



# Hydrogen Production Infrastructure Options Analysis

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Project ID # AN1

This presentation does not contain any proprietary or confidential information

# Overview

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## Timeline

- Start: ~May 2005
- End: February 2007
- 50% complete

## Barriers

- Lack of understanding of the transition of a hydrocarbon-based economy to a hydrogen-based economy.
- Lack of prioritized list of analyses for appropriate and timely recommendations.
- Stove-piped/Siloed Analytical Capabilities.

## Budget

- Total project funding: \$750,000
- FY05: \$200,000
- FY06: \$300,000
- FY07: \$250,000

## Partners

- Sentech, Inc.
- Advisory Board:
  - H2Gen Innovations
  - ChevronTexaco
  - Teledyne Energy Services
  - Air Products
  - Sentech, Inc.

# Project Objectives

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## Objectives

- Create **a tool** robust enough to test the impact of different assumptions on the development of hydrogen infrastructure.
- Exercise the tool under different assumptions to understand the infrastructure's **sensitivity to different scenarios.**
- Suggest to DOE **areas of further research** based on the parameters most influential in the infrastructure development.

## Unique Features

- Evaluates infrastructures with varying utilization over lifetime. (differs from H2A)
- Ease of Use: Designed to be used by wide audience/DOE (differs from HyTrans).
- Allows easy incorporation into Macro Model.
- Provides investor demand foresight.
- Includes stranded asset logic.
- Allows dynamic calculation of hydrogen costs over a multi-year analysis horizon.
- Demand, efficiencies, and costs can all be varied.

# Overall Approach

Research

Assumptions  
Costs  
Technologies

H2A  
Production

H2A  
Dispensing

Cost  
Database

Capital Cost  
Efficiency  
Feedstock prices  
Plant Location

DTI Model  
(Tool)

Evaluate Installed Capacity for  
the next B years

Determine Additional Infrastructure  
Needed for next B Years (including  
effects of stranding assets)

Evaluate Objective Function for all  
Infrastructure Options over next B  
years using expected plant  
operating capacity factor

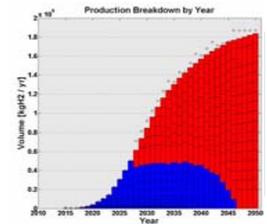
Pick Infrastructure Option with  
lowest Objective Function Cost. (This  
is Prod/Del/Disp pathway to be built that year.)  
Record choice as Selection for year.

Update Installed Capacity

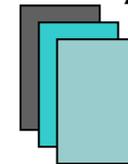
Go to next Calendar  
Year

Results &  
Sensitivity

Cheapest Prod  
H<sub>2</sub> Profited Cost  
Stranded Assets



Modify parameter



Cost  
Database

Re-run model to  
assess impact



# H<sub>2</sub> Production Variables

Variable	[Units]	Variable	[Units]
Description	[Text]	Land Required	[acres]
CY Start	[Year]	Replacement Costs	[\$]
Lifetime	[Years]	Fixed Costs OM	[\$/year]
IRR Period	[Years]	Fixed Costs Other	[\$/year]
IRR	[%]	Variable Costs Other	[\$/kgH <sub>2</sub> ]
CY	[Year]	MACRS Recovery Period	[Years]
PY	[Year]	Tax Rate	[%]
Design Capacity	[kgH <sub>2</sub> /year]	Other Costs	
Max Utilization	[% of Design Capacity/yr.]	H <sub>2</sub> Subsidy	[\$]
Feedstock Energy Ratios		Emissions	[g/kgH <sub>2</sub> ]
Capital (Depreciable)	[\$]	Capital Credit	[% of Capital Depreciable]

# Baseline Production Option Summary

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- **Coal Gasification**
  - Gaseous & Liquid production
  - w & w/o CO<sub>2</sub> sequestration
  - Multiple sizes:
    - Central: ~300tpd
    - CG: 15tpd
  - Cases: 1-18
- **Natural Gas Steam Methane Reforming**
  - Gaseous & Liquid production
  - w & w/o CO<sub>2</sub> sequestration
  - Multiple sizes:
    - Central: ~380tpd
    - CG & IC: 15tpd
    - Forecourt: 0.1 & 1.5 tpd (no CO<sub>2</sub> seq.)
  - Cases: 19-26, 37, 39
- **Electrolysis**
  - Gaseous & Liquid production
  - w & w/o CO<sub>2</sub> sequestration
  - Multiple sizes:
    - Central: ~700tpd (Nuclear)
    - Forecourt: 0.1 & 1.5 tpd (Marginal mix elec., no CO<sub>2</sub> seq.)
  - Cases: 27-34
- **Biomass Gasification**
  - Gaseous & Liquid production
  - Central: 195tpd
  - Cases: 35-36
- **Existing H<sub>2</sub> (Los Angeles)**
  - Gaseous (Liquid prod. Negligible)
  - No CO<sub>2</sub> sequestration
  - Cases: 38
- **Future Options**
  - Ethanol Forecourt
  - Wind Electrolysis
  - Bio-Oil (from Biomass)
  - FT Fuel (from Coal)

