Hydrogen Production Infrastructure Options Analysis

Brian James, Julie Perez, Pete Schmidt
Directed Technologies, Inc.
18 May 2006

Project ID # AN1

Overview

Timeline

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

Budget

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

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.

Partners

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

Project Objectives

Objectives

- Create **<u>a tool</u>** 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 **<u>sensitivity to different scenarios.</u>**
- Suggest to DOE **<u>areas of further research</u>** 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	DTI Model (Tool)	Results & Sensitivity

Research

Assumptions
Costs
Technologies

Scenario Model
H2A Production
H2A Dispensing
Other
Cost Database

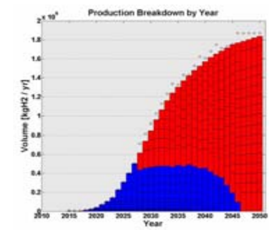
Capital Cost
Efficiency
Feedstock prices
Plant Location

DTI Model (Tool)

1. Evaluate Installed Capacity for the next B years
2. Determine Additional Infrastructure Needed for next B Years (including effects of stranding assets)
3. Evaluate Objective Function for all Infrastructure Options over next B years using expected plant operating capacity factor
4. 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.
5. Update Installed Capacity
6. Go to next Calendar Year

Results & Sensitivity

Cheapest Prod
H_2 Profited Cost
Stranded Assets

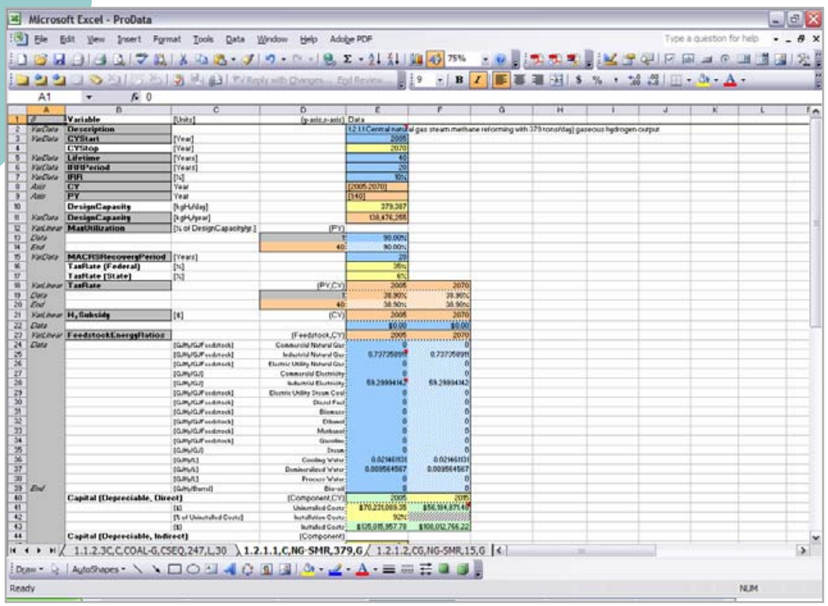


Modify parameter
Cost Database

Re-run model to assess impact

Production Database

Design Philosophy: User modifies production parameters in Excel, and MATLAB code reads and extracts necessary data for calculations.



Technology worksheet developed from Sentech's research efforts

- Excel database consists of any number of **Technology** worksheets, a **Global** worksheet and any number of **Supplemental** worksheets (in that order)
- **Technology** worksheets contain data relevant to a certain technology of the appropriate type (e.g. FC NG-SMR for the Production workbook)
- Each production method is on a separate **Technology** worksheet.
- **Global** worksheets contain data relevant to all technologies in a given workbook (e.g. Feedstock Prices)

H_2 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	[$/year]
IRR	[%]	Variable Costs Other	[$/kgH2]
CY	[Year]	MACRS Recovery Period	[Years]
PY	[Year]	Tax Rate	[%]
Design Capacity	[kgH2/year]	Other Costs	
Max Utilization	[% of Design Capacity/yr.]	H_2 Subsidy	[$]
Feedstock Energy Ratios		Emissions	[g/kgH2]
Capital (Depreciable)	[$]	Capital Credit	[% of Capital Depreciable]

