysis	Liquid truck or pipeline
Existing Capacity	Liquid truck

Distributed (FC) Production
Steam Methane Reforming (SMR)
Electrolysis
Ethanol Reforming

Vehicles
Fuel Cell Electric Vehicles (FCEVs) with 350 bar compressed gas storage

CCS: Carbon Capture and Sequestration

Key Assumptions

Approach

Many assumptions are embedded in the models being linked but can be changed in sensitivity runs.

Pathway Assumptions

- NAS buildout rates
- Urban demand area
- 12,000,000 person city
- 50% FCEV penetration in 2050
- 1500 kg/day station design capacity
- Mid-size FCV –
  - Current – 45 mi / GGE

Financial

- 10% IRR
- 20 year plant life
- MACRS depreciation where appropriate
- 1.9% inflation

Production

- Central Biomass
  - Current – 48% feedstock efficiency
  - Advanced – 50% feedstock efficiency
- Coal Gasification
  - Current – 56% feedstock efficiency
  - Advanced – 64% feedstock efficiency
  - CCS Current – 55% feedstock efficiency
  - CCS Advanced - 61% feedstock efficiency
- Distributed SMR
  - Current – 73% feedstock efficiency
  - Advanced – 78% feedstock efficiency
- Electrolysis
  - Current – 62% feedstock efficiency
  - Advanced – 75% feedstock efficiency

HDSAM

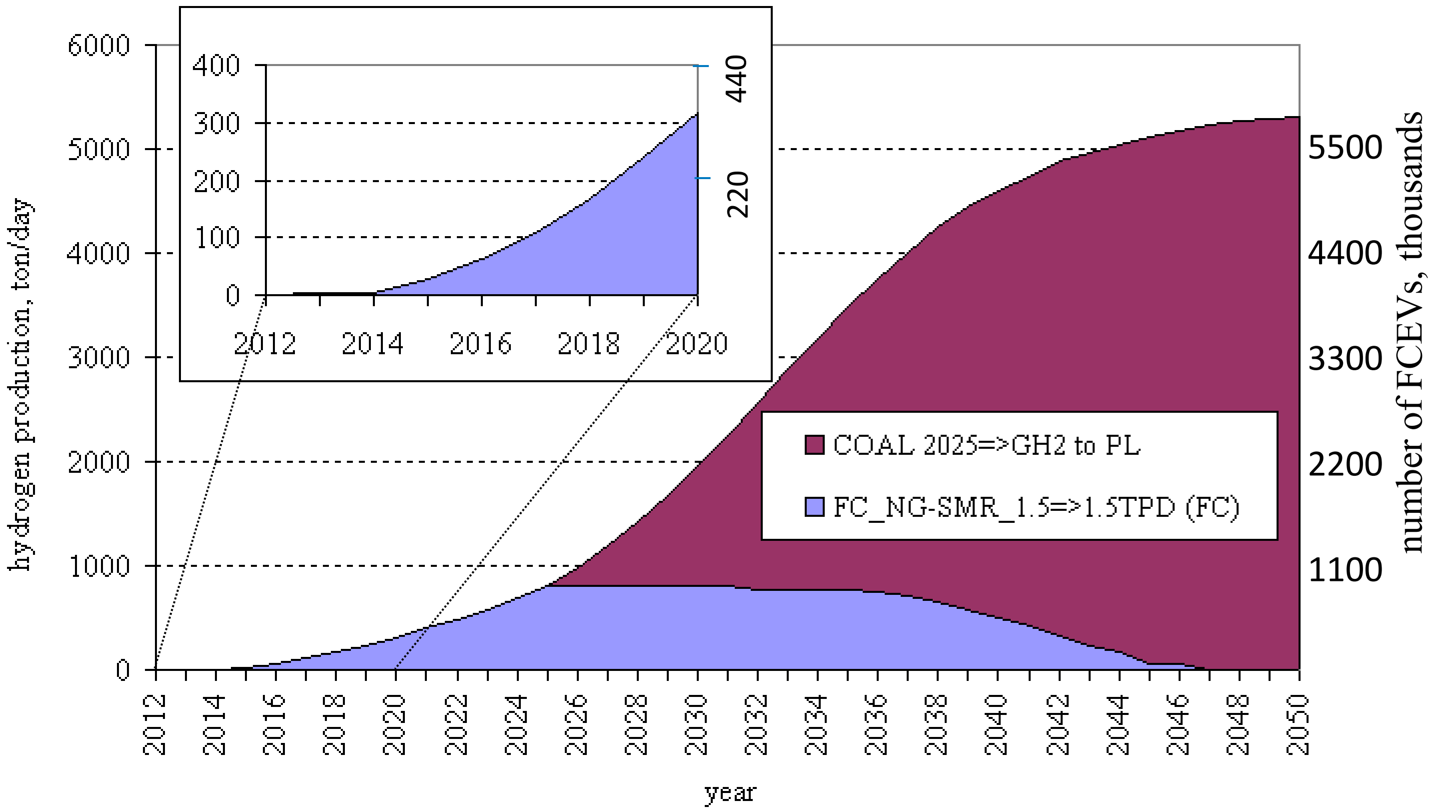
- Fueling station capacity factor = 0.84
- 62 miles from central production to city
- Liquefier efficiency 72%

GREET

- Gasoline is RFG without oxygenate
- Current technologies use U.S. average grid mix
- Advanced technologies use future grid mix with 90% of CO_2 from coal plants sequestered

Base Case Results

Using default cost parameters, distributed SMR is built out initially followed by central coal with pipeline delivery.