# DTI Model Approach

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- Develop a **time-based, computational dynamic model of H<sub>2</sub> production** in the continental US.
- **Use model** and other methods **to understand** how a H<sub>2</sub> production infrastructure:
  - will develop over time,
  - the factors that will drive it, and
  - the role of externalities, such as policy and technology.
- Use **consistent & transparent** financial & technological **assumptions**
- Evaluate H<sub>2</sub> production & delivery costs dynamically (as opposed to statically) **with changing demand and utilization.**

# DTI Model Approach, cont'd

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- Model economics from **H<sub>2</sub> supplier/investor point of view.**
- **Postulate/Input annual demand** and allow foresight in planning infrastructure.
- Identify **stranded assets** due to technological and demand changes in time.
- Apply to **regions of homogeneous H<sub>2</sub> demand** (constant kg H<sub>2</sub>/day/km<sup>2</sup>).
  - Regions are nominally Urban, Rural, or Interstate but can represent any region of uniform demand.
- Allow simulation of **existing facilities.**
- Write model in **MATLAB.**
- Allow **easy interaction** with other models.

**Overall Goal: Simulate investment analysis of industry so transition model results are realistic.**

# Basic Premises of Model

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- Business wants to maximize profit.
- Profit is hard to quantify (requires knowledge of H<sub>2</sub> price).
- Will use H<sub>2</sub> cost as surrogate for Price.
- Minimize Cost => Maximizing Profit.
- Cost vs. Price.
  - Price: Dictated by Market.
  - “Profited Cost”: Price to yield a specified real, after-tax IRR.
  - Cost: Total cost to produce with zero profit.

**Simulate decision making process of Hydrogen supplier/investor.**

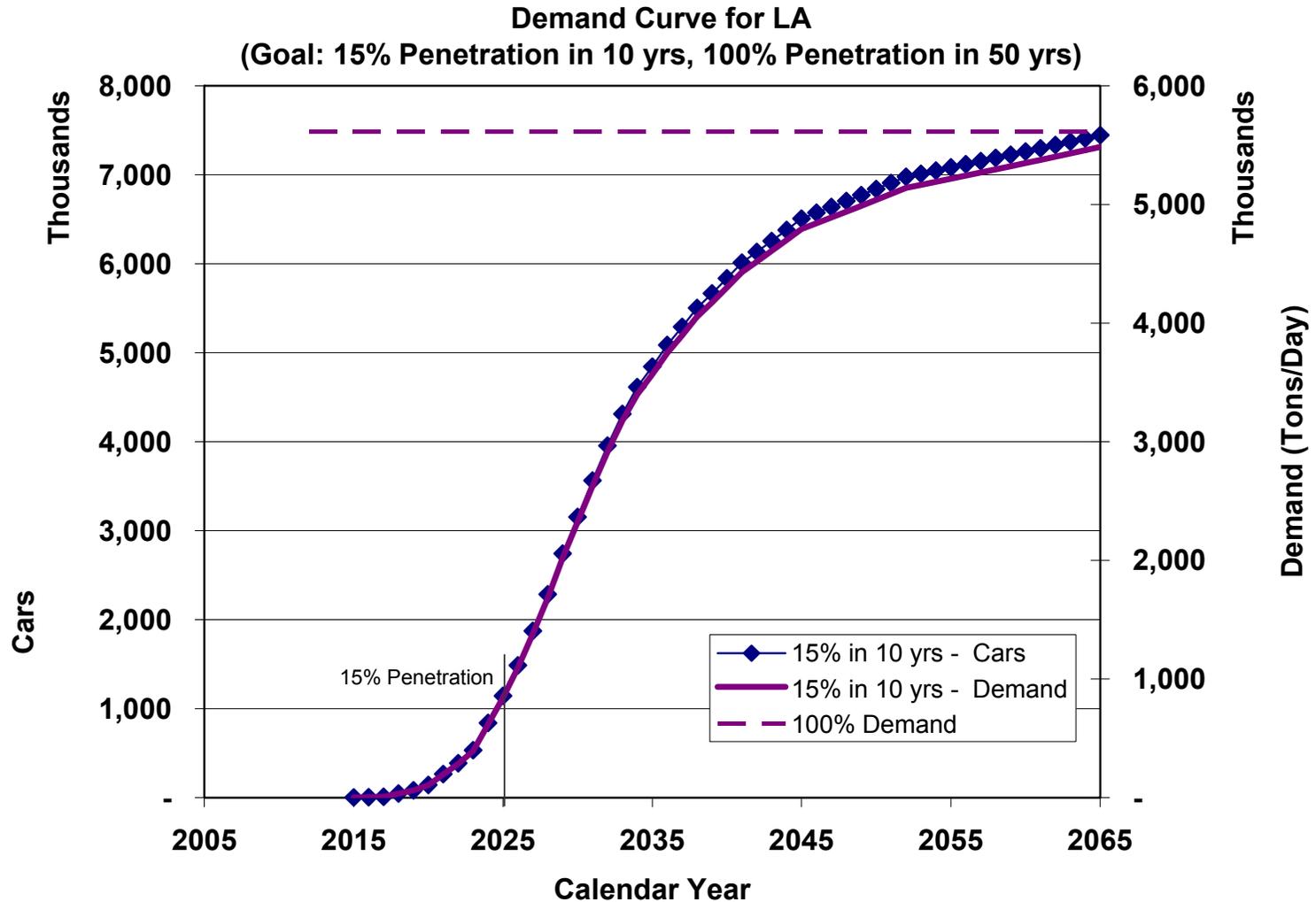
# Objective Function & Decision to Build