Baseline Production Option Summary

- **Coal Gasification**
  - Gaseous & Liquid production
  - w & w/o CO_2 sequestration
  - Multiple sizes:
    - Central: ~300tpd
    - CG: 15tpd
  - Cases: 1-18
- **Natural Gas Steam Methane Reforming**
  - Gaseous & Liquid production
  - w & w/o CO_2 sequestration
  - Multiple sizes:
    - Central: ~380tpd
    - CG & IC: 15tpd
    - Forecourt: 0.1 & 1.5 tpd (no CO_2 seq.)
  - Cases: 19-26, 37, 39
- **Electrolysis**
  - Gaseous & Liquid production
  - w & w/o CO_2 sequestration
  - Multiple sizes:
    - Central: ~700tpd (Nuclear)
    - Forecourt: 0.1 & 1.5 tpd (Marginal mix elec., no CO_2 seq.)
  - Cases: 27-34
- **Biomass Gasification**
  - Gaseous & Liquid production
  - Central: 195tpd
  - Cases: 35-36
- **Existing H_2 (Los Angeles)**
  - Gaseous (Liquid prod. Negligible)
  - No CO_2 sequestration
  - Cases: 38
- **Future Options**
  - Ethanol Forecourt
  - Wind Electrolysis
  - Bio-Oil (from Biomass)
  - FT Fuel (from Coal)

DTI Model Approach

- Develop a **time-based, computational dynamic model of H_2 production** in the continental US.
- **Use model** and other methods **to understand** how a H_2 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_2 production & delivery costs dynamically (as opposed to statically) **with changing demand and utilization**.

DTI Model Approach, cont'd

- Model economics from **H_2 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_2 demand** (constant kg H_2/day/km^2).
  - 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

- Business wants to maximize profit.
- Profit is hard to quantify (requires knowledge of H_2 price).
- Will use H_2 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.

