Forecourt Storage and Compression Options

> **DOE Annual Merit Review and Peer Evaluation**
> Arlington, VA
> 16 May 2006

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Gas Technology Institute

PDP 19

Overview

- Timeline
  - Phase 1: June 2005 to February 2006
  - Phase 2: TBD
- Budget
  - Phase 1: $150 K ($100 K limit through Feb ’06)
  - Phase 2: $818 K
- Barriers addressed
  - 3.2.4.2 F: Hydrogen Delivery Infrastructure Storage Costs
  - 3.2.4.2 H: Storage Tank Materials and Costs
- Partners
  - Phase 1: None
  - Phase 2: TBD

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Objectives

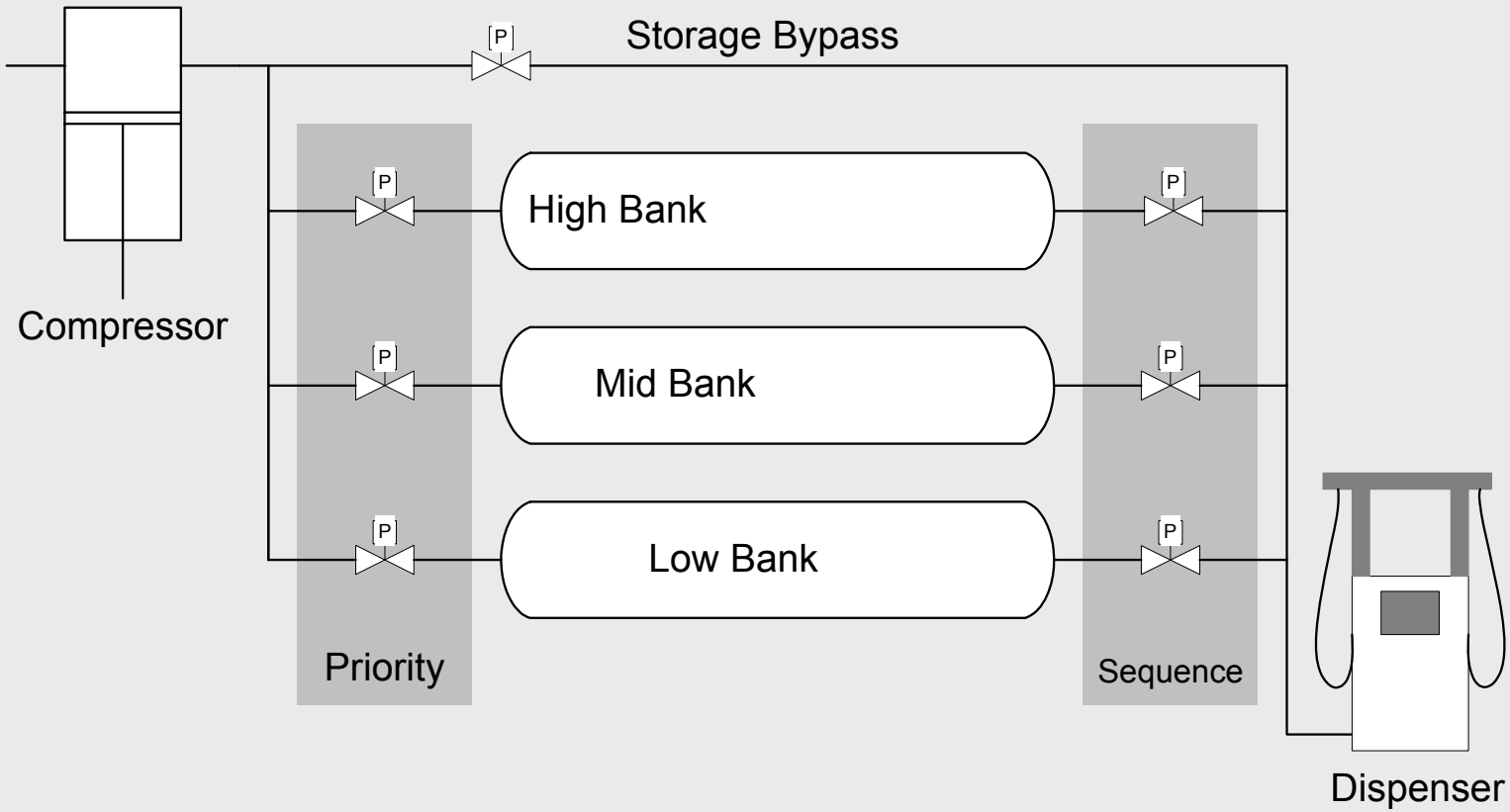
- Examine technical feasibility and cost implications of a wide variety of forecourt compression and storage configurations

