H2A Delivery Analysis

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2005 DOE Hydrogen Program Review

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Evolved from H2A Project

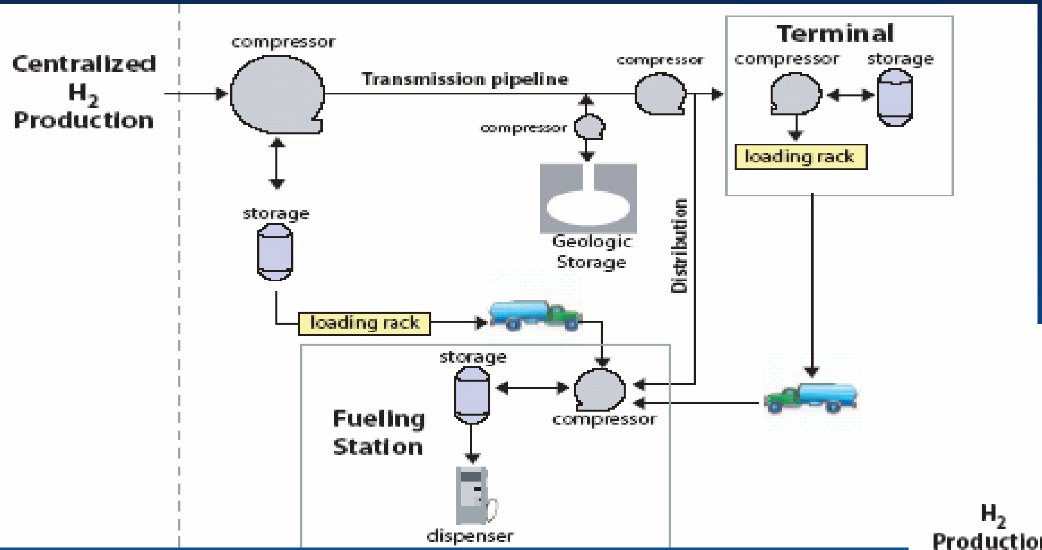
- Addresses MYPP Hydrogen Delivery Barriers :
  - A. H2 and H2-carrier infrastructure analysis (primary)
  - F. Hydrogen delivery infrastructure storage costs (secondary)
- FY05 Focus: Model building, coordination, quality control, peer review
  - Budget ~$350k, 60% complete
  - Partners
    - Argonne National Lab (ANL)
    - National Renewable Energy Lab (NREL)
    - University of California at Davis (UCD)
    - Pacific Northwest National Lab (PNNL)
- FY06 Focus: Model expansion & analysis (with Nexant team)

Objectives

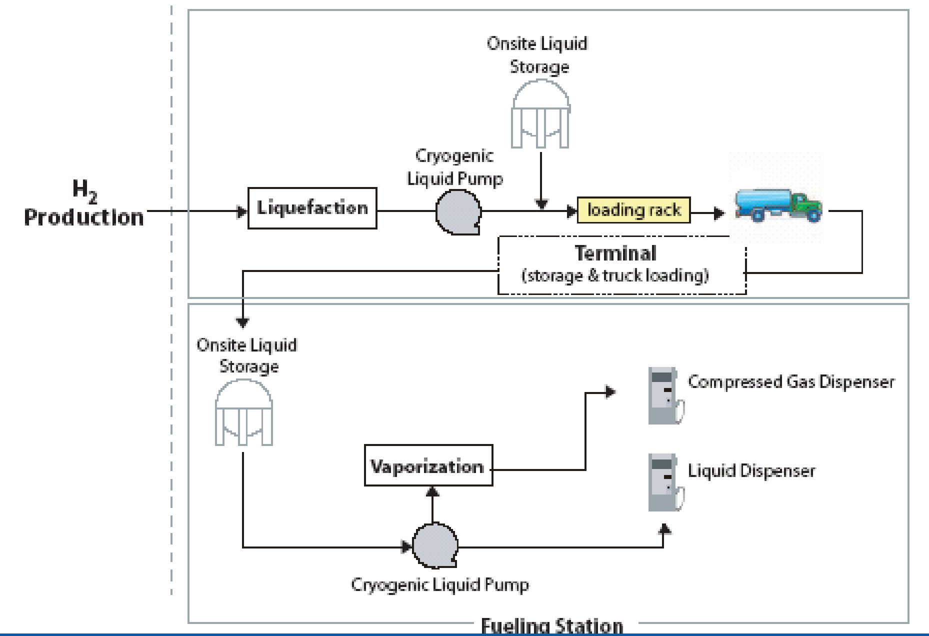
- ❑ Develop methodology to understand contribution of individual delivery components and entire delivery infrastructure to H2 cost
- ❑ Develop tools for consistent and transparent analysis of hydrogen delivery within framework of the H2A Model
  - Delivery Component Model (Version 1.0 completed 3/05)
  - Delivery Scenario Model (Version 1.0 completed 5/05)
  - Build on past/current efforts and common analytical tools
    - Microsoft EXCEL based
    - Common building blocks from H2A Program
      - “First principles” approach
      - Discounted cash flow analysis
      - Common format, financial and energy assumptions
      - Above-ground storage, compression, “forecourt”
- ❑ Work with industry to validate assumptions and analysis approach
  - H2A Key Industrial Collaborators
  - Delivery Tech Team