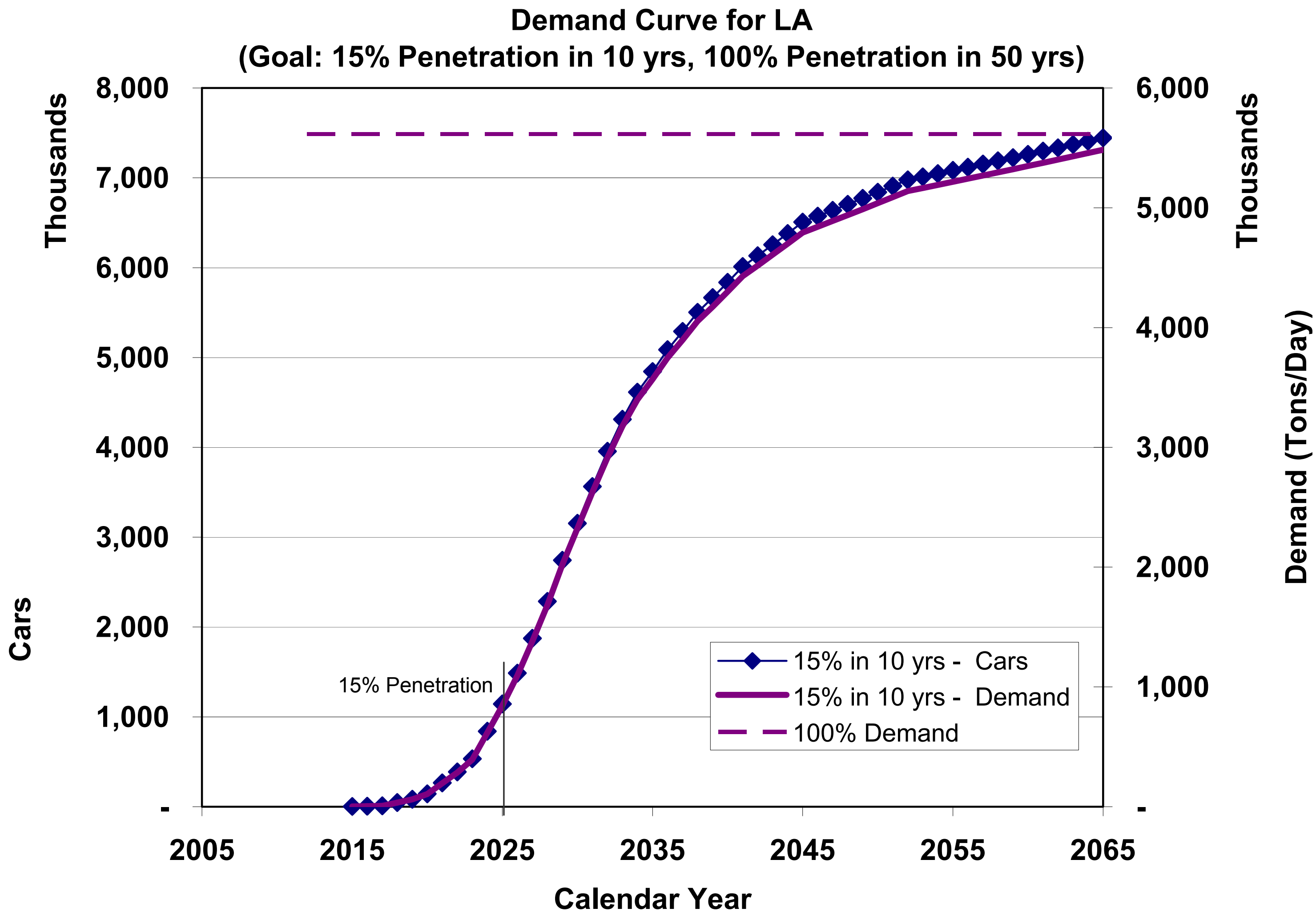
Objective Function & Decision to Build

- Objective Function defined as average Profited Cost:

Profited Cost of Hydrogen [$/kg] at Pump =
Production cost + Delivery cost + Dispensing cost + 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_2 Demand Curve – Los Angeles

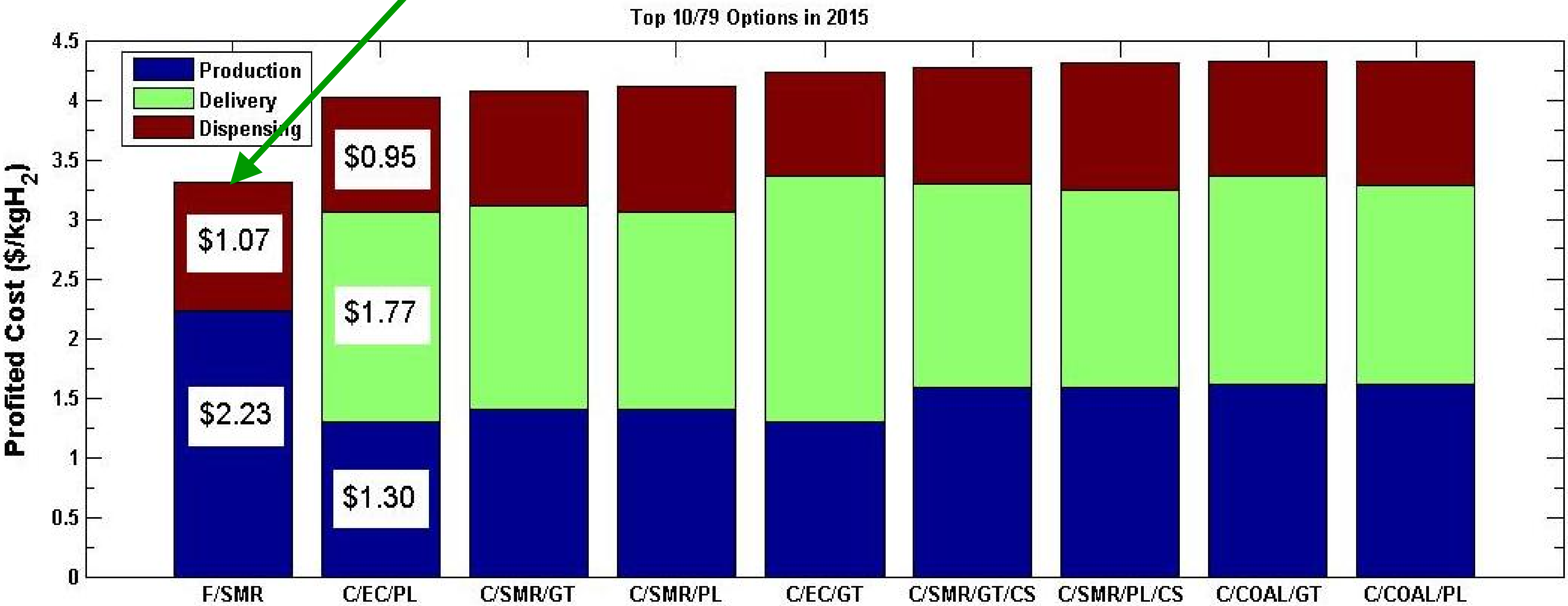


The demand curve is an input to the model.