Approach

- Update station sizing software tool
  - Allow for a wider variety of station configurations
- Equipment cost data collection
- Perform economic analyses
- Examine additional tradeoffs
  - Cryo pump vs. compressor
  - Under ground vs. above ground
  - Advanced composites vs. steel

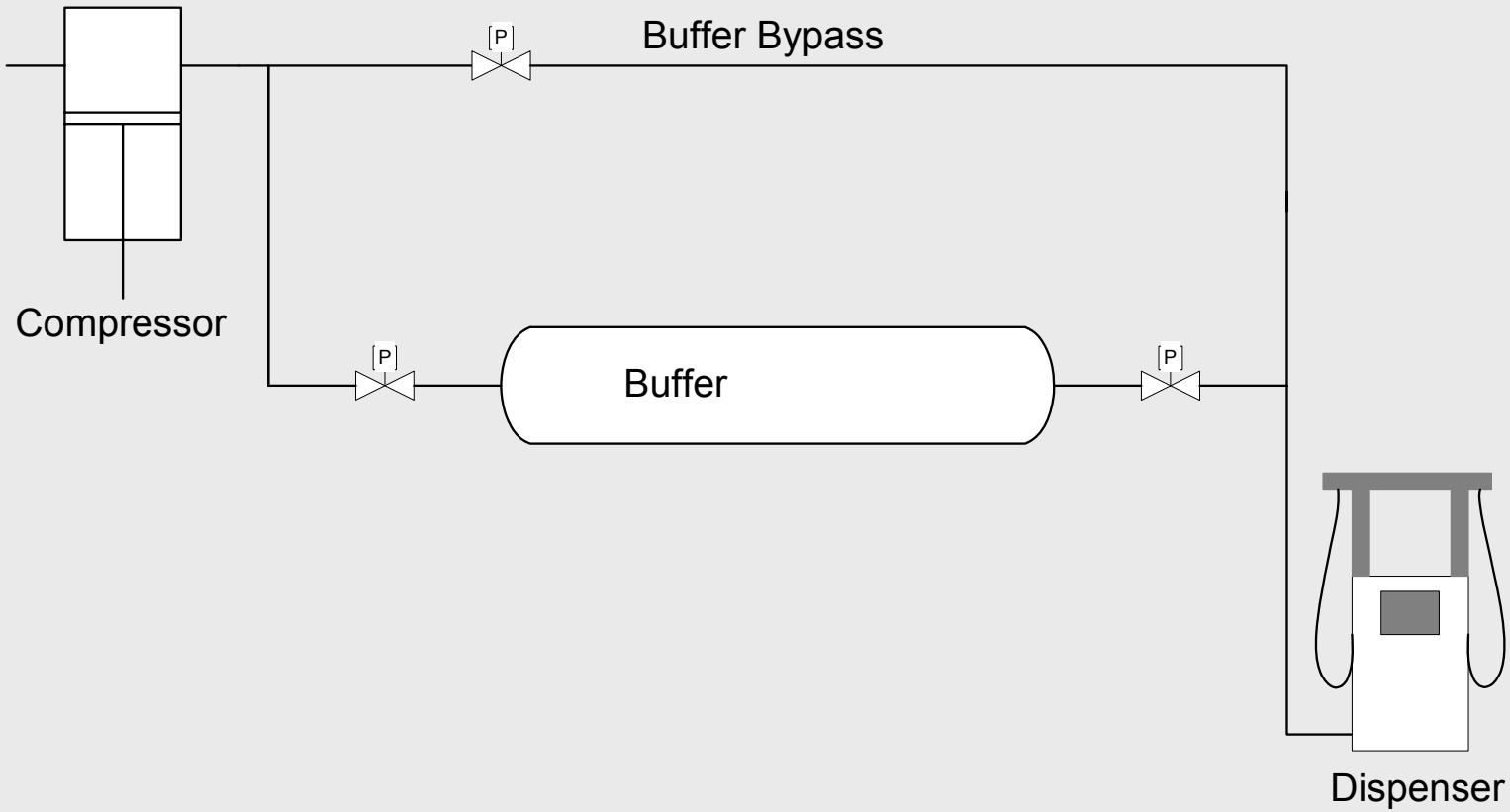
Station Configuration: Cascade Fill

- Uneven demand from smaller vehicles
- Sporadic demand from larger vehicles



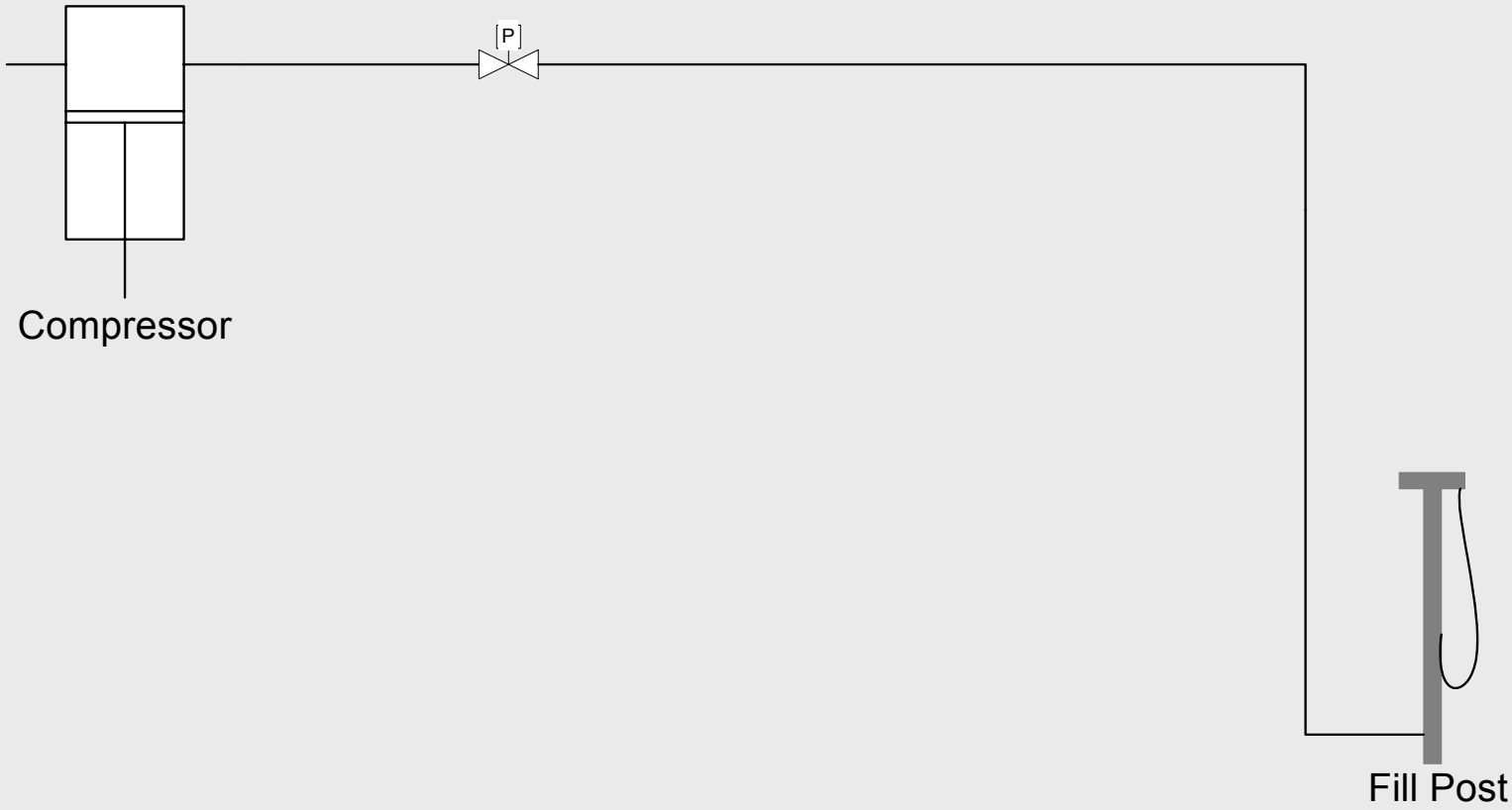
Station Configuration: Buffer Fill

- Large vehicles fueling continuously
- Most fueling directly from compressor(s)