Overall Approach

LH2 and GH2 Delivery Require Different Components; Analyses Require Component Modeling



Gaseous Delivery Path



Liquid Delivery Path

Overall Approach

With Component and Scenario Models Individual Pieces or Entire Delivery Paths Are Compared

- Define paths from plant gate to “forecourt” (“well” to “pump”) with associated components
- For each component, estimate:
  - Capital and operating cost, lifetime, operating profile, etc.
  - Size to satisfy scenario demand
  - Account for losses, efficiencies, new technologies, scale, “learning”
- Apply consistent financial and operating assumptions
  - Debt vs. equity, project lifetimes, ROI, etc.
  - Availability
- Link component results to estimate:
  - Delivery cost contribution and cash flow
  - Energy and GHG emissions associated with H2 delivery
  - Lower cost paths under alternative assumptions

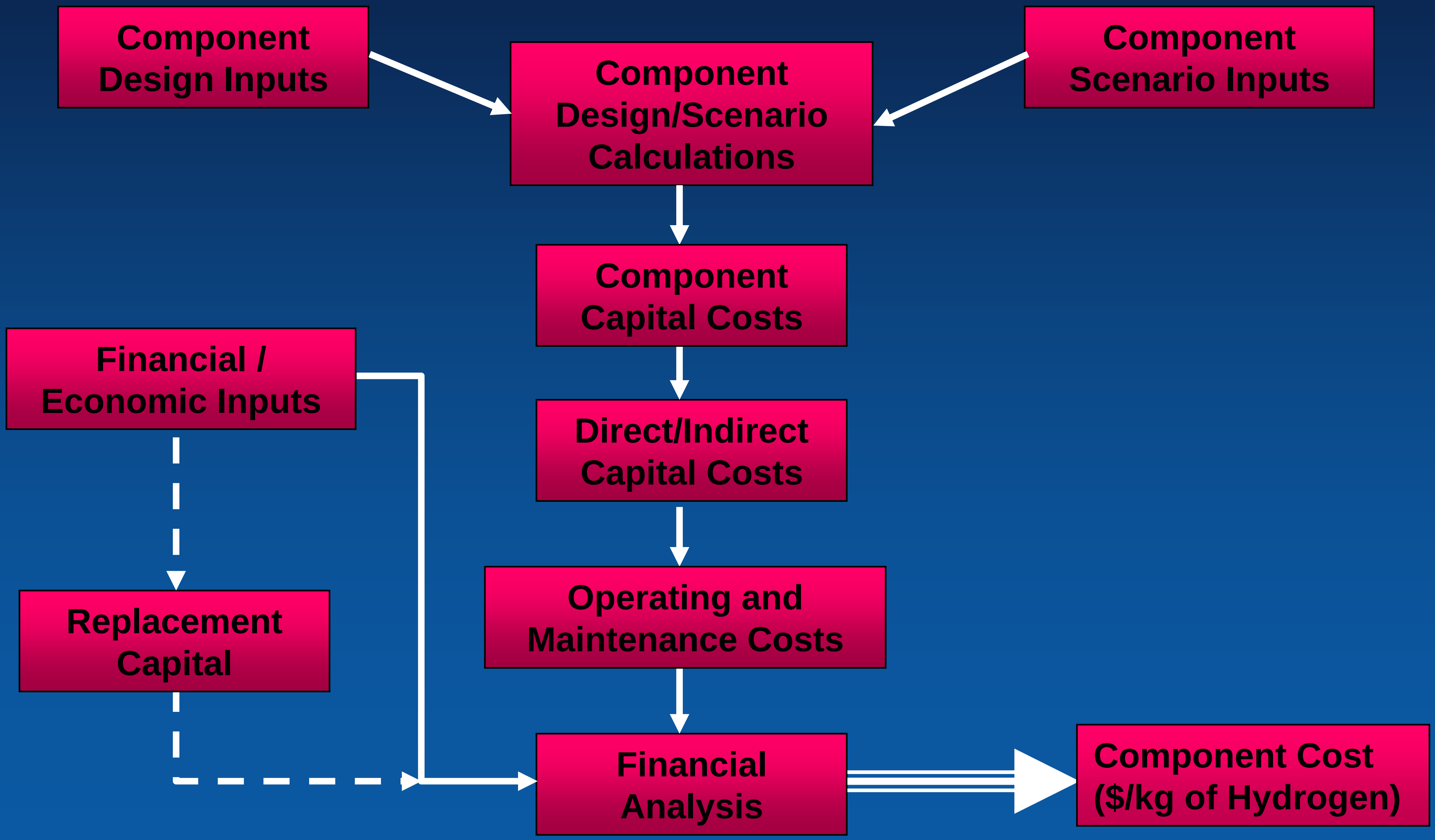
Approach

Hydrogen Delivery Components Model

- Excel-based tool with separate tabs for each component