- Objective Function defined as average Profited Cost:

$$\text{Profited Cost of Hydrogen [$/kg] at Pump} = \text{Production cost} + \text{Delivery cost} + \text{Dispensing cost} + \text{Other Costs}$$

- **Production costs:** determined by NPV calculations performed dynamically and include effects from:
  - State of technology development,
  - Infrastructure capacity, and
  - Varying plant utilization
- **Delivery costs:** determined offline & averaged over analysis period.
- **Dispensing costs:** determined offline & averaged over analysis period.
- **Other costs:** credits and taxes which can be quantified in \$/kg but not directly attributed to a specific segment of the infrastructure.
- Pathway with the lowest Profited Cost is selected to be built.

# Baseline Case: H<sub>2</sub> Demand Curve – Los Angeles



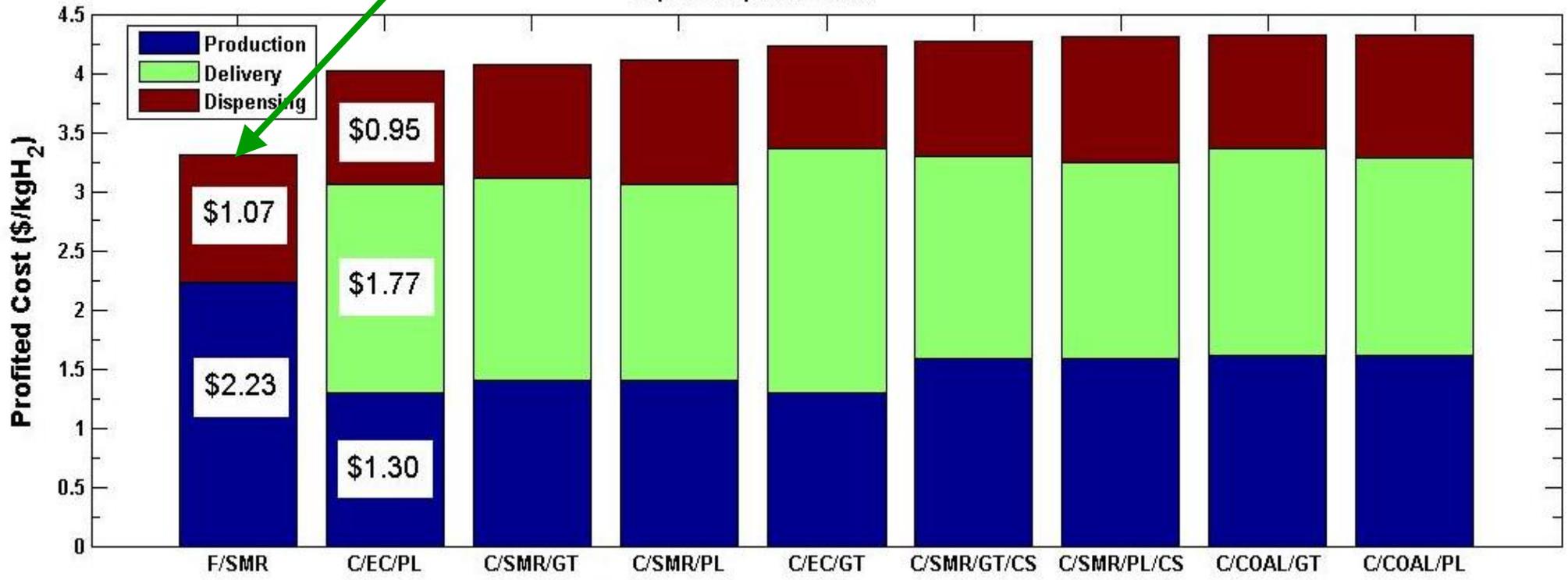
**The demand curve is an input to the model.**

# 2015 Total Pathway Cost

F	Forecourt
PL	Pipeline
GT	High Pressure Gas Truck
CS	Carbon Sequestration
EC	Existing Capacity
C	Central