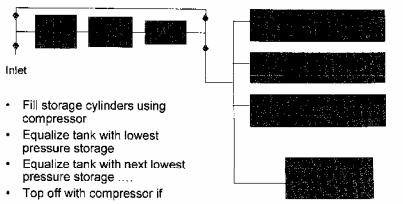
Station Configuration: Time Fill

- Vehicles return to property for several hours
- Total fill cycle will usually requires 8+ hours



Other Potential Configurations

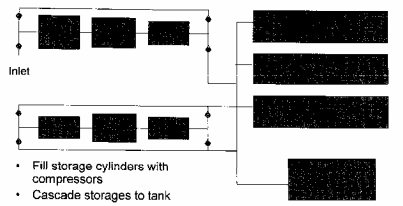
Fueling Strategies
Cascade Fill – With Multi-Stage Compressor and Multiple Storage Cylinders



- Fill storage cylinders using compressor
- Equalize tank with lowest pressure storage
- Equalize tank with next lowest pressure storage ….
- Top off with compressor if necessary

Hydro-Pac, Inc.

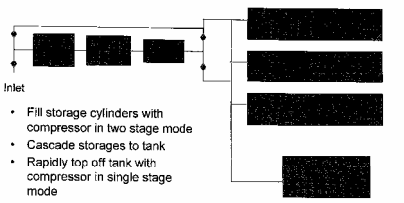
Fueling Strategies
Rapid Fill – With Multiple Intensifiers and Multiple Storage Cylinder



- Fill storage cylinders with compressors
- Cascade storages to tank
- Rapidly top off tank with single stage compressor

Hydro-Pac, Inc.

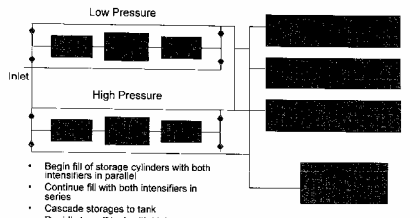
Fueling Strategies
Rapid Fill – With Hybrid Intensifier and Multiple Storage Cylinders



- Fill storage cylinders with compressor in two stage mode
- Cascade storages to tank
- Rapidly top off tank with compressor in single stage mode

Hydro-Pac, Inc.

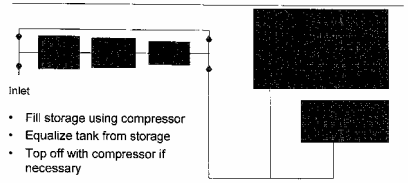
Fueling Strategies
Rapid Fill – With Two Single Stage Intensifiers in parallel and/or Series



- Begin fill of storage cylinders with both intensifiers in parallel
- Continue fill with both intensifiers in series
- Cascade storages to tank
- Rapidly top off tank with high pressure single stage compressor

Hydro-Pac, Inc.

Fueling Strategies
Slow Fill – With Multi-Stage Compressor and Large Storage



- Fill storage using compressor
- Equalize tank from storage
- Top off with compressor if necessary

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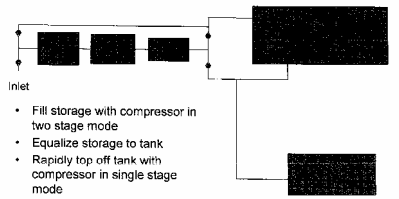
Fueling Strategies
Rapid Fill – With Hybrid Intensifier and Single Storage



- Fill storage with compressor in two stage mode
- Equalize storage to tank
- Rapidly top off tank with compressor in single stage mode

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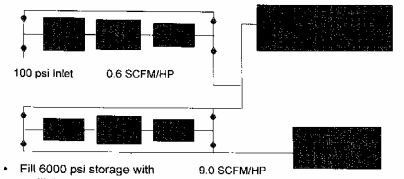
Fueling Strategies
High Pressure Fill – With Medium Pressure Storage



- Fill 6000 psi storage with multistage compressor
- Rapidly fill 10,000 psi tank with single stage compressor