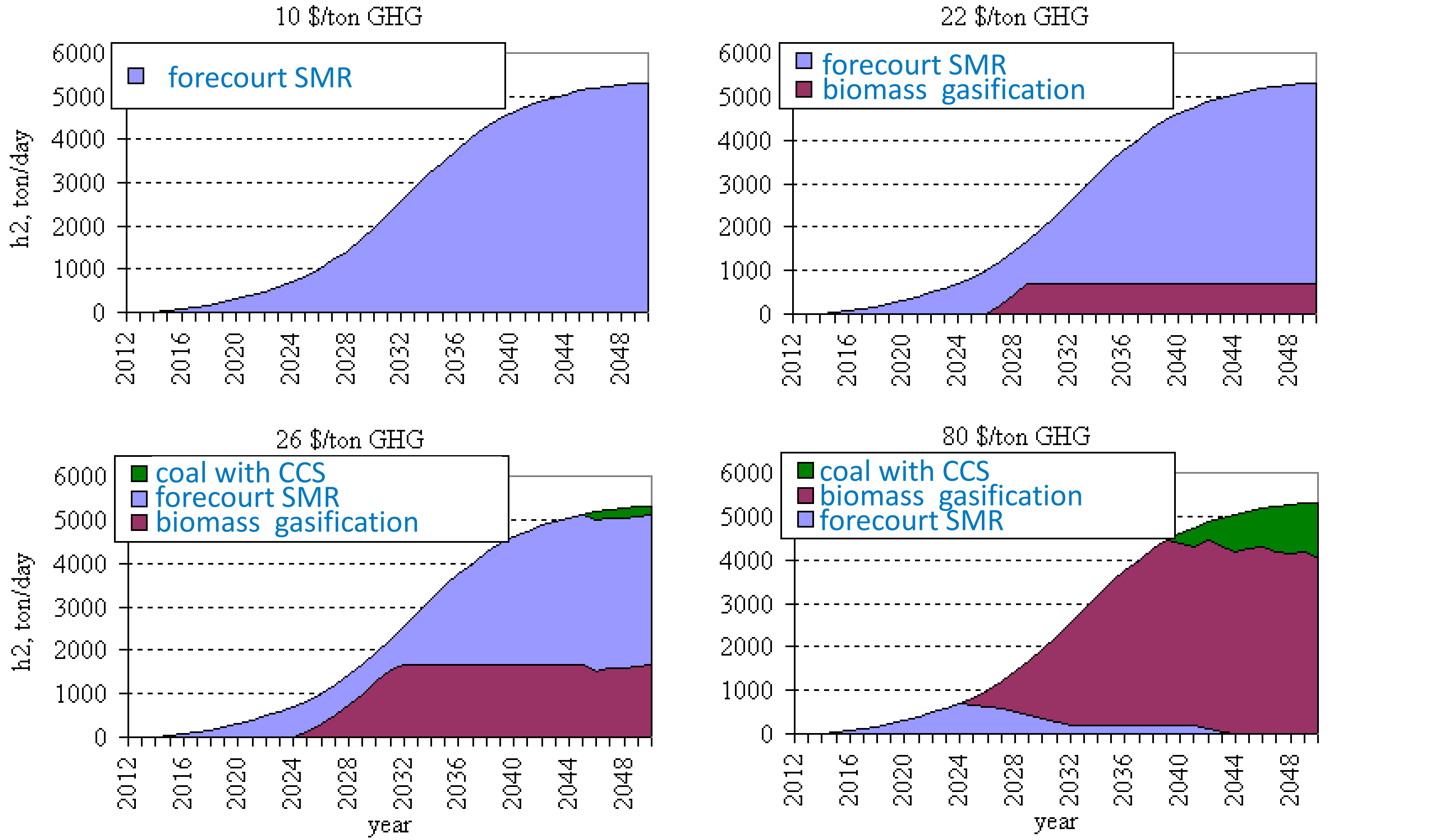


Exogenous demand curve based on form recommended by the National Academy of Sciences (2004). Adapted for Los Angeles and 50% penetration of FCEVs with fuel economies of 45 mpgge

Cost of Carbon

Accomplishments

Adjusting the cost of carbon affects the technology selection.