2015 Total Pathway Cost

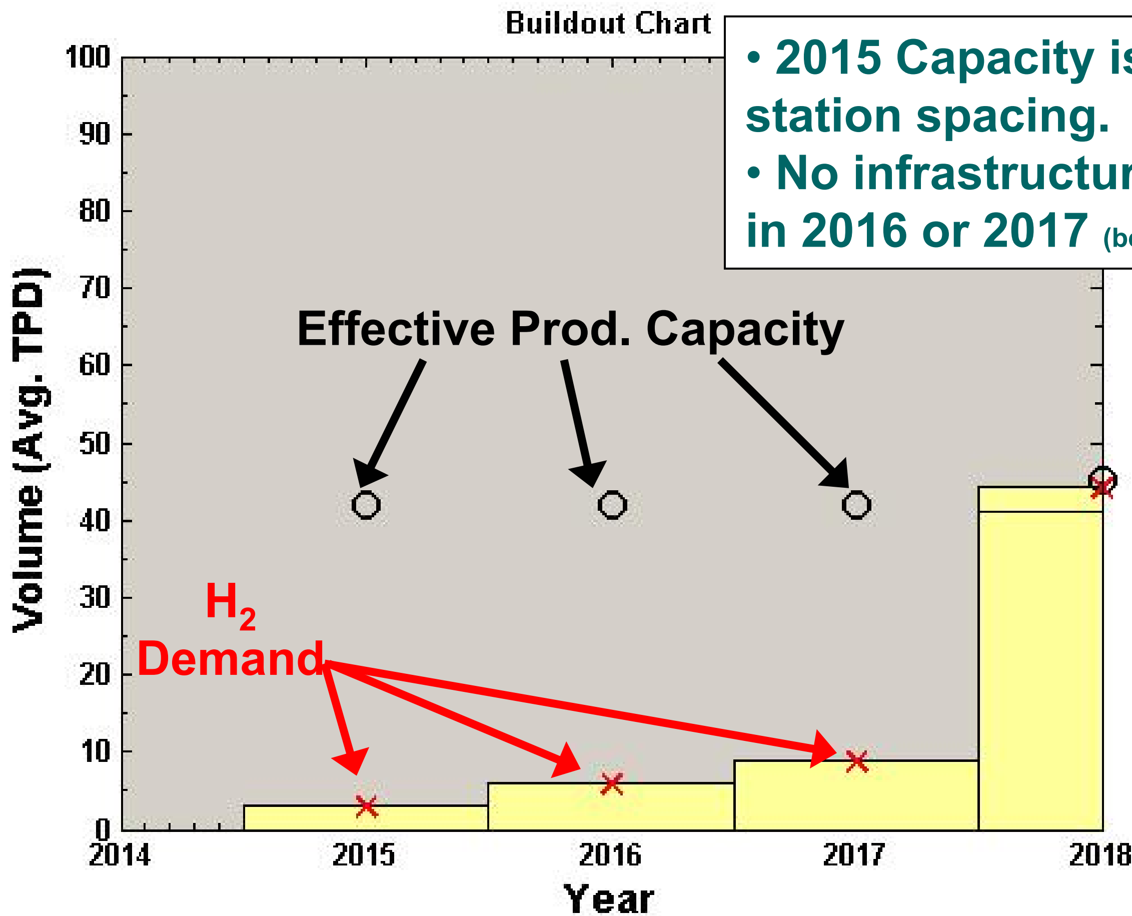
F	Forecourt
PL	Pipeline
GT	High Pressure Gas Truck
CS	Carbon Sequestration
EC	Existing Capacity
C	Central