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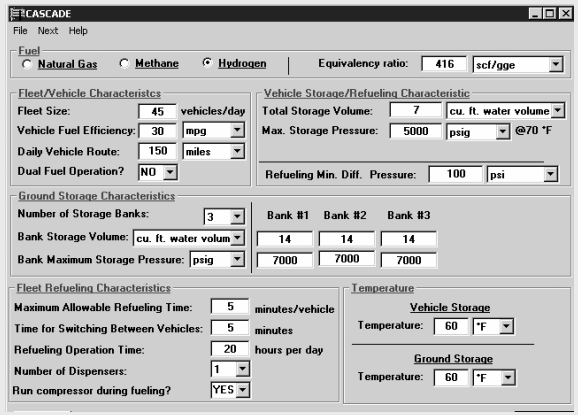
Hydrogen Station Sizing: CASCADE H2

- Simulate compressed gaseous fuel station operation
  - Facilitates quick system sizing and tradeoff analysis
  - System compression and storage sizing
  - Matching station fuel supply to demand
  - Models peak fuel demand periods
  - Helps minimize capital costs and maximize utilization

NATURAL GAS & HYDROGEN
FUELING STATION SIZING



Developed by GTI & available through: InterEnergy Software www.interenergysoftware.com

CASCADE H2 PRO Enhancements

- Improved system flow representation
- Multiple, simultaneous vehicle fueling
- User selectable maximum dispenser flow rate
- Multiple vehicle types and flexible scheduling
- User definable compressor characteristics
  - Power consumption, volumetric efficiency
- Compressor electric power and demand calculation
  - Time of day and seasonal rates
- Station life cycle cost analysis
- Improved charting and reporting features

CASCADE H2 PRO Inputs

- Variable configuration parameters
  - Vehicles (type and quantity), storage capacities and pressures, dispensers, peak flow
- Variable cost elements
  - Peak and off peak electricity (seasonally), time dependent costs (per year), usage dependent costs (per kg)
  - Economic life, cost of capital, taxes, inflation, depreciation methods

CASCADE H2 PRO File: C:\Burn Folder\cascade tests\DOEm1.mdb

File Unit: I-P (English) Next Help

Vehicle Storage/Refueling Characteristic

A | B | C | D

Total Storage Volume:	8.5	cu. ft. water volume
Rated Storage Pressure:	5075	psig @ 59°F
Max. Allowable Storage Pressure:	6344	psig
Min. Allowable Storage Pressure:	50	psig
Capacity Before Refueling:	12.5	% of Full

Vehicle Description: Description for A..

Unit Selection

I-P (English)

SI (Metric)

Fuel

Hydrogen

Equivalency ratio: 416 scf/gge

Ground Storage Characteristics

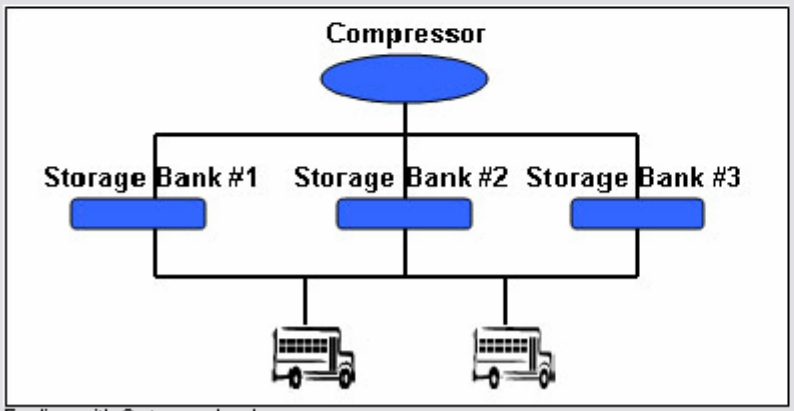
Number of Storage Banks: 3

	Bank #1	Bank #2	Bank #3
Bank Storage Volume: cu. ft. water volume	30	20	10
Bank Maximum Storage Pressure: psig @ 59°F	7000	7000	7000