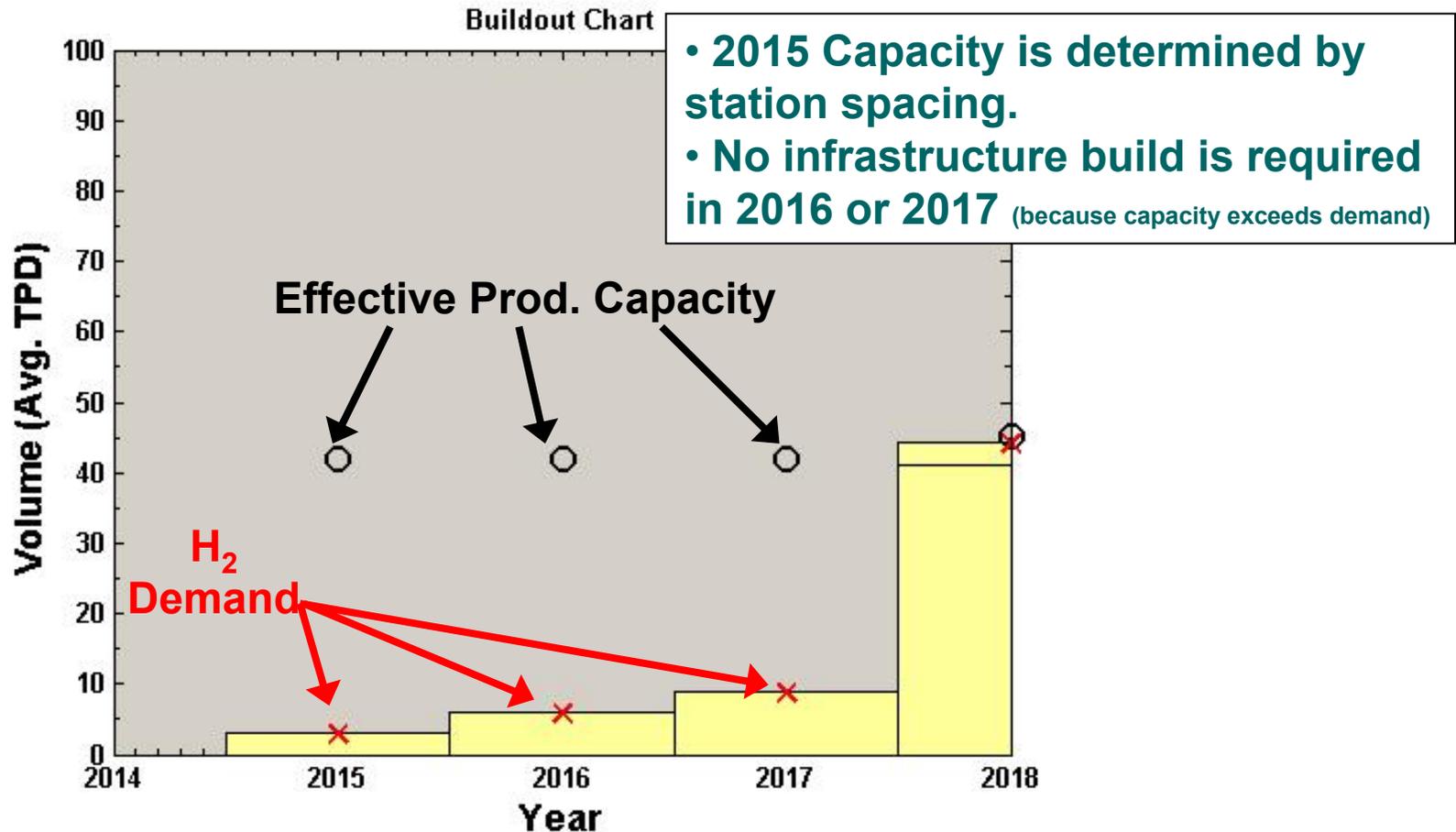
1.5tpd Forecourt SMR has the lowest total cost (\$3.30/kg)

Top 10/79 Options in 2015



In the first year of the analysis (2015), all prod/del/disp pathways are evaluated and Forecourt SMR is seen to have the lowest total cost (lowest avg. profited cost over the analysis period). It is selected to be built.