- Determines “generic” contribution to H2 cost by component
- Consistent assumptions for:
  - Discount Rate – 10%
  - Dollar Year – 2005
  - Startup Year – 2005
  - Depreciation Type – MACRS
  - Analysis Period – 20 years
  - Federal Taxes – 35%
  - State Taxes – 6%
  - Total Tax Rate – 38.6%
- H2 cost calculated in real dollars using fixed charge rate

Approach

Components Model Hierarchy



Technical Accomplishments:

Components Model Features

Delivery Components	Storage Components
- Truck – Tube Trailer - Truck - LH2 - Pipeline - Liquefier - Compressor (single & multi-stage) - Forecourt Compressor	- Compressed Gas Tube System - Bulk Liquid Hydrogen System - Geologic - Forecourt
-Terminals (gaseous and liquid)	

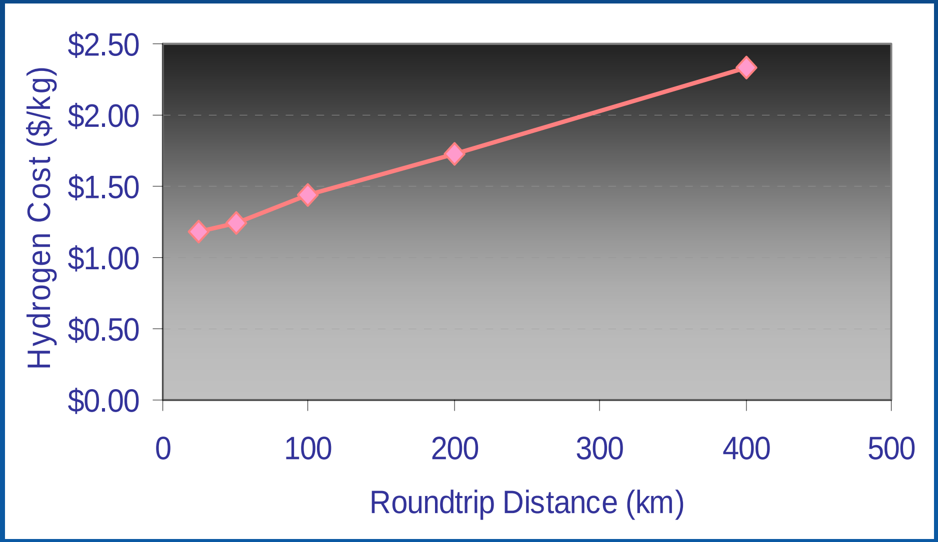
- Yes/no toggle switches for user input or H2A defaults
- Error messages alert user to input errors
- MACRS depreciation options
- Color-coded to facilitate user input

(light blue)	Calculated Cells
(orange)	User Input Required
(green)	Optional Input
(yellow)	Information