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



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



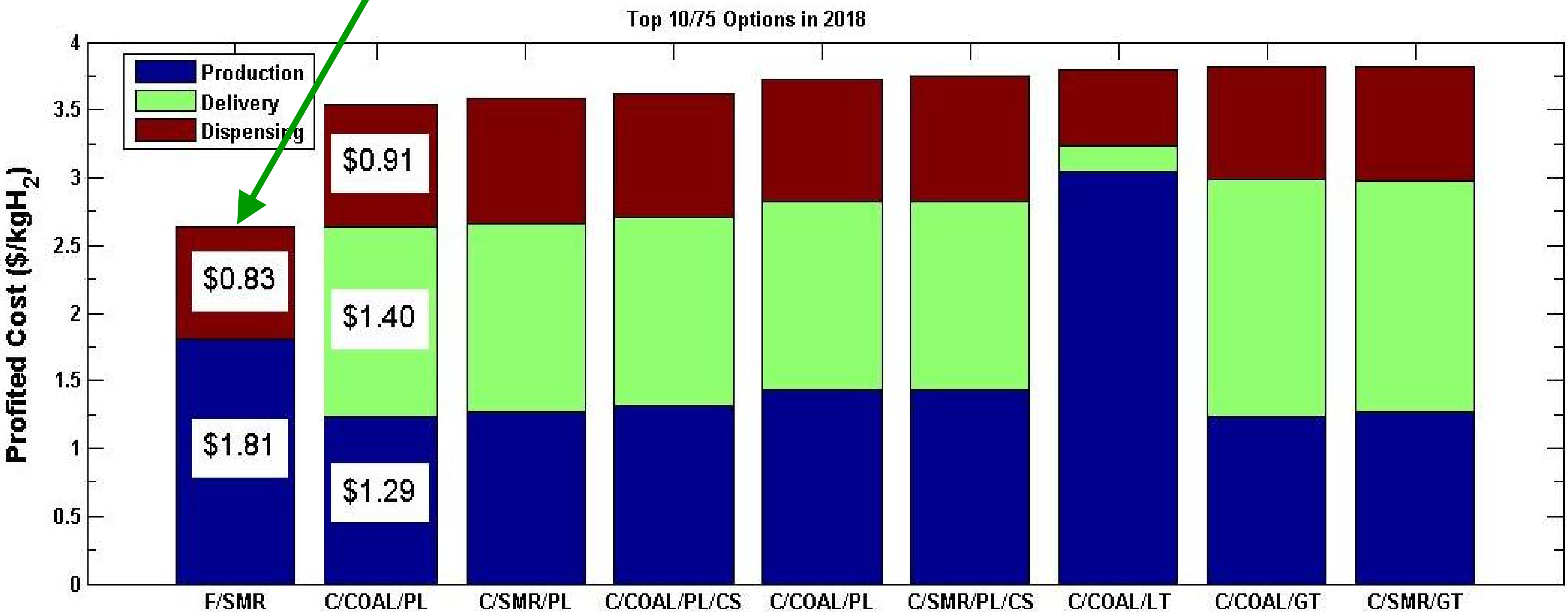
- 2015 Capacity is determined by station spacing.
- No infrastructure build is required in 2016 or 2017 (because capacity exceeds demand)

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

2018 Total Pathway Cost

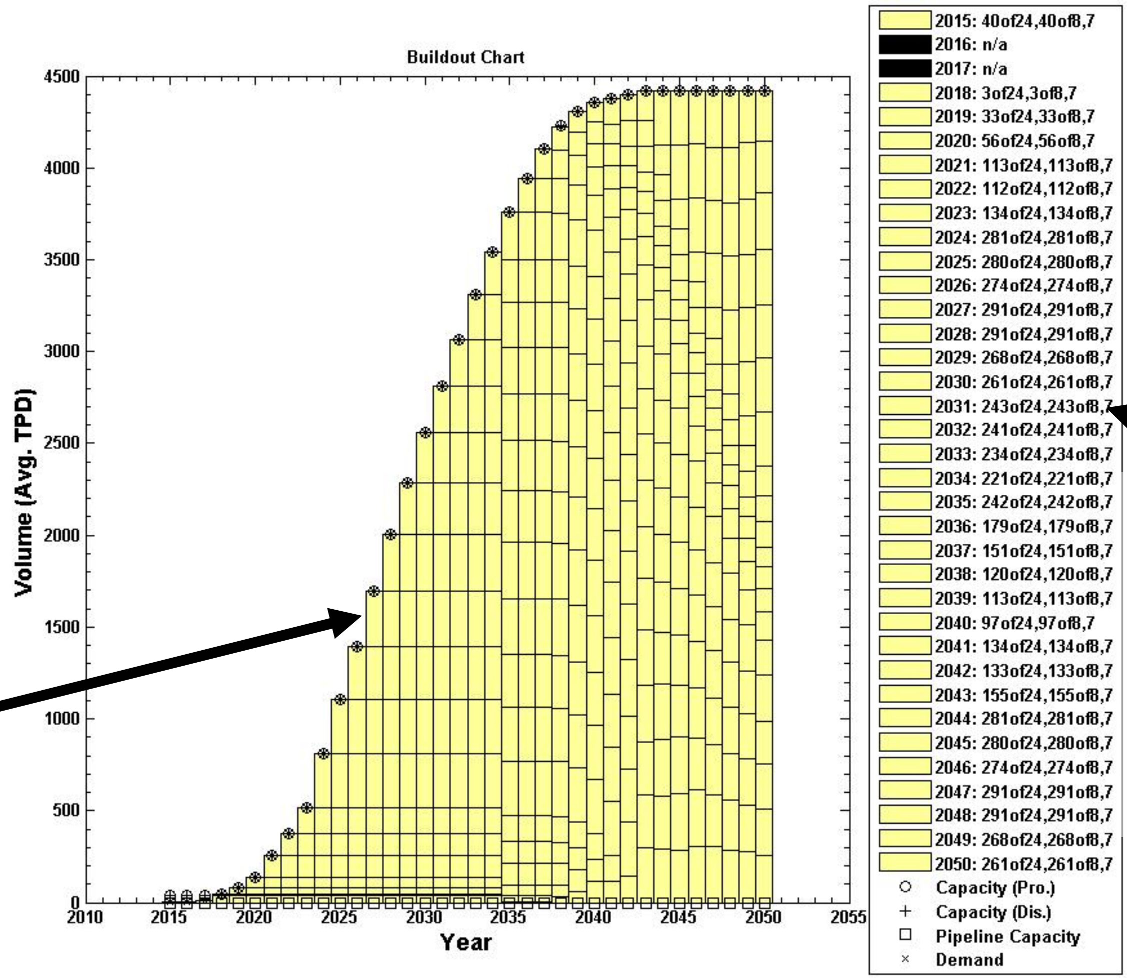
F	Forecourt
PL	Pipeline
GT	High Pressure Gas Truck
LT	Liquid Truck
CS	Carbon Sequestration
EC	Existing Capacity
C	Central