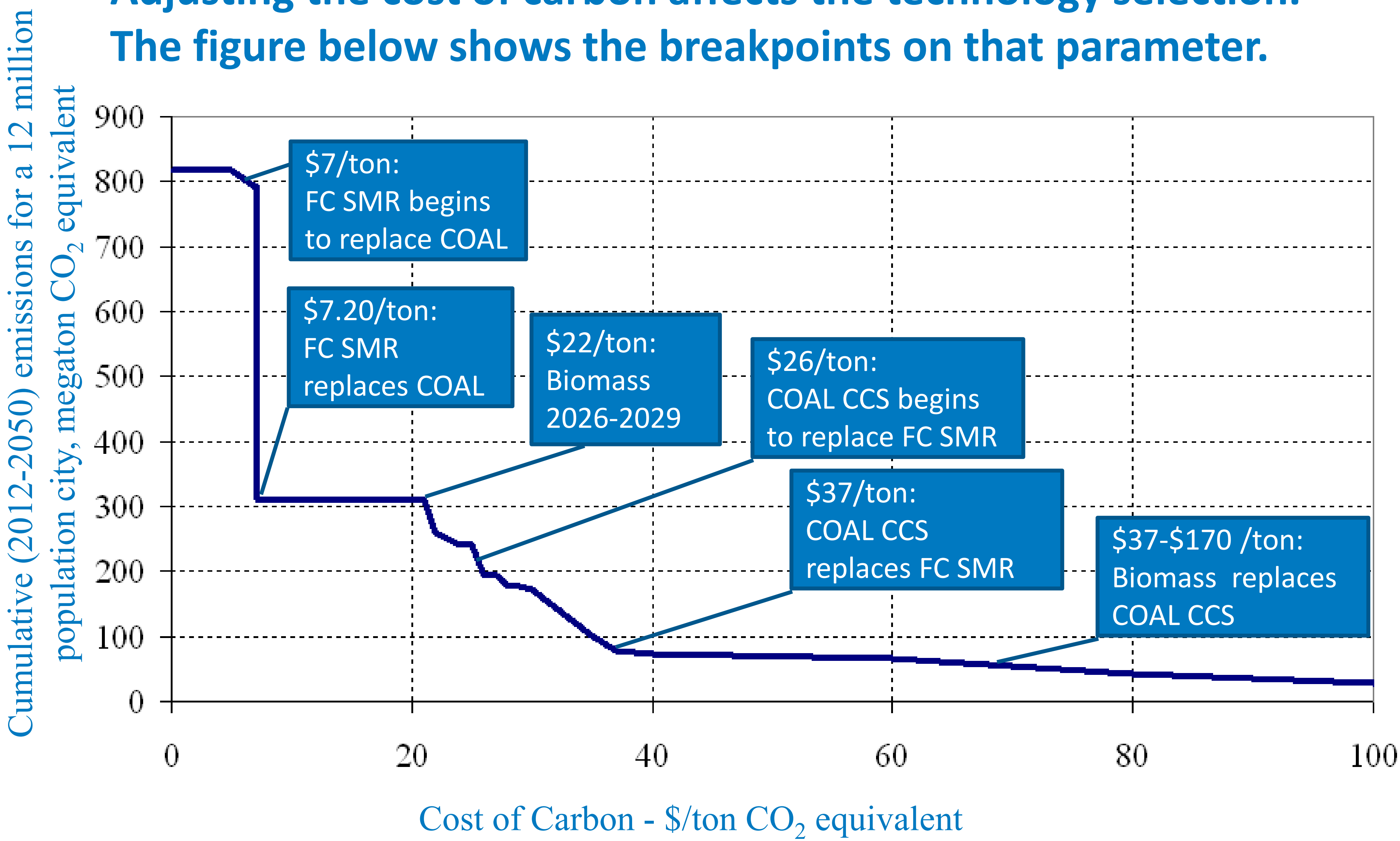


A \$10/ton CO_2eq cost of carbon pushes the selection to distributed SMR, higher costs result in biomass-based hydrogen, \$80/ton results in some penetration of coal gasification with CCS

Breakpoints in GHG Emissions

Accomplishments

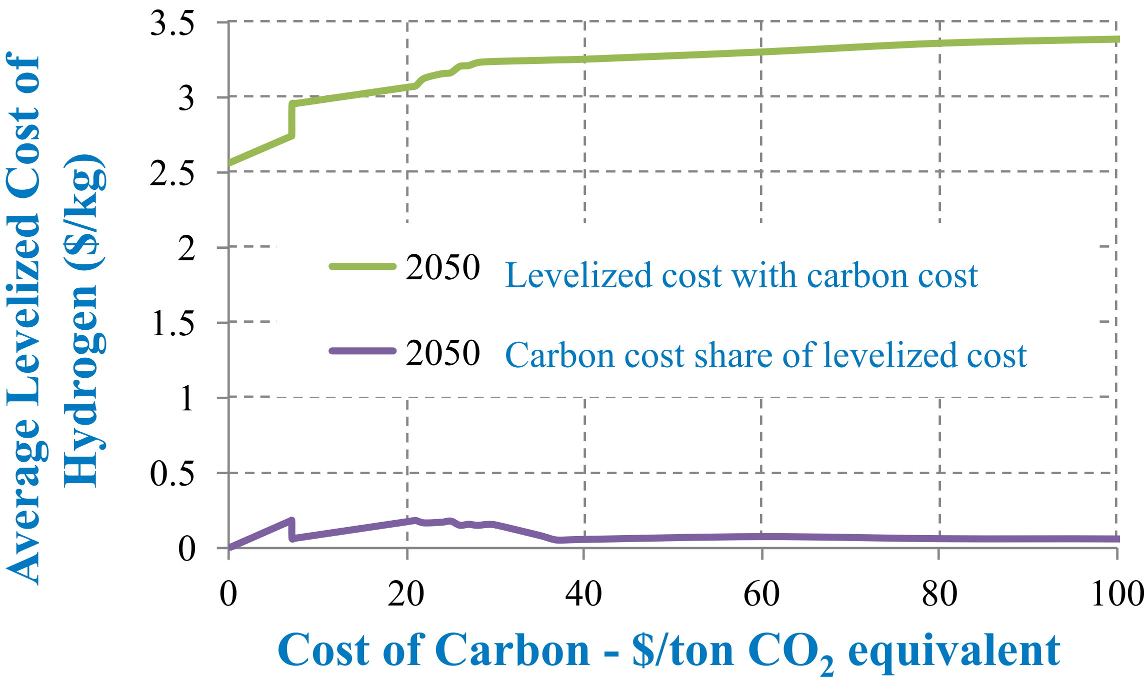
Adjusting the cost of carbon affects the technology selection. The figure below shows the breakpoints on that parameter.



Expenditures for Carbon Emissions

Accomplishments

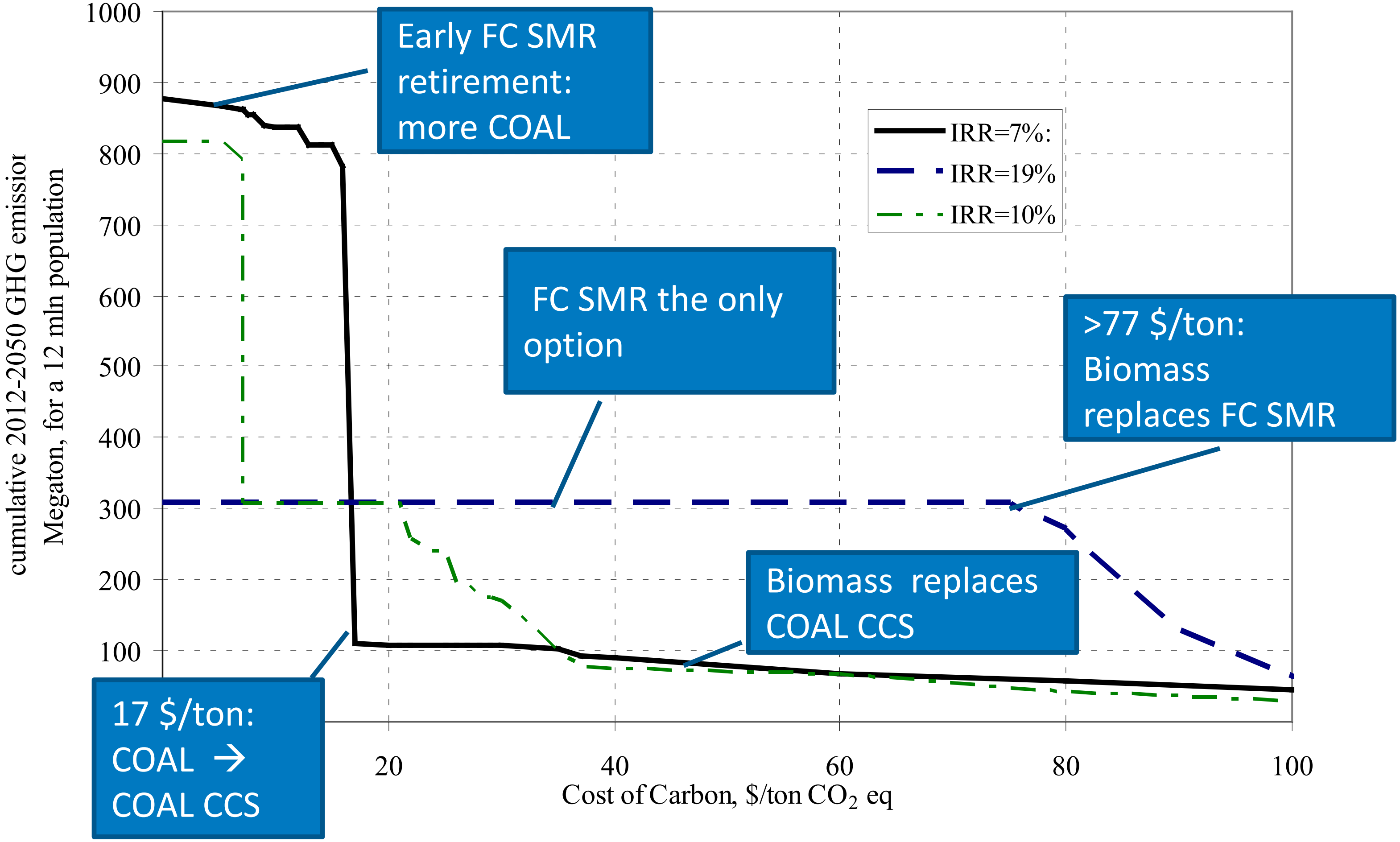
Increased costs of carbon open the markets for more expensive but cleaner technologies. Consumer costs (levelized cost plus cost of carbon) go up and the carbon footprint goes down but the amount paid for carbon emissions is limited.