Technical Accomplishments

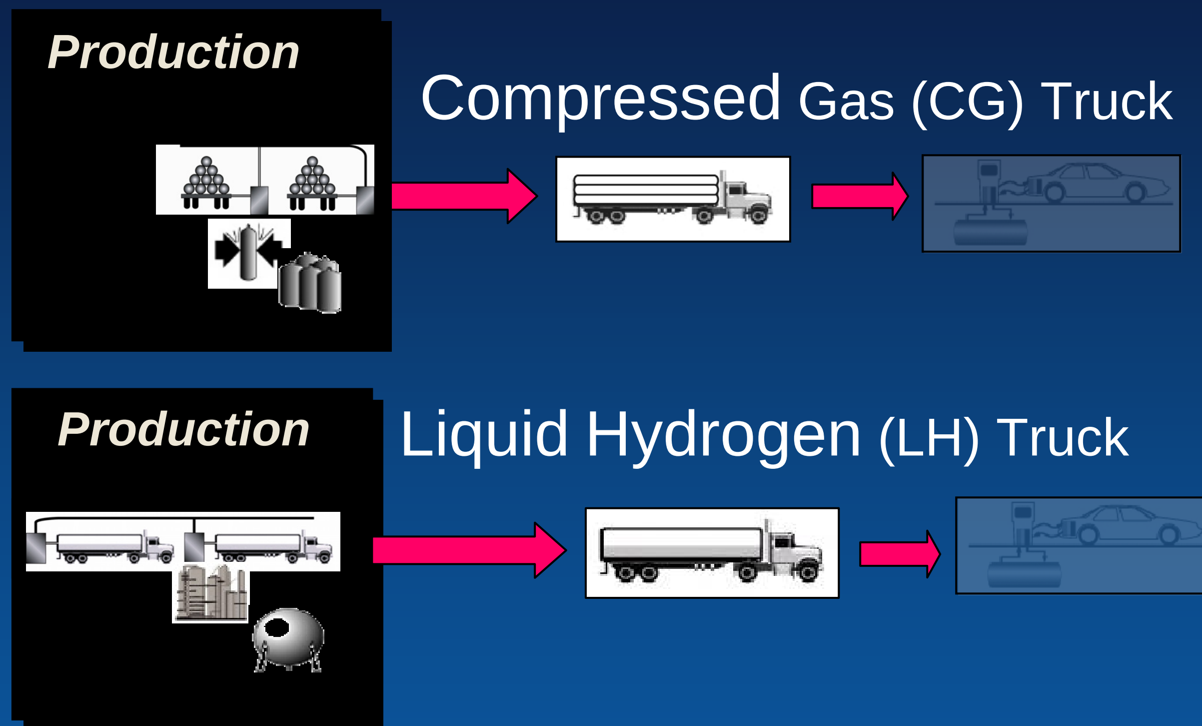
Components Model Illustrative Results: Compressed Gas Truck (Tube Trailer)

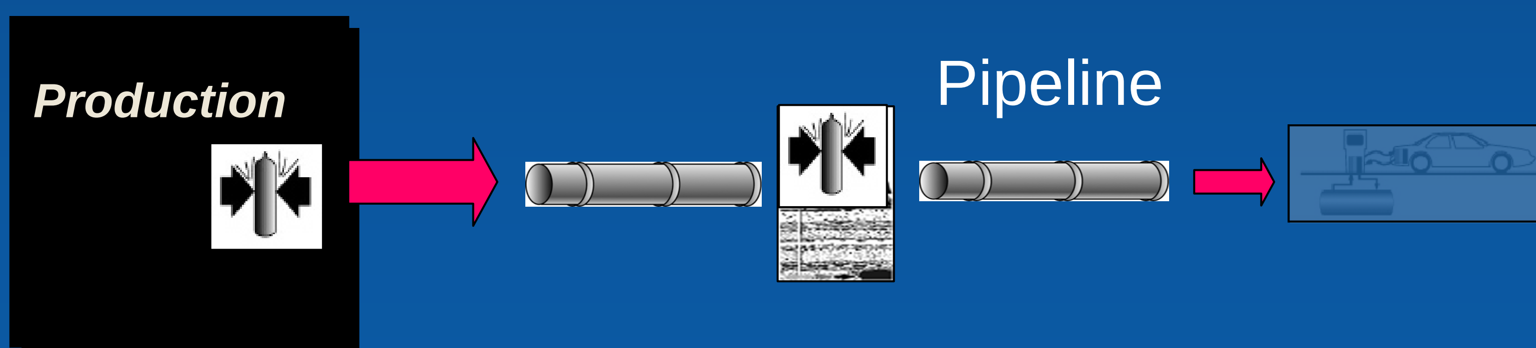
- Tube trailer dropped off at forecourt
- One tractor and sufficient number of trailers to maximize tractor utilization
- 20 yr analysis period
- 180 atm (2760 psia) maximum pressure
- 100 kg/d station demand