Temperature

Vehicle Storage: 59 °F

Ground Storage: 59 °F



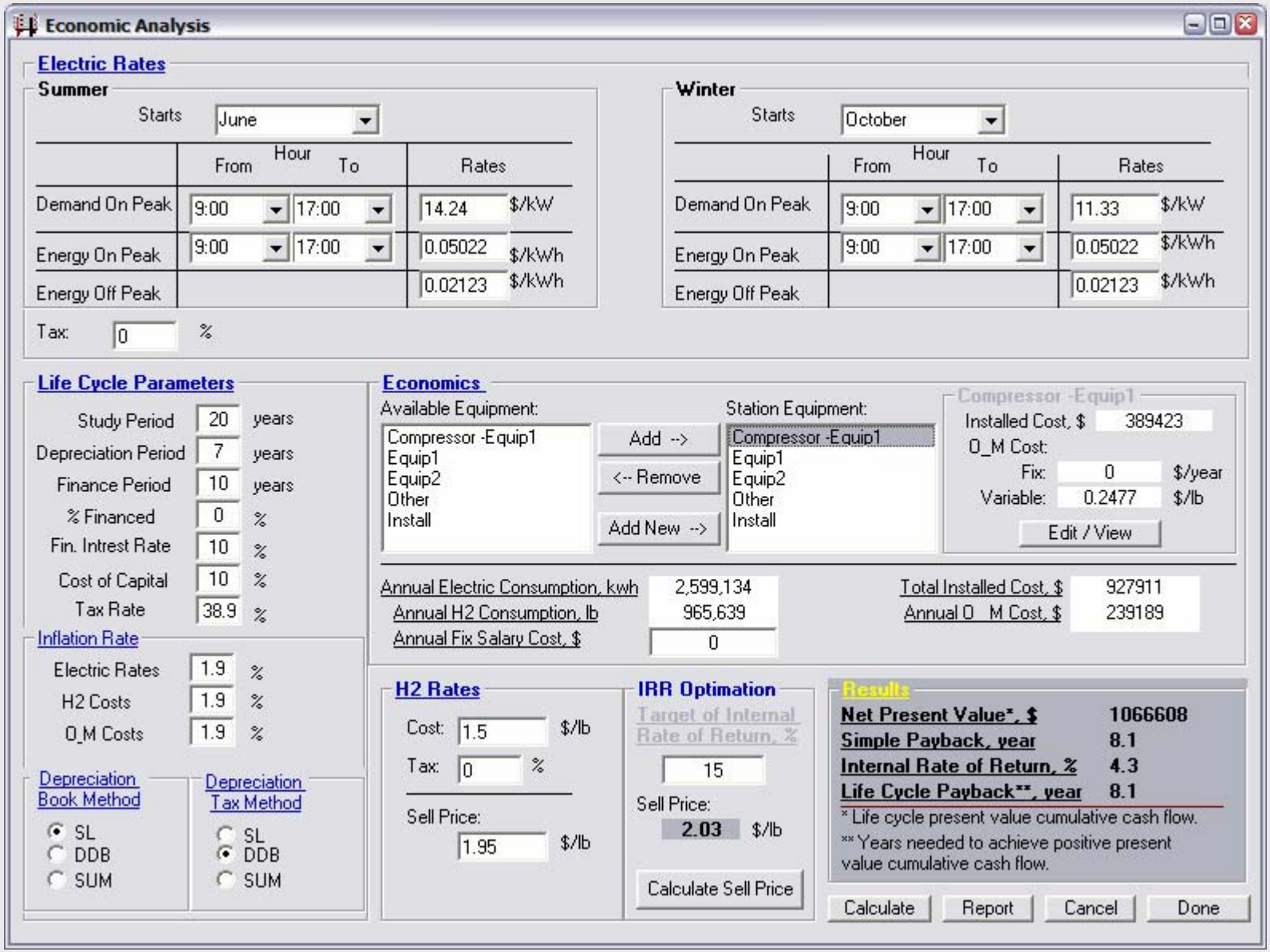
Fueling with 3 storage banks.

Fueling Station Characteristics

Time for Switching Between Vehicles:	3	minutes
Dispenser Rating Point Pressure:	7000	psig
Dispenser Rating Point Flow Rate:	8	lb/min
Dispenser Min. Diff. Pressure:	100	psi
Number of Dispensers:	2	
Run compressor during fueling?	YES	