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



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



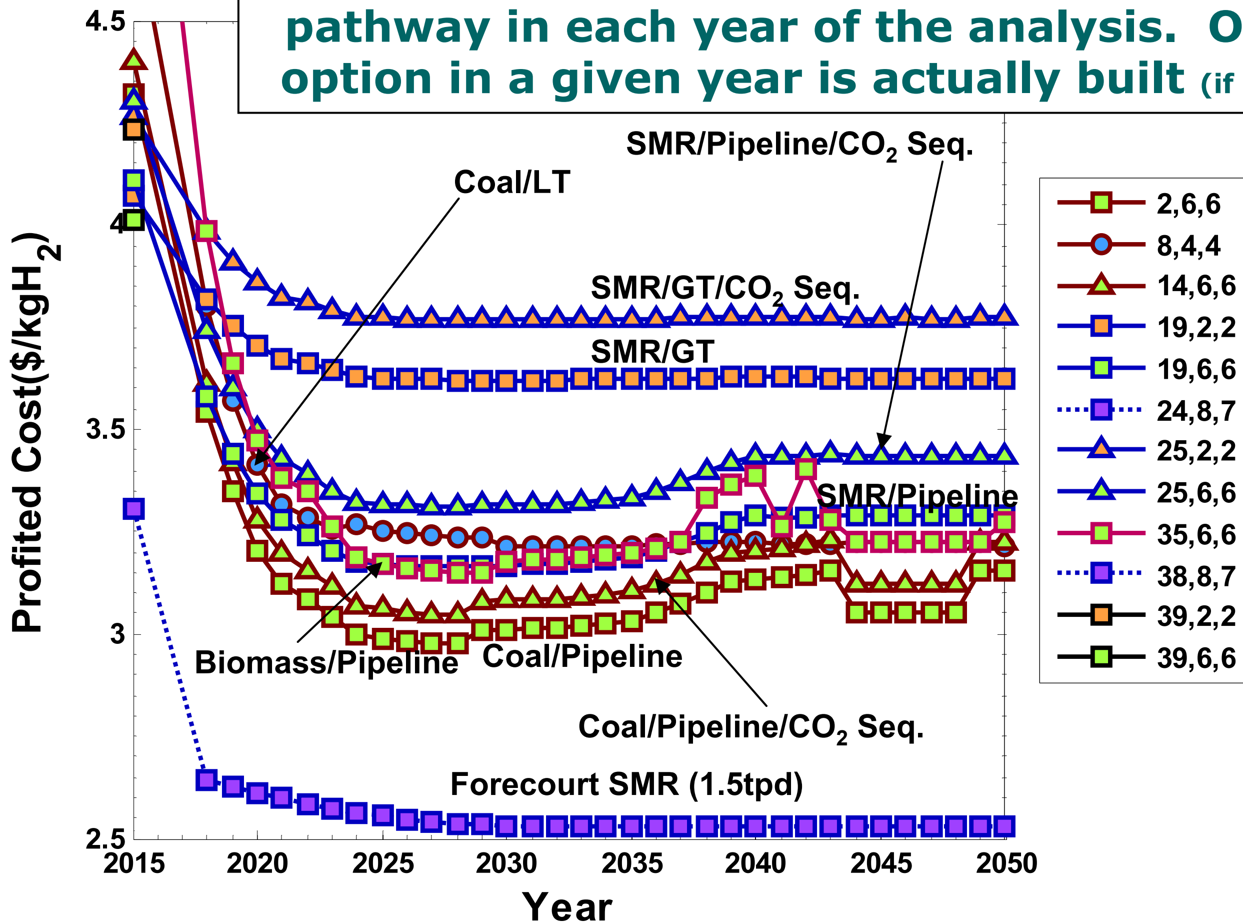
Each color in the plot indicates a different pathway.
(since only Forecourt SMR is ever built, there is only one color)