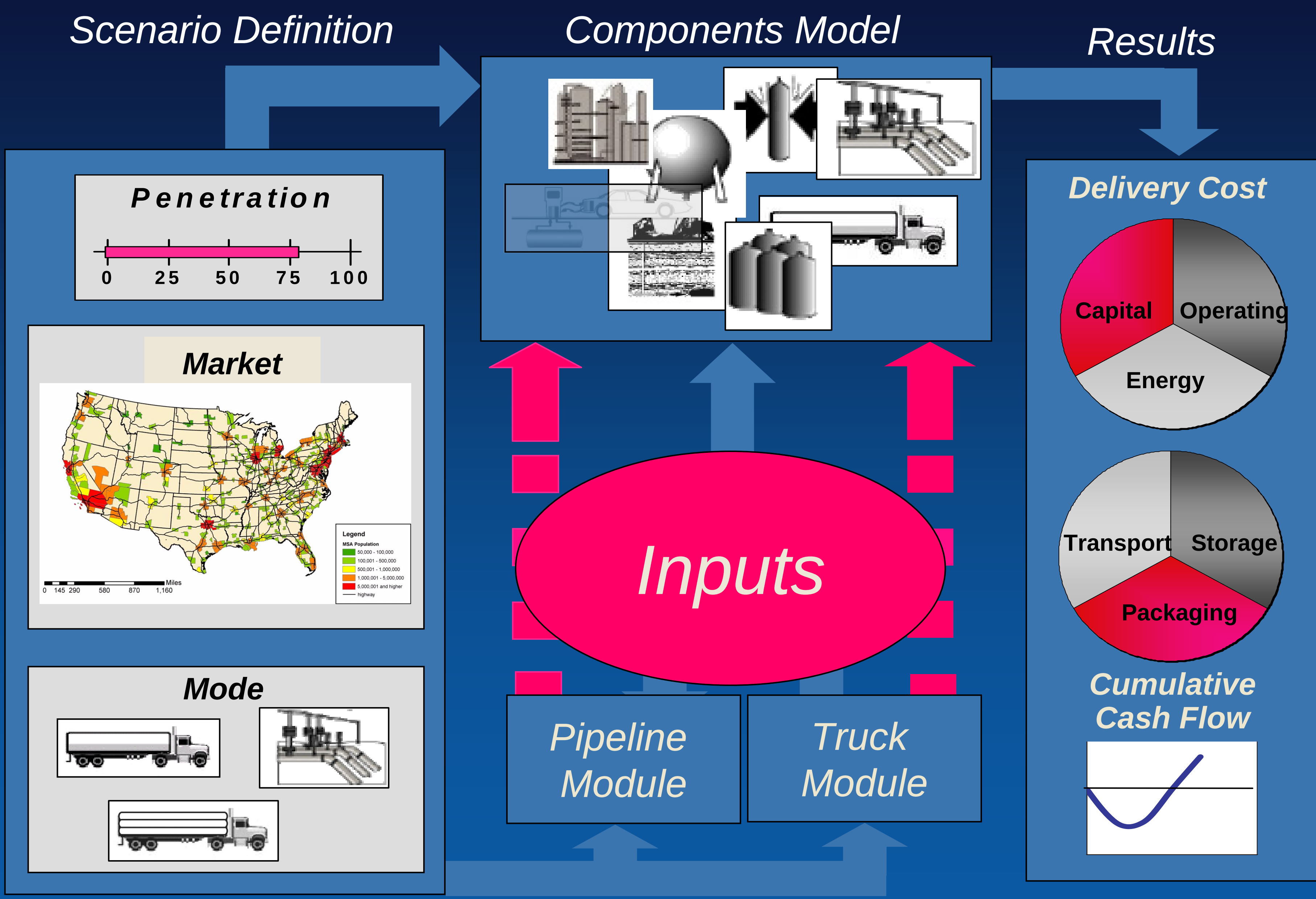
Delivery Scenarios Model

Version 1.0 contains three pathways with pre-defined demand based on market, penetration and modal efficiencies. Delivery is by a single user-defined mode. Loading, packaging and storage are inside the plant gate