# Build-Out in Early Years



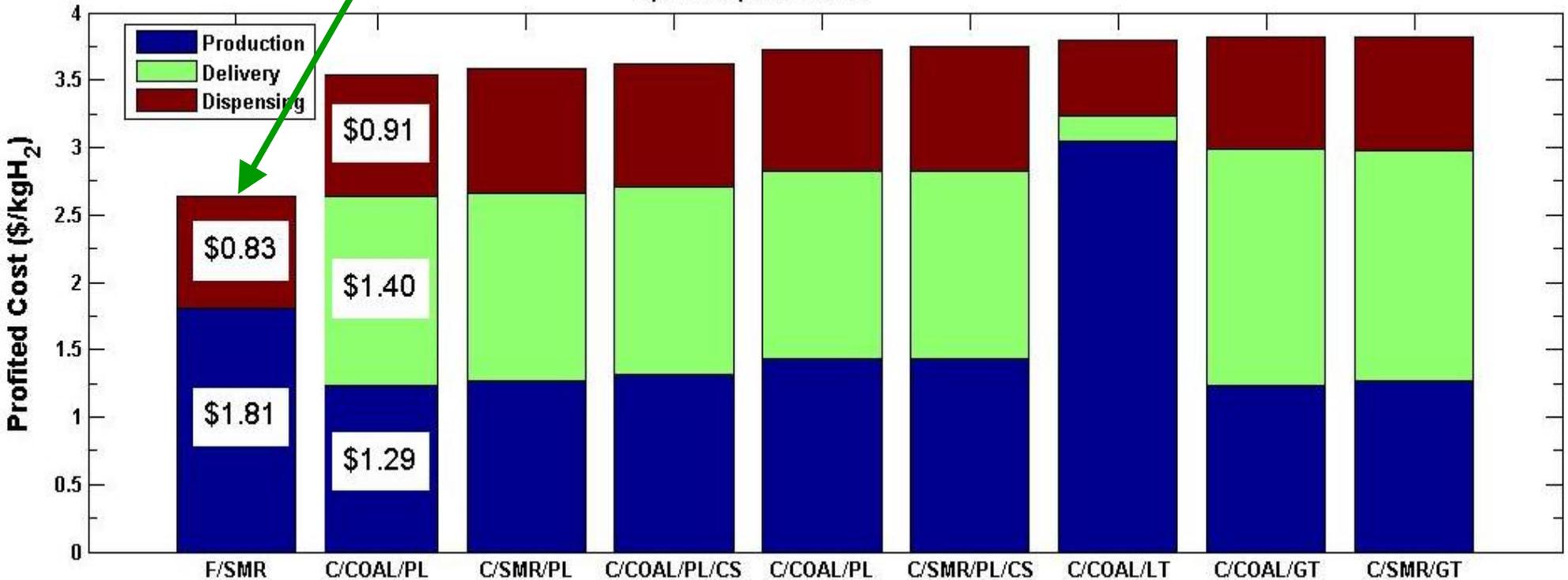
The Build-Out Plot shows how much installed production capacity is built each year and the level of utilization.

# 2018 Total Pathway Cost

F	Forecourt
PL	Pipeline
GT	High Pressure Gas Truck
LT	Liquid Truck
CS	Carbon Sequestration
EC	Existing Capacity
C	Central

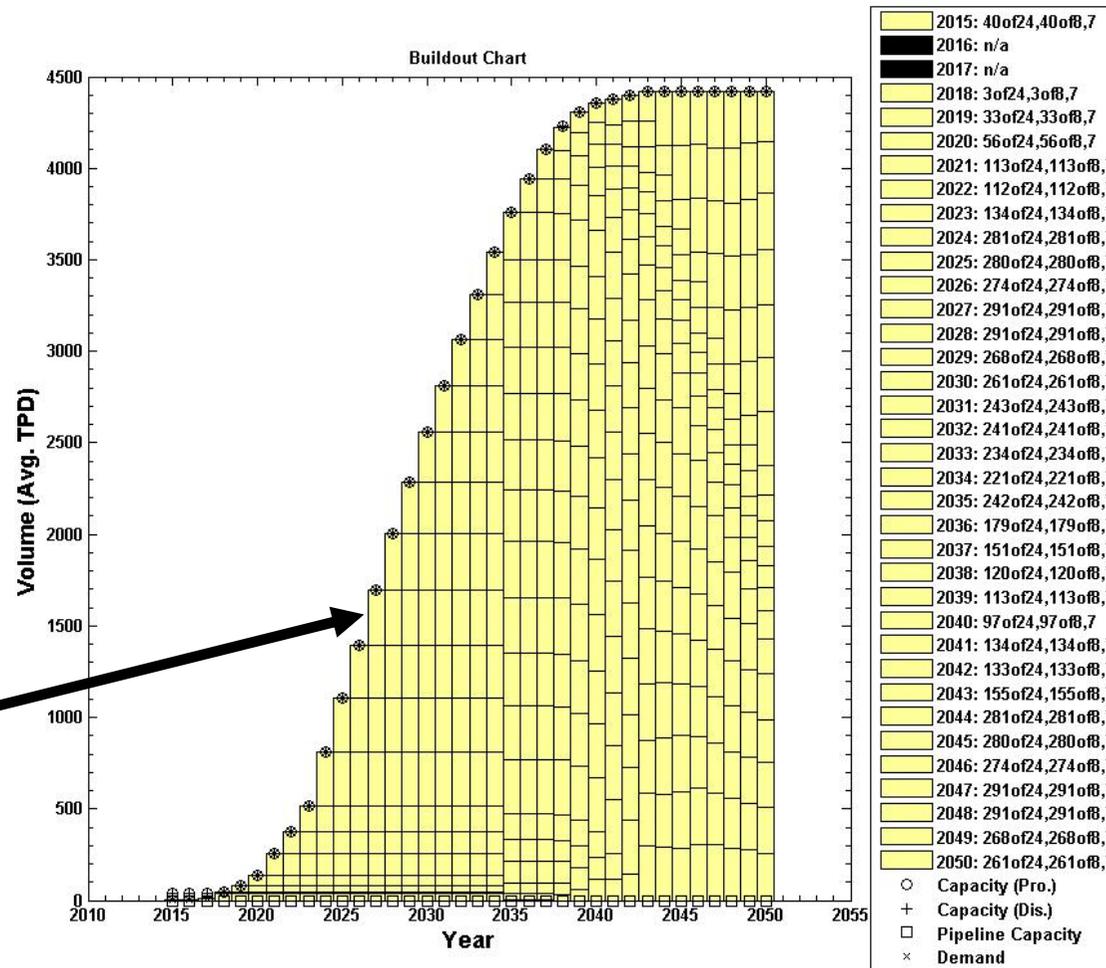
1.5tpd Forecourt SMR has the lowest total cost (\$2.64/kg)