Carbon Cost, IRR, & Emissions

Accomplishments

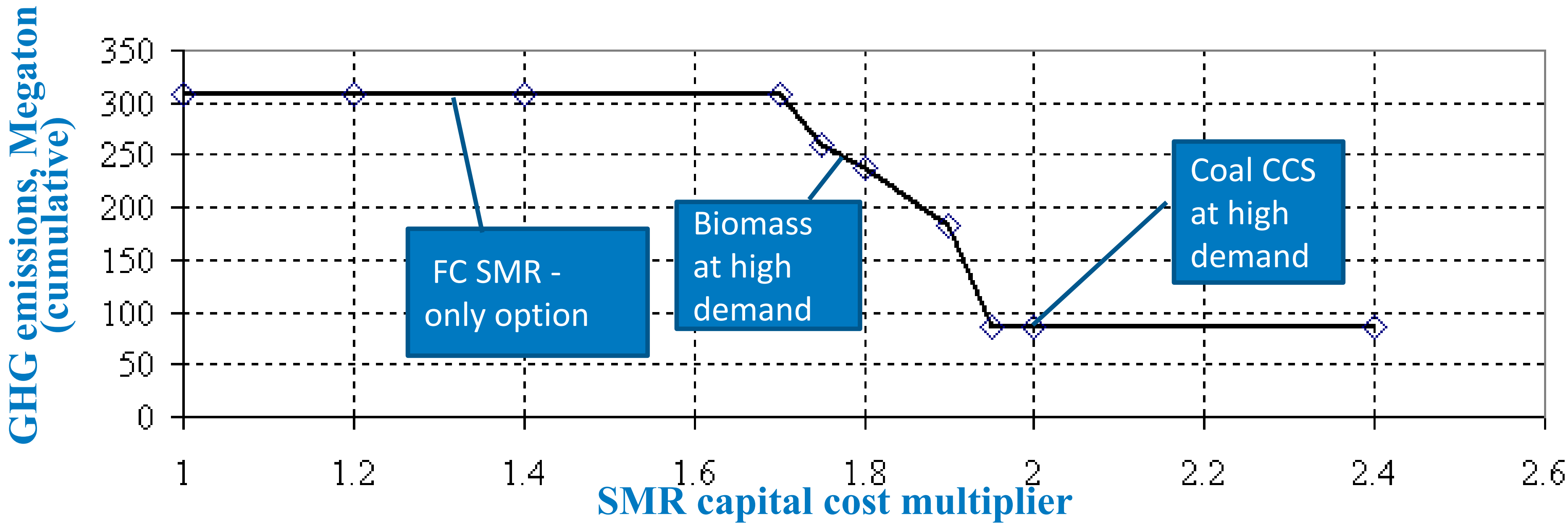
Required internal rate of return (IRR) also affects technology selection



Increased SMR Capital Costs

Accomplishments

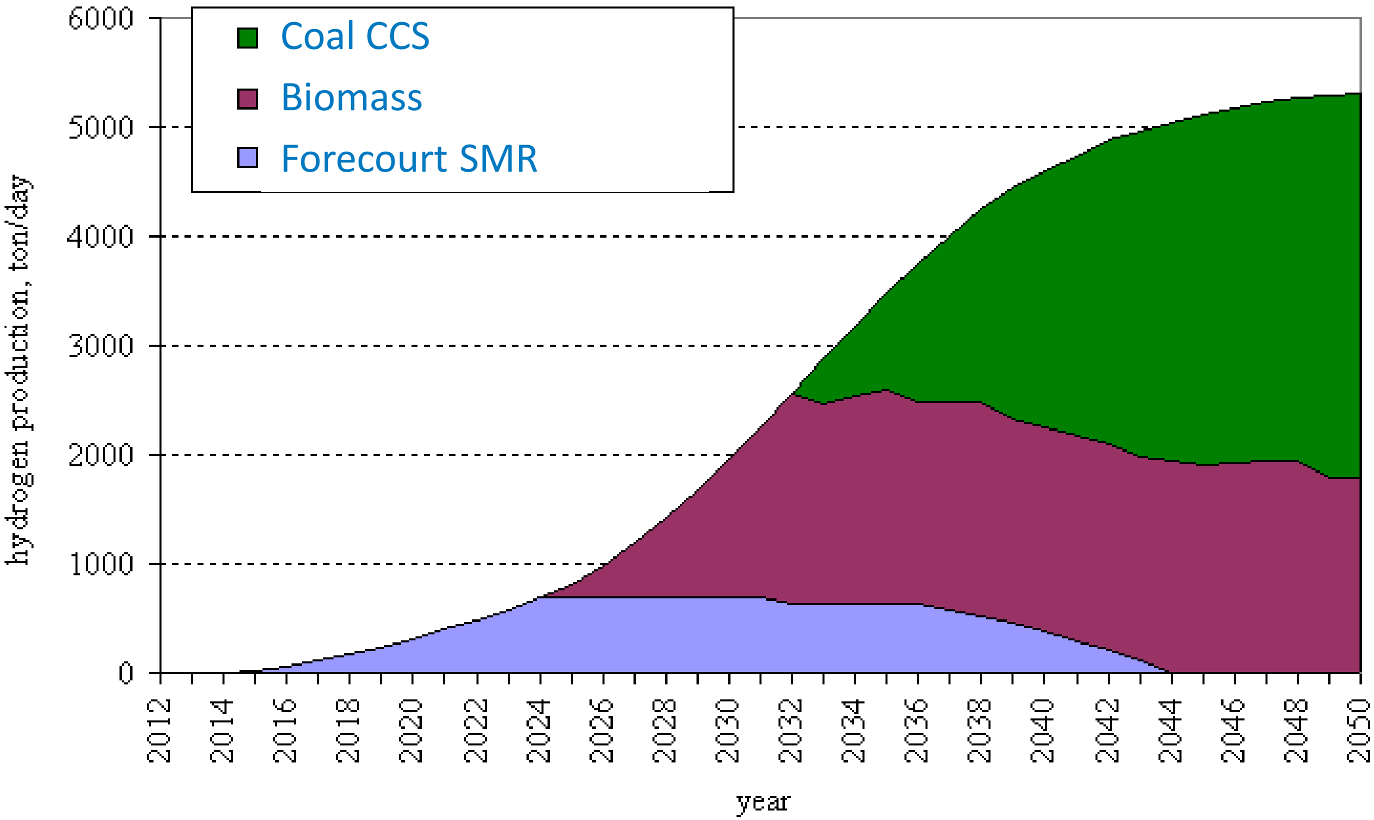
In scenarios where coal without CCS is not allowed, distributed SMR is the only technology selected. Other technologies do not become cost competitive until capital cost of distributed SMR is increased by over 70%.