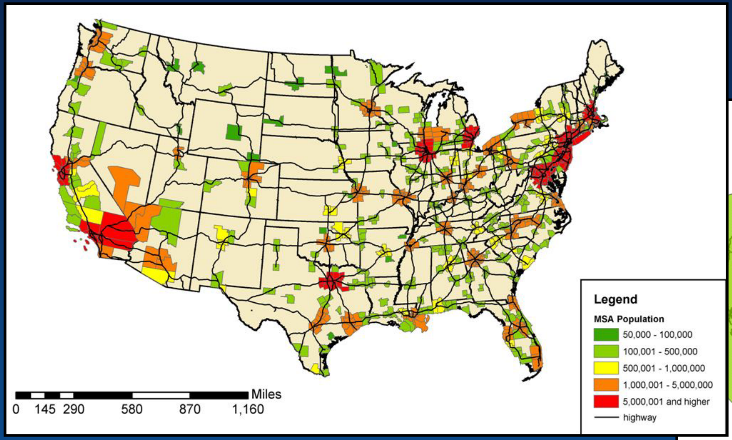


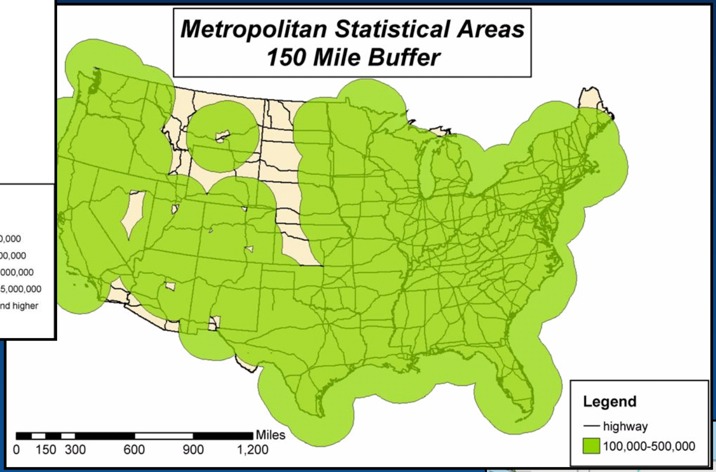
H2A Delivery



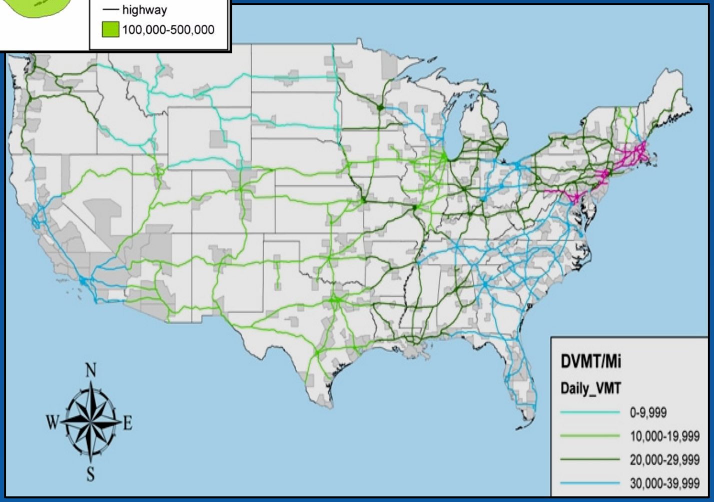
Technical Accomplishments

Delivery Scenarios Defined by Urban Area Size and Interstate Highway Traffic Density





- Interstate highways = 1% of rural roads but 23% of rural travel (FHWA 2003)
- Traffic density = <1000->50,000 vmt/mi/d
- Fuel use = 700 kg/d avg ~50-2000 kg/mi/d range



- 75% of population in urbanized areas
- Urban areas large and clustered E of Mississippi & on W coast
- Urban areas smaller & more dispersed in Plains
- Most of the Great Plains and Mountain States are within 200 highway miles (320 km) of smaller urban areas

Technical Accomplishments

Delivery Scenario Variables

- Urban areas
  - Population, land area, vehicle density
  - Distance from central H2 production
- Intercity/rural travel
  - Highway miles
  - Travel density, fuel demand
- Hydrogen-fueled vehicles
  - Number, fuel economy, utilization
- H_2 stations (forecourts)
  - Number, capacity, avg. kg dispensed
  - Distance between stations
  - Ratio to gasoline stations
- LH_2 and GH_2 trucks
  - Fuel economy, losses, capacity, delivery volume
  - Speed, load/unload time, drops/trip
  - Physical & economic life
- Pipelines
  - Inlet, city gate, forecourt pressure
  - Transmission, distribution, service length
  - Circuity factors
  - Physical & economic life
  - Ratio to capital cost of natural gas pipelines

Technical Accomplishments

V 1.0 Models 32 Scenarios Defined by Market, Penetration and Delivery Mode

Penetration / Market	1%	10%	30%	70%
Large urban	CG Truck	LH Truck Pipeline	LH Truck Pipeline	LH Truck Pipeline
Small urban	CG Truck	LH Truck Pipeline	LH Truck Pipeline	LH Truck Pipeline
Intercity – long segment	---	CG Truck LH Truck Pipeline	CG Truck LH Truck Pipeline	CG Truck LH Truck Pipeline
Intercity – short segment	---	CG Truck LH Truck Pipeline	CG Truck LH Truck Pipeline	CG Truck LH Truck Pipeline

Technical Accomplishments

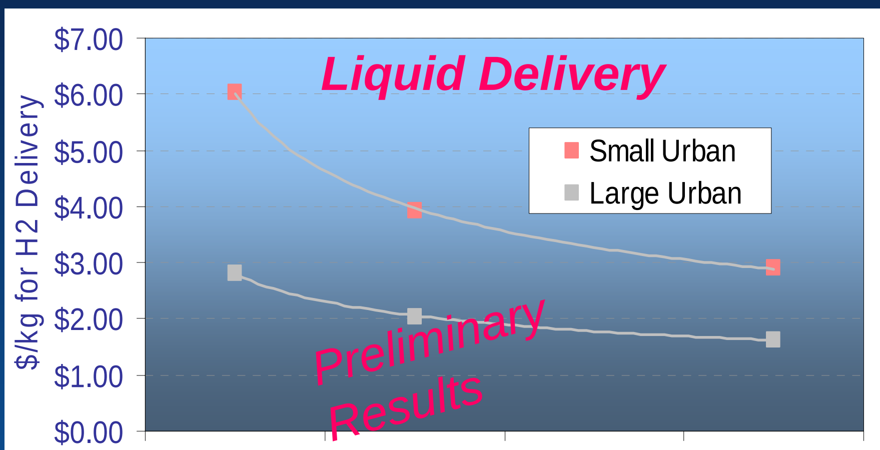
Preliminary Results That Follow Are NOT Based on Fully Integrated Model