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

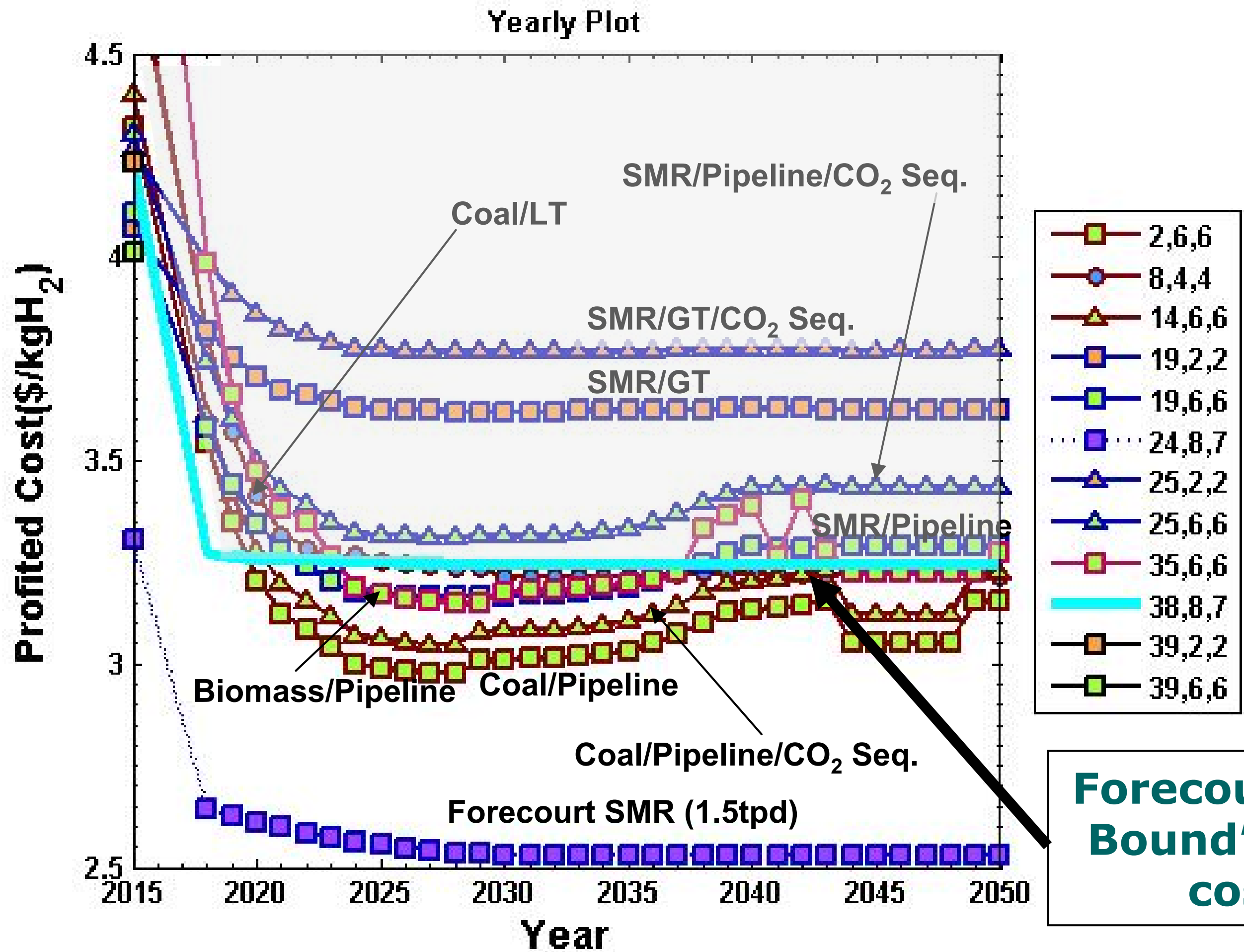
The Cost Curve shows the expected profited cost of each pathway in each year of the analysis. Only the lowest cost option in a given year is actually built (if additional capacity is needed).