Increased SMR Capital Costs

Accomplishments

At capital cost factors of 1.95 and above, multiple technologies are selected.

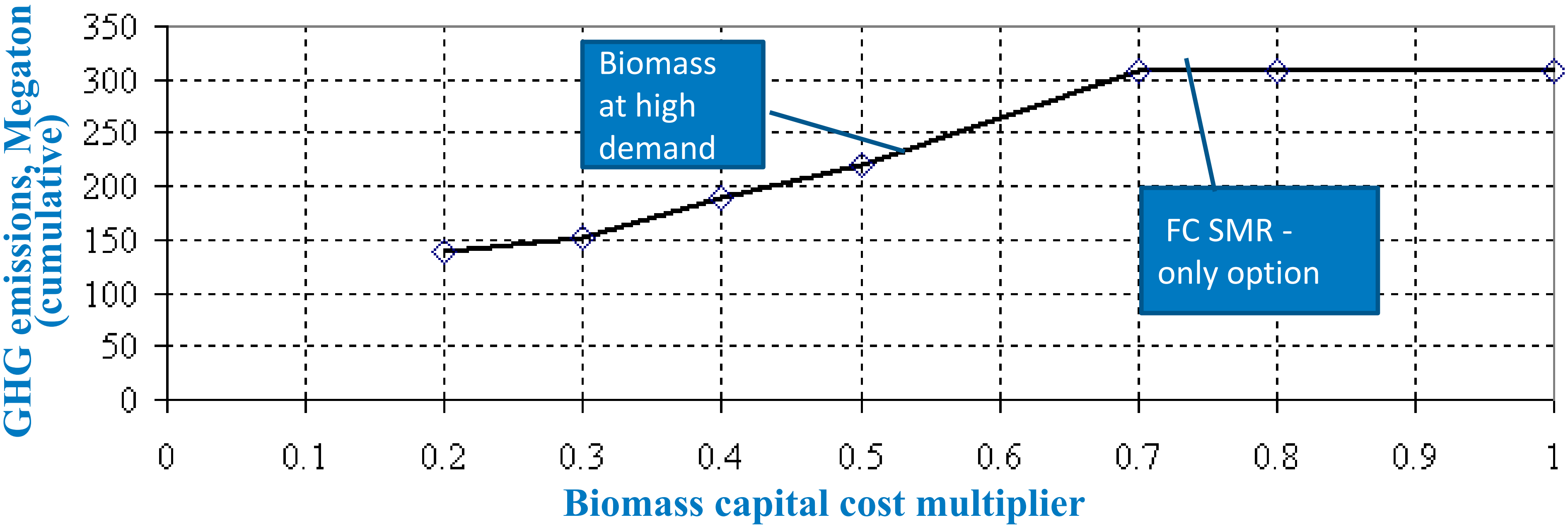


Buildout scenario with SMR capital cost factor of 1.95

Decreased Biomass Capital Costs

Accomplishments

Biomass capital costs need to be reduced by 30%-70% before central biomass gasification with hydrogen delivered in pipelines becomes cost competitive with distributed SMR at high demand growth.