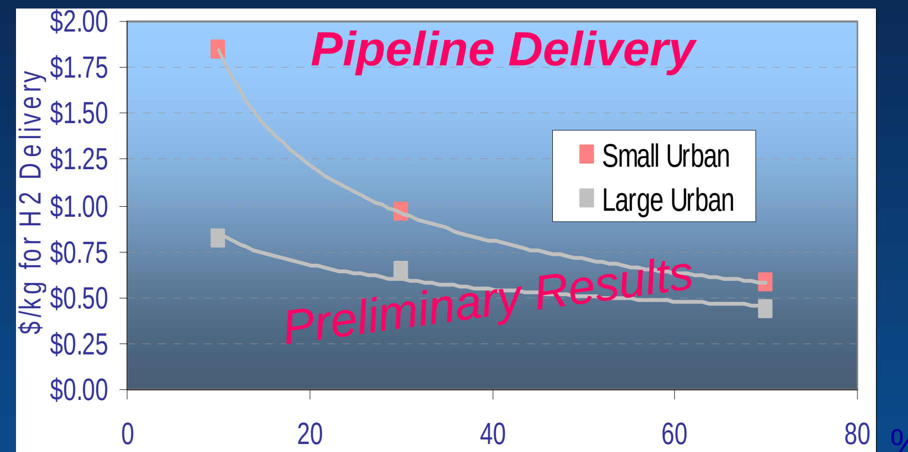
- Not based on detailed financial analysis
- Intended to illustrate:
  - Types of analyses being conducted
  - Types of comparisons being made
  - Types of conclusions that might be drawn
- Fully integrated model completed after slide preparation

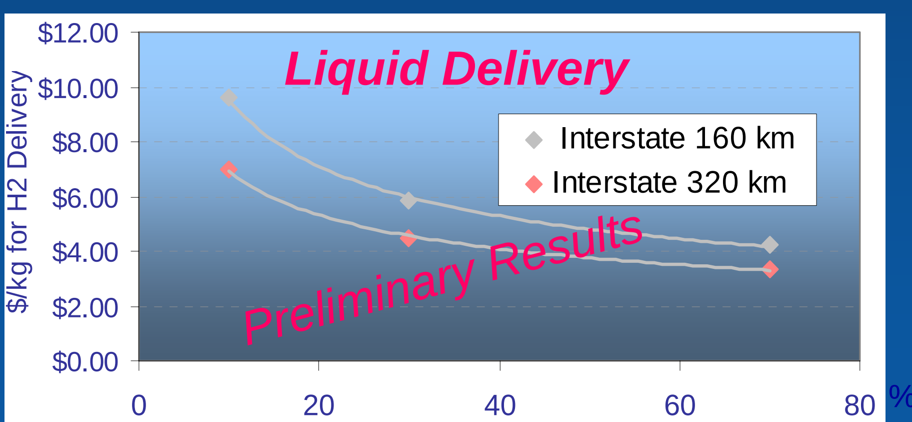
H2A Delivery

Technical Accomplishments

Illustrative Results: Depending on Volume, Delivery Cost Can Vary by 2-3 for Current Technologies