Only representative top pathway options are shown: >100 actual pathways are evaluated.

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

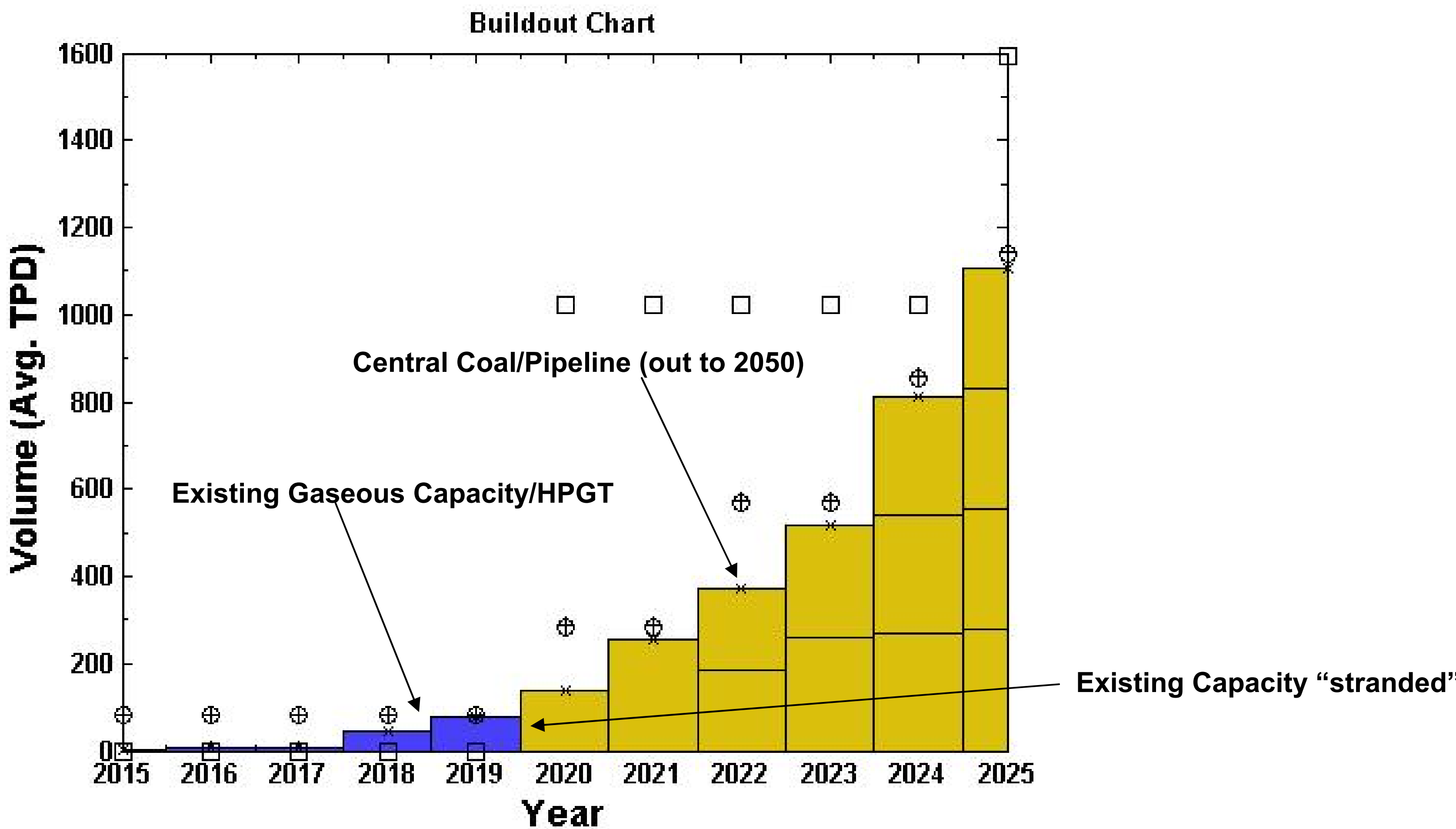
Forecourt Sensitivity (1,500kg/day station)



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

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_2
- **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_2 credits.

Summary

- 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

- Project was not reviewed last year

Presentations and Publications

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

Critical Assumptions and Issues

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.