Edit Station Load Profile / Schedule

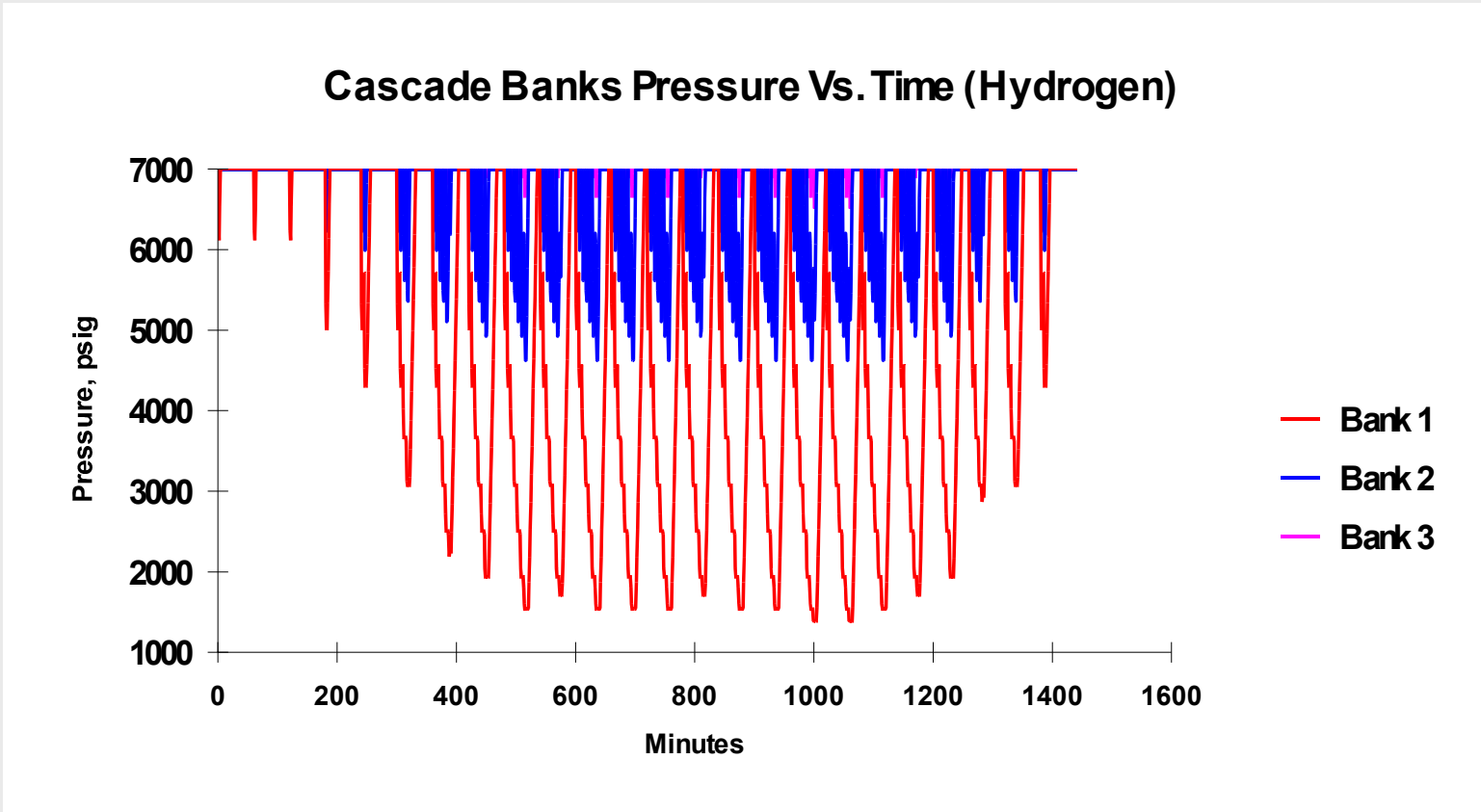
Help Next


Economic Analysis
Electric Rates
Summer
Starts June
Hour From To Rates
Demand On Peak 9:00 17:00 14.24 $/kW
Energy On Peak 9:00 17:00 0.05022 $/kWh
Energy Off Peak 0.02123 $/kWh
Winter
Starts October
Hour From To Rates
Demand On Peak 9:00 17:00 11.33 $/kW
Energy On Peak 9:00 17:00 0.05022 $/kWh
Energy Off Peak 0.02123 $/kWh
Tax: 0 %
Life Cycle Parameters
Study Period 20 years
Depreciation Period 7 years
Finance Period 10 years
% Financed 0 %
Fin. Intrest Rate 10 %
Cost of Capital 10 %
Tax Rate 38.9 %
Inflation Rate
Electric Rates 1.9 %
H2 Costs 1.9 %
O_M Costs 1.9 %
Depreciation Book Method
SL
DDB
SUM
Depreciation Tax Method
SL
DDB
SUM
Economics
Available Equipment:
Compressor -Equip1
Equip1
Equip2
Other
Install
Add -->
<-- Remove
Add New -->
Station Equipment:
Compressor -Equip1
Equip1
Equip2
Other
Install
Compressor -Equip1
Installed Cost, $ 389423
O_M Cost:
Fix: 0 $/year