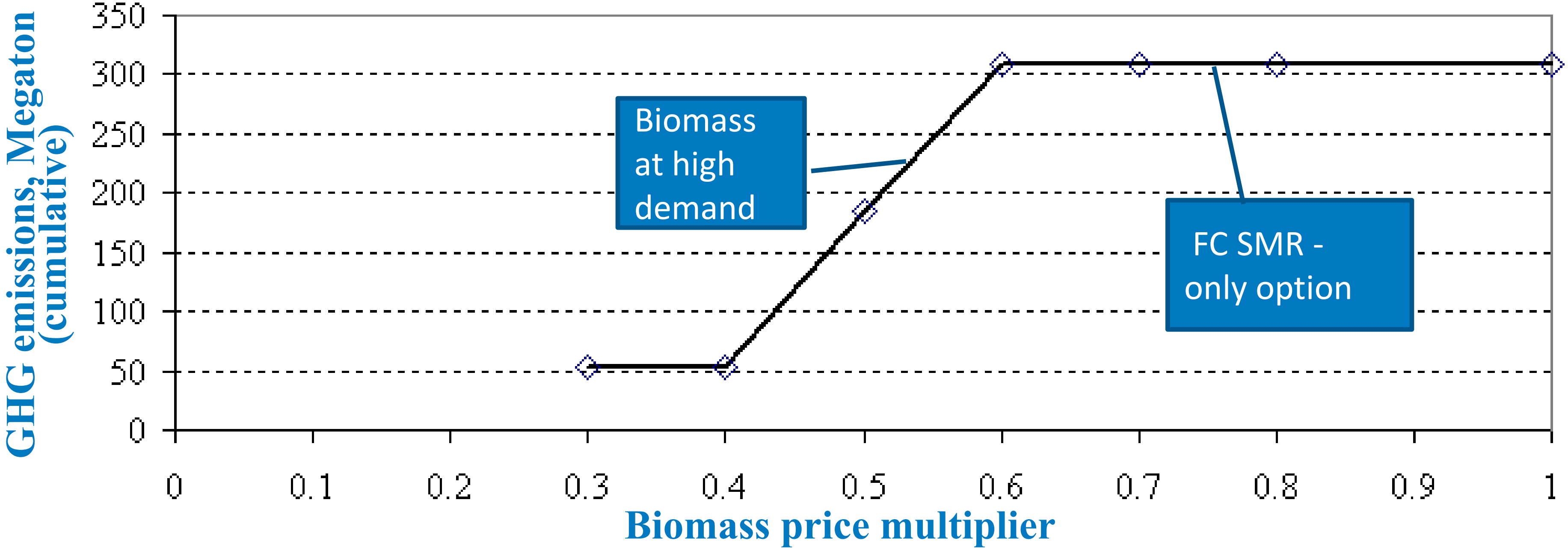


Coal without CCS not allowed for this scenario

Decreased Biomass Price

Accomplishments

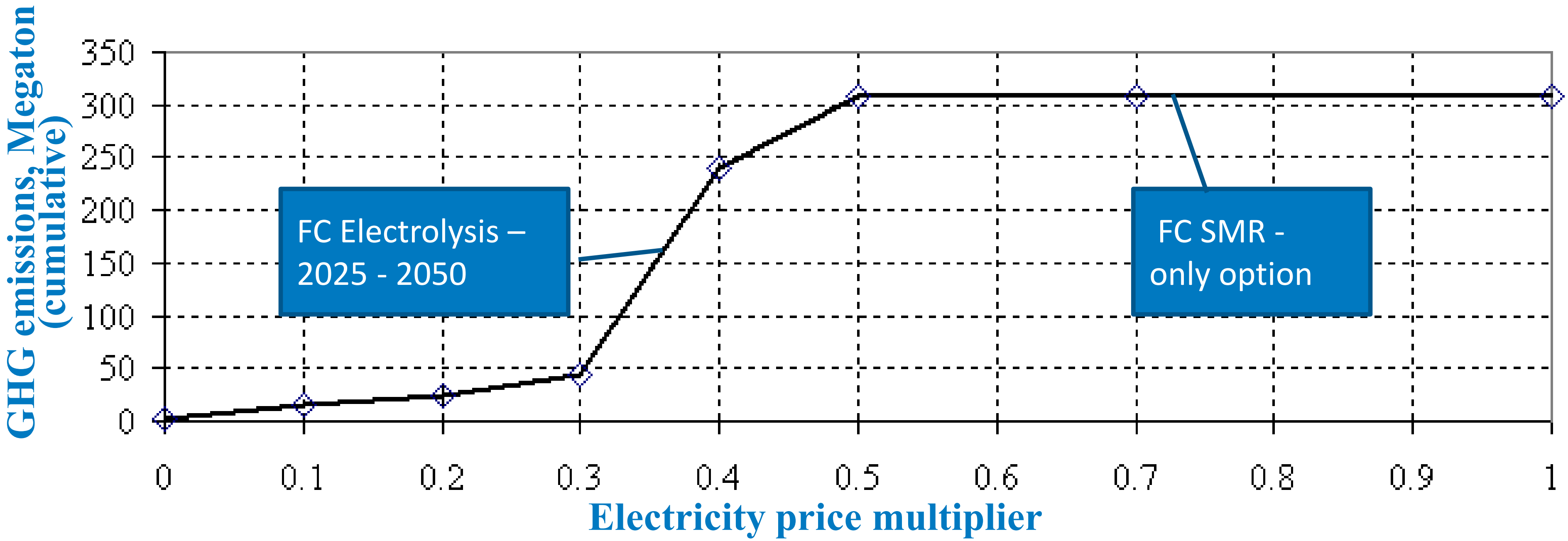
Biomass feedstock prices need to be reduced by 40%-60% before central biomass gasification with hydrogen delivered in pipelines becomes cost competitive with distributed SMR at high demand growth.



Coal without CCS not allowed for this scenario

Decreased Electricity Price

Electricity prices need to be reduced by 30%-50% before distributed electrolysis becomes cost competitive with distributed SMR.



Coal without CCS not allowed for this scenario

Conclusions

- Based on current cost projections and a required 10% IRR, distributed SMR is the most cost-effective technology to roll out in the early commercial stage.
- Central coal (without CCS) is the most cost-effective technology at higher demand growth if carbon is not limited.
- The cost of carbon limits coal without CCS. It is replaced by distributed SMR, biomass, and coal with CCS as the cost increases.
- Distributed SMR is the most cost-competitive technology when central coal without CCS is not allowed. Other technologies need large capital or feedstock cost reductions.

Proposed Future Work

This analysis is complete and no future work is planned. If we had funding, we would like to:

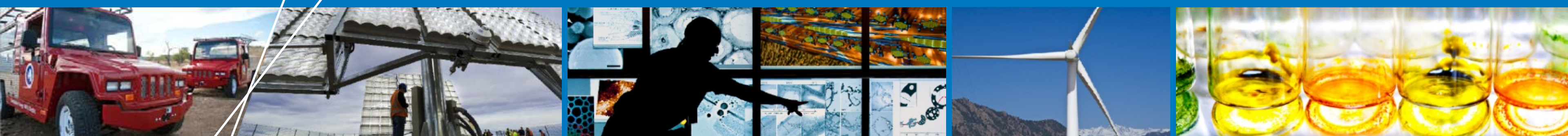
- **Update the analysis using new versions of H2A, HDSAM, and GREET**
- **Update the analysis with 200 kg/day stations, tube trailer delivery, and tri-generation options**
- **Spread out technology improvement (potentially using learning curves)**
- **Use supply curves instead of single values**
- **Add unforeseen randomness to the demand function**

As an ongoing project, the MSM is being updated, and an analysis of the parameters used in estimating levelized cost, energy use and emissions is underway.