Top 10/75 Options in 2018



2018 is the next year in which production capacity needs to be built. All pathways are considered and SMR Forecourt is seen to have the lowest cost. It is selected again to be built.

# Baseline Build-Out Plot

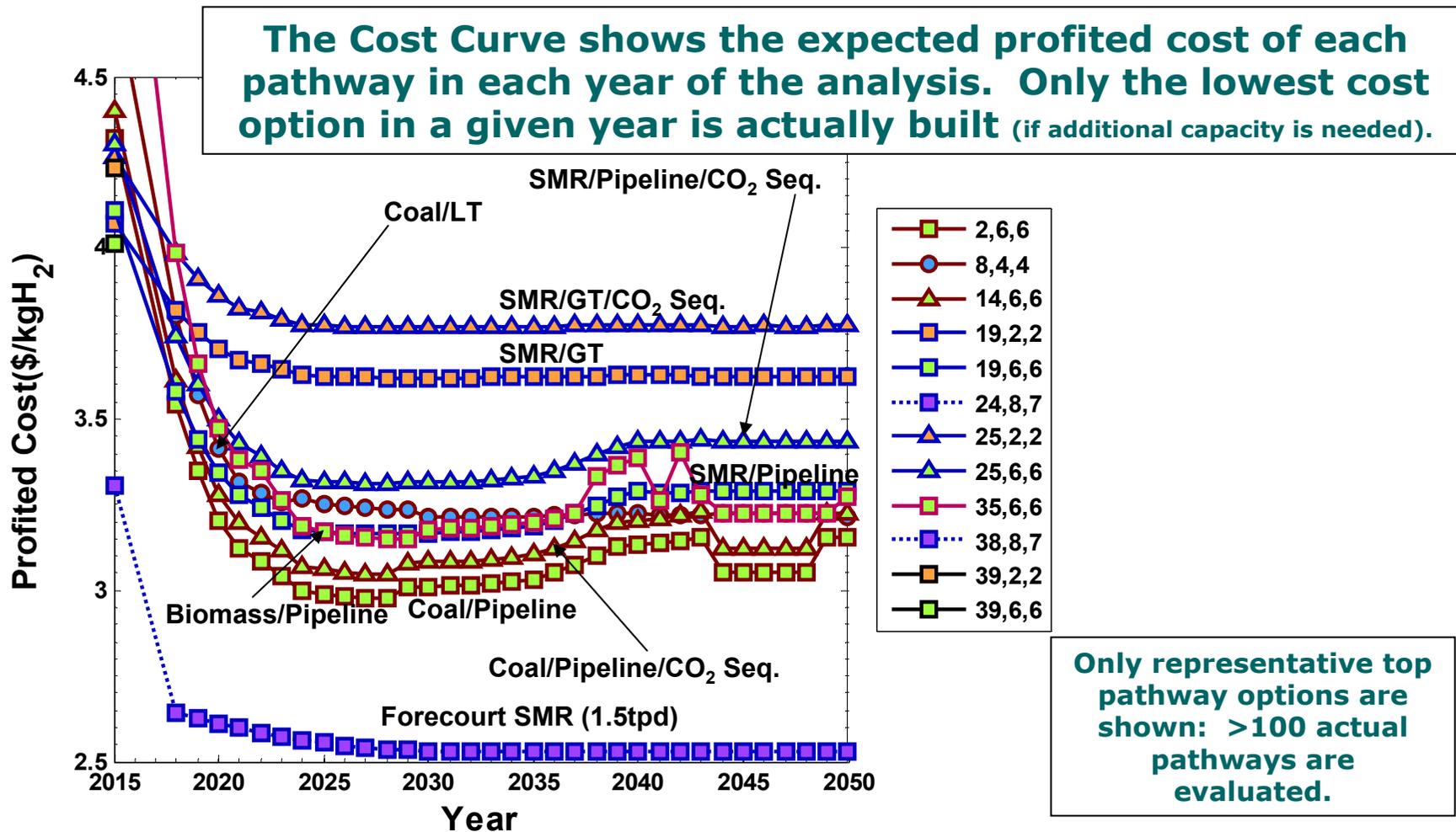


Each color in the plot indicates a different pathway. (since only Forecourt SMR is ever built, there is only one color)

Legend defines which pathways are built in each year.