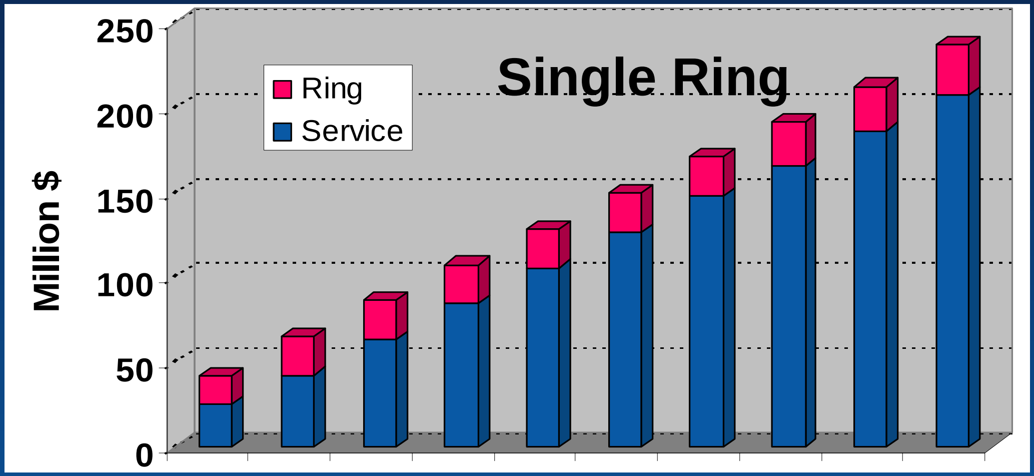
Market Penetration

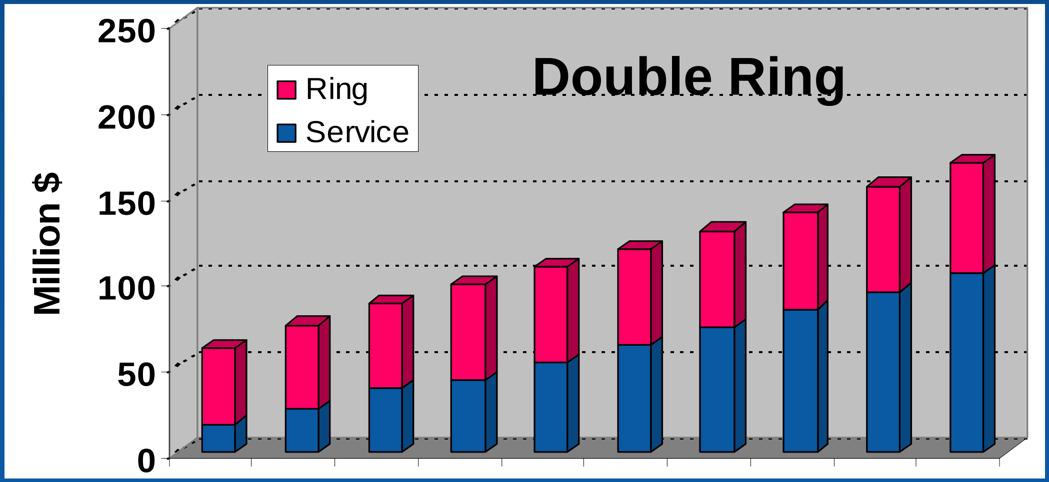
- Pipeline delivery cost can be double in small urban markets yet still be below LH2 delivery
- Even at high volume LH2 delivery to interstate stations is expensive
- $/kg excludes forecourt compression, storage & dispensing

H2A Delivery

Technical Accomplishments

Illustrative Results: Depending on Geometry, Service Lines May Account for Increasing Share of Pipe Delivery





- For 1-ring system, service lines account for 60 to 87% pipeline cost
- For 2-ring system, service lines account for 27 to 62%
- 1-Ring system less costly below 30% penetration
- Lowest cost 2-ring mileage achieved at 40% penetration

Future Work

Planned Model Enhancements and Applications

- Remainder FY05
  - Beta testing by KIC members, implementation of recommendations
  - Forecourt model
  - Mixed pathways (e.g., pipeline to GH2 terminal)
  - Mixed demands/markets (e.g., combining multiple urban areas and urban with interstate demand)
  - Additional scenarios (e.g., larger urban area, 2-trailer dropoff)
  - Technology improvements (e.g., 10,000 psi storage)
  - Energy efficiencies and CO_2 emissions
- FY06
  - Sensitivity analyses (service ratio, service lines, storage/compression tradeoffs, etc.)
  - Novel solid/liquid hydrogen carriers
  - Tradeoffs between system options (e.g., pressure vs. storage)

Additional Members of Project Team

Daryl Brown, PNL
Jay Burke, ANL
Jerry Gillette, ANL
James Li, ANL
John Molburg, ANL
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Publications and Presentations

Mintz, Marianne, Jerry Gillette, Jay Burke, John Molburg and Joan Ogden, *Hydrogen Delivery Scenarios Model*, Presented at the National Hydrogen Association Annual Meeting, Washington, DC (March 30, 2005)

Ringer, Matt, *Hydrogen Delivery Components Model*, Presented at the National Hydrogen Association Annual Meeting, Washington, DC (March 30, 2005)

Molburg, John, Marianne Mintz and Jerry Gillette, *Modeling Pipeline Delivery of Compressed Gaseous Hydrogen to Urban Refueling Stations*, Transportation Research Board Annual Meeting, Washington, D.C (January 10, 2005)

Ringer, Matt, *Hydrogen Delivery Components Model*, Presented at the H2PS Conference, Washington, DC (December 8, 2004)

Ringer, Matt, *Analysis of Hydrogen Pipeline Delivery and Other Hydrogen Storage and Delivery Systems*, Presented at the ASME 5th International Pipeline Conference, Calgary, Alberta, Canada (October 5, 2004)

Ogden, Joan, Marianne Mintz and Matt Ringer, *H2A Scenarios for Delivering Hydrogen from a Central Production Plant to Light Duty Vehicles*, Presented at the National Hydrogen Association Annual Meeting, Los Angeles (April 28, 2004)

H2A Delivery

Hydrogen Safety

- There is no significant hydrogen hazard associated with this project.
- This project is conducted in a typical office setting. No experimental work is involved.

Hydrogen Safety

No safety measures beyond normal office procedures are required.