Collaborations

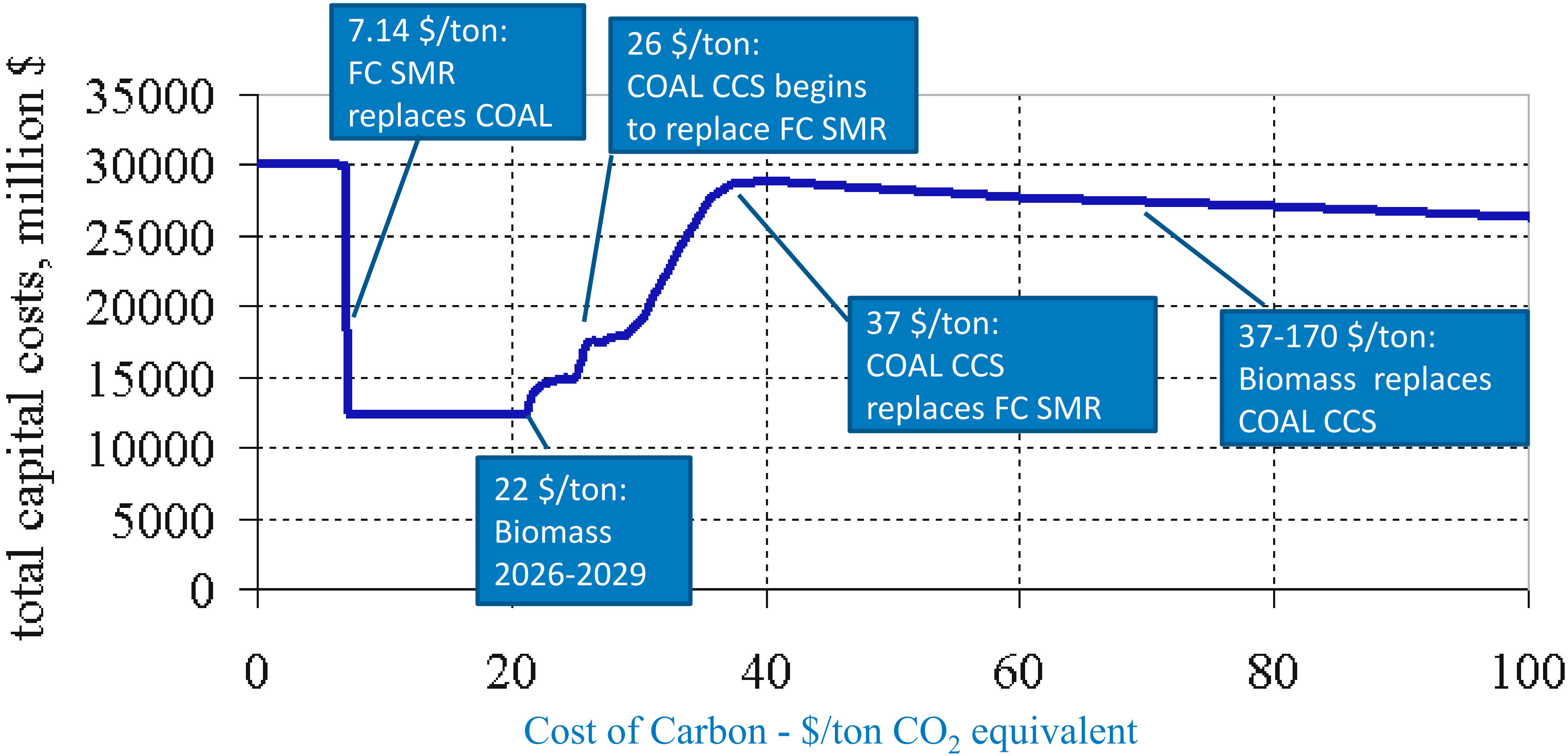
- NREL and DTI (now part of Strategic Analysis, Inc.) collaborated in the modeling and analysis
- Sandia National Laboratories developed much of the MSM interface
- Models from NREL and Argonne National Laboratory were used to generate inputs
- MSM parameters and results were reviewed by members of the Fuel Pathway Integration Technical Team: ExxonMobil, Chevron, Shell, ConocoPhillips