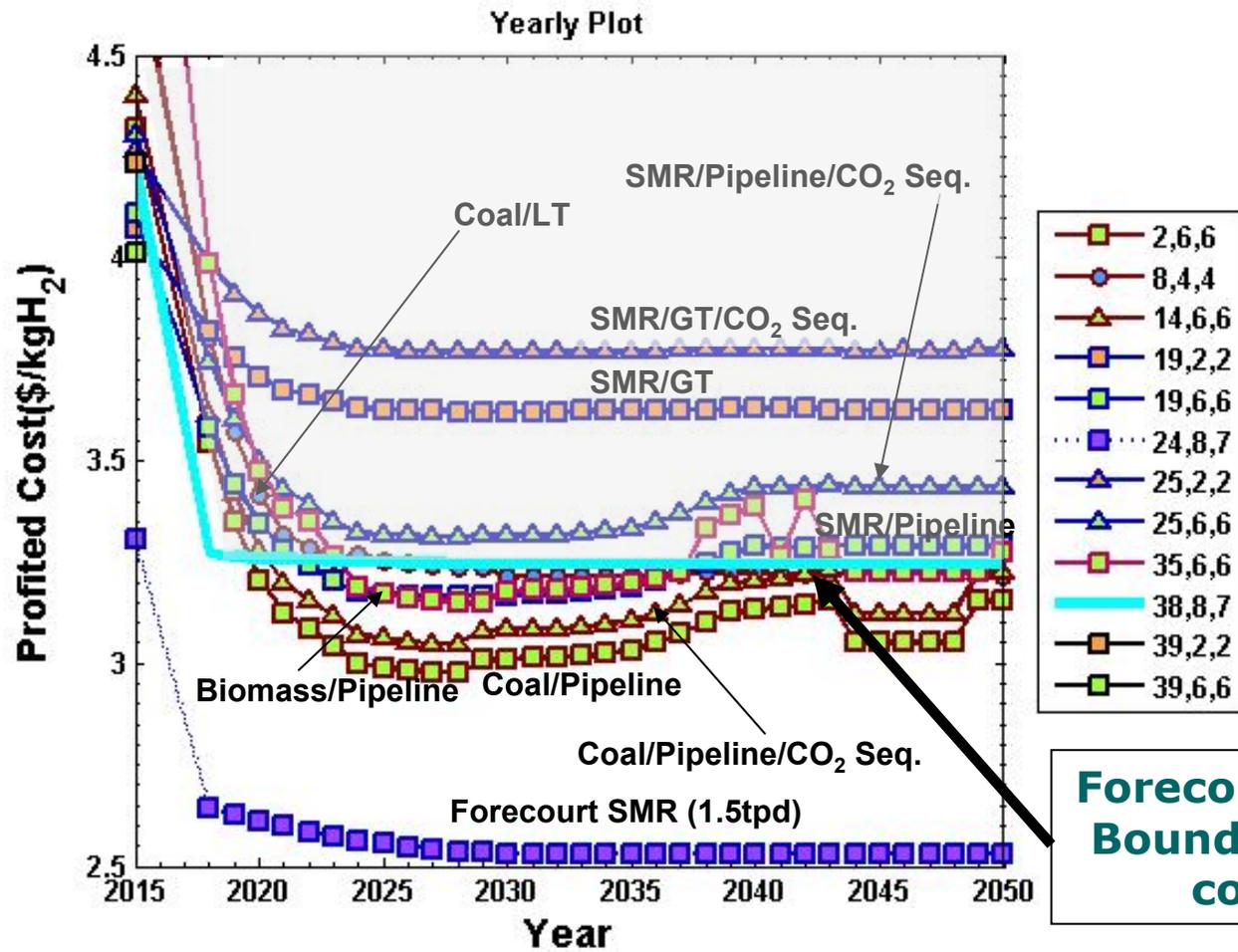
Evaluation & Selection Process is repeated for each year of the analysis. Forecourt SMR is seen to win every year.

# Forecourt SMR Capital Cost Sensitivity



Baseline Forecourt SMR is seen to be ~\$0.50/kg less expensive than other pathways but...