Technical Backup Slides



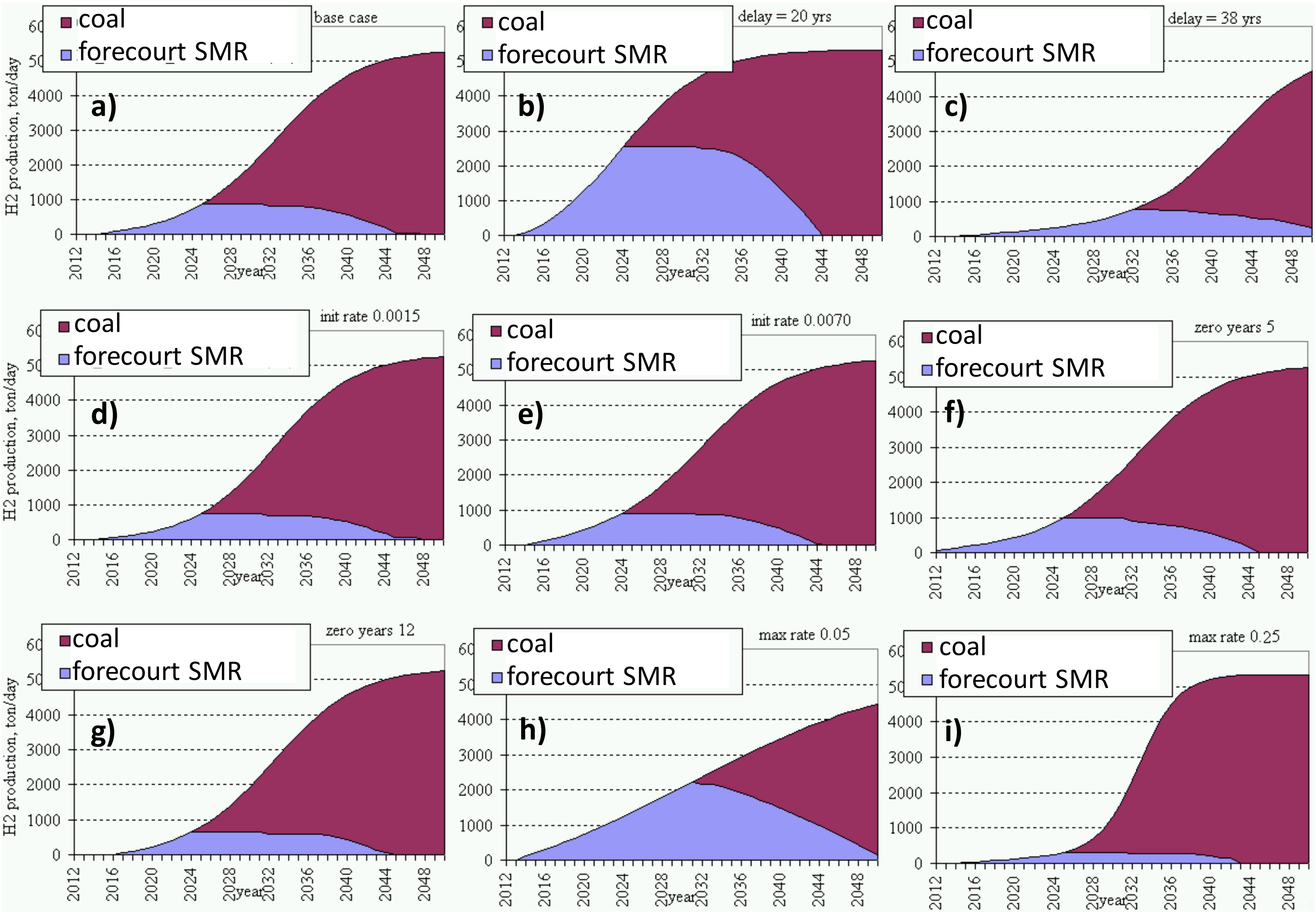
Carbon Cost & Capital Investment

Moving from central to distributed production reduces capital investment due to a cost of carbon

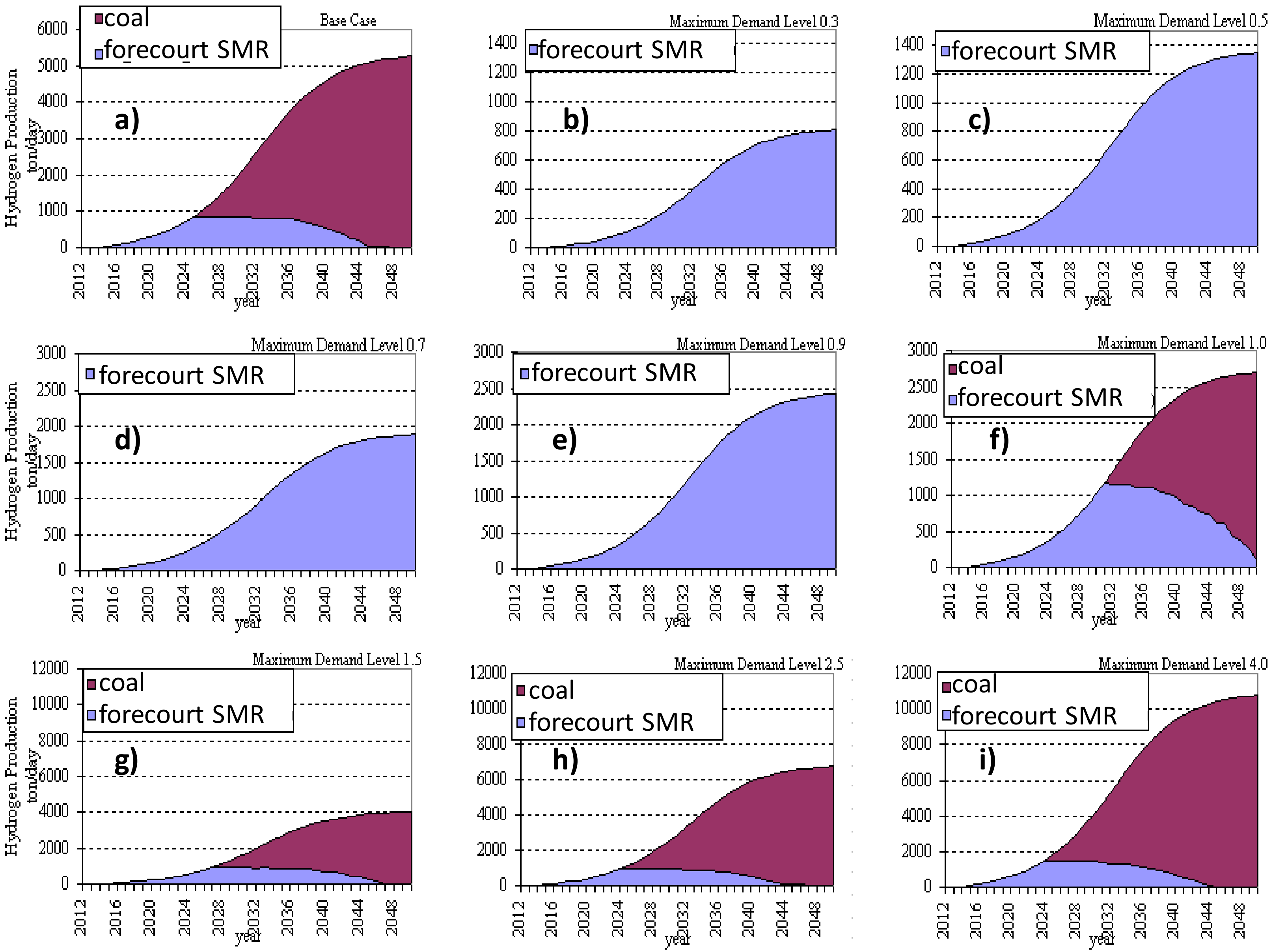


Demand Curve Parameters Affect Timing But Not Technologies Selected

Accomplishments and Progress



But Maximum Penetration Affects Technology Selection



Approach: Model Validation

- Model inputs and results were reviewed by the Fuel Pathway Integration Tech Team (FPITT), others in the H_2 analysis community and industry experts
- One major MSM output – Pathway Report(s) – undergo thorough reviews by FPITT. The data reported in that report were used for this analysis.
- The H2A Production models and HDSAM are built in a transparent way and undergo their own validation prior to being published; these models are reviewed by the Production Tech team and by the Delivery Tech team
- GREET is widely used and is being constantly reviewed and updated

Validating models at both integrated and component levels