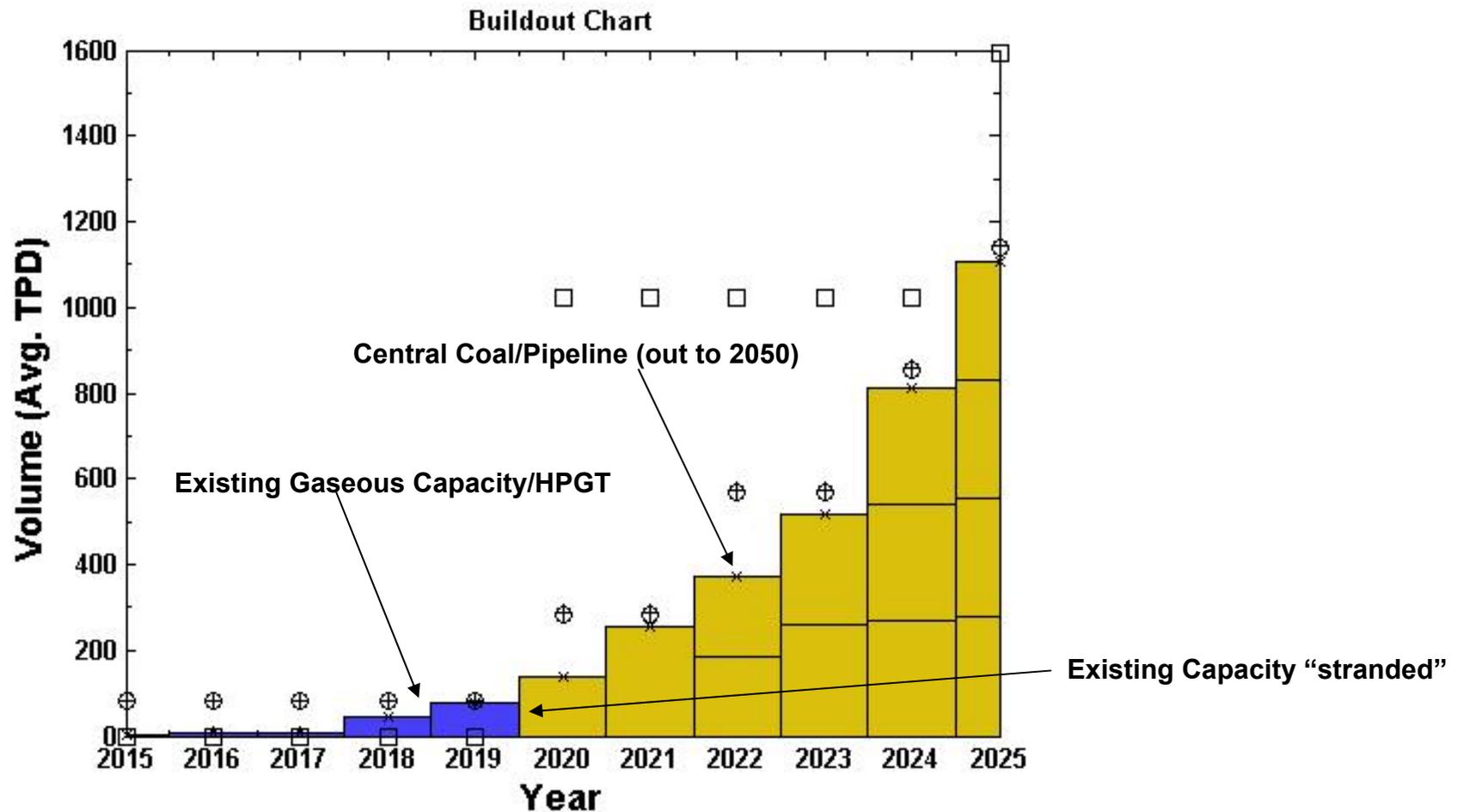
# Forecourt Sensitivity (1,500kg/day station)



**Forecourt SMR with "Upper Bound" capital cost raises cost substantially**

**... "Upper Bound" Forecourt SMR has a higher cost than leading pathways and thus...**

# Build-Out Plot (using “Upper Bound” Forecourt SMR)



**Revised Build-Out Plot shows selection of different lowest cost pathways.**

# Future Work

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Task 1: Cost and Performance Database Creation



Task 2: Baseline Production Transition Analysis



**Task 3: Sensitivity Analysis, Case Studies, and In-depth Examinations**



- **Ethanol:** Add option of Forecourt Ethanol production of H<sub>2</sub>
- **Future Delivery Options:** Add options and include DOE Delivery cost targets
- **Production Unit Learning Curve:** Link production options capital cost to number of units built
- **Capital Investment:** Tabulate yearly total investment cost of various build-out scenarios

**Task 4: Opportunities and Considerations Summary**

**Policy Considerations:** Postulate and assess impact of various subsidies, tax changes, H<sub>2</sub> credits.

# Summary

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- Transition Model is a tool that allows us to look at the impact of different sets of data and assumptions.
- Baseline model and sensitivities have been completed.
- Further scenario, options, and policies are being evaluated now.
- Model output is only as good as data input. Results should be understood as potential solutions under a set of given parameters.

# Previous Year Reviewers' Comments

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- Project was not reviewed last year

# Presentations and Publications

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- Presentations
  - FPITT - 21 Sept 05 & 27 Apr 06
  - DOE Transition Team – 25 Jan 06
- Publications – None.

# Critical Assumptions and Issues

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## Assumptions

- Demand will always increase
- Supply will always meet or exceed demand
- Area considered is of homogeneous demand
- 10 year analysis period for Forecourt production, 20 years for City Gate and Central.
- 10% real after-tax rate of return.

## Issues

- Insufficient input data. There are limited references for key model parameters such as liquefiers.
- Discrepancies in input data. The error bounds on some data such as capital cost and efficiencies are large and affect results.