Variable: 0.2477 $/lb
Edit / View
Annual Electric Consumption, kwh 2,599,134
Annual H2 Consumption, lb 965,639
Annual Fix Salary Cost, $ 0
Total Installed Cost, $ 927911
Annual O_M Cost, $ 239189
H2 Rates
Cost: 1.5 $/lb
Tax: 0 %
Sell Price: 1.95 $/lb
IRR Optimation
Target of Internal Rate of Return, % 15
Sell Price: 2.03 $/lb
Calculate Sell Price
Results
Net Present Value*, $ 1066608
Simple Payback, year 8.1
Internal Rate of Return, % 4.3
Life Cycle Payback**, year 8.1
* Life cycle present value cumulative cash flow.
** Years needed to achieve positive present value cumulative cash flow.
Calculate
Report
Cancel
Done

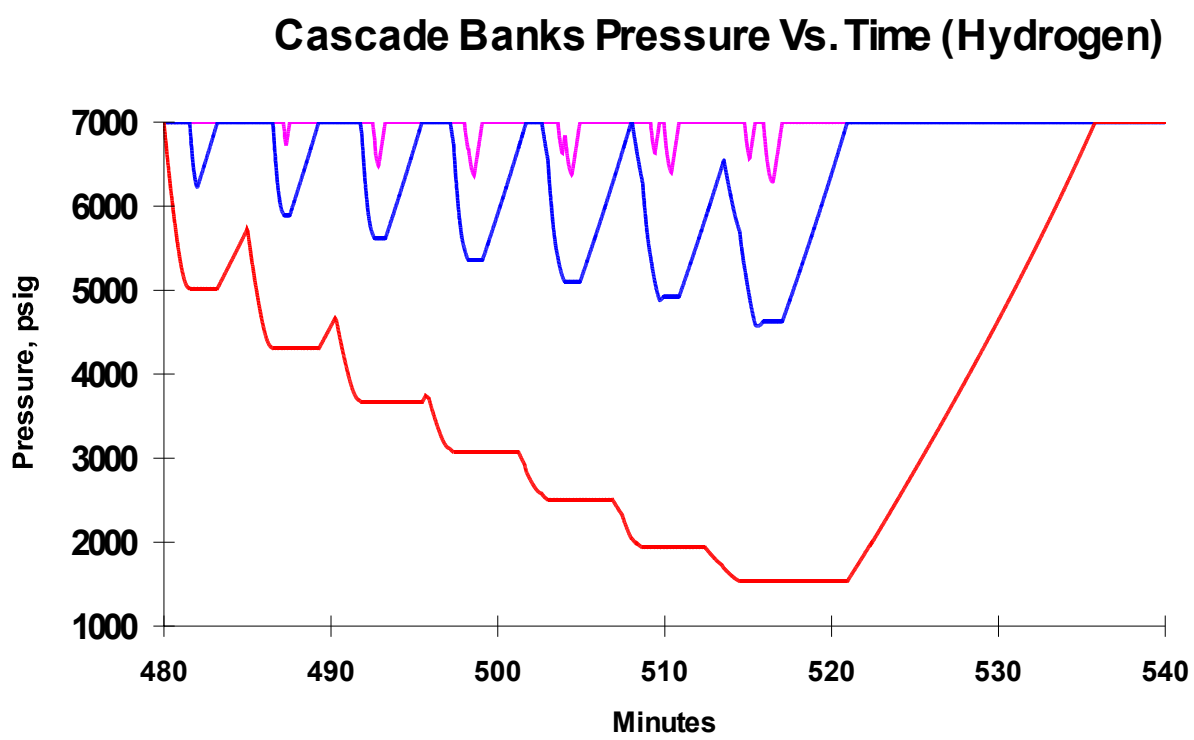
CASCADE H2 Pro Results

- Performance
  - Cascade pressure, capacity
  - Compressor output, power, electric demand
  - Station and dispenser load profiles
  - Vehicles fully served (or not), maximum fill pressure, filling times
- Economic
  - Net present value
  - Payback (simple and discounted)
  - Rate of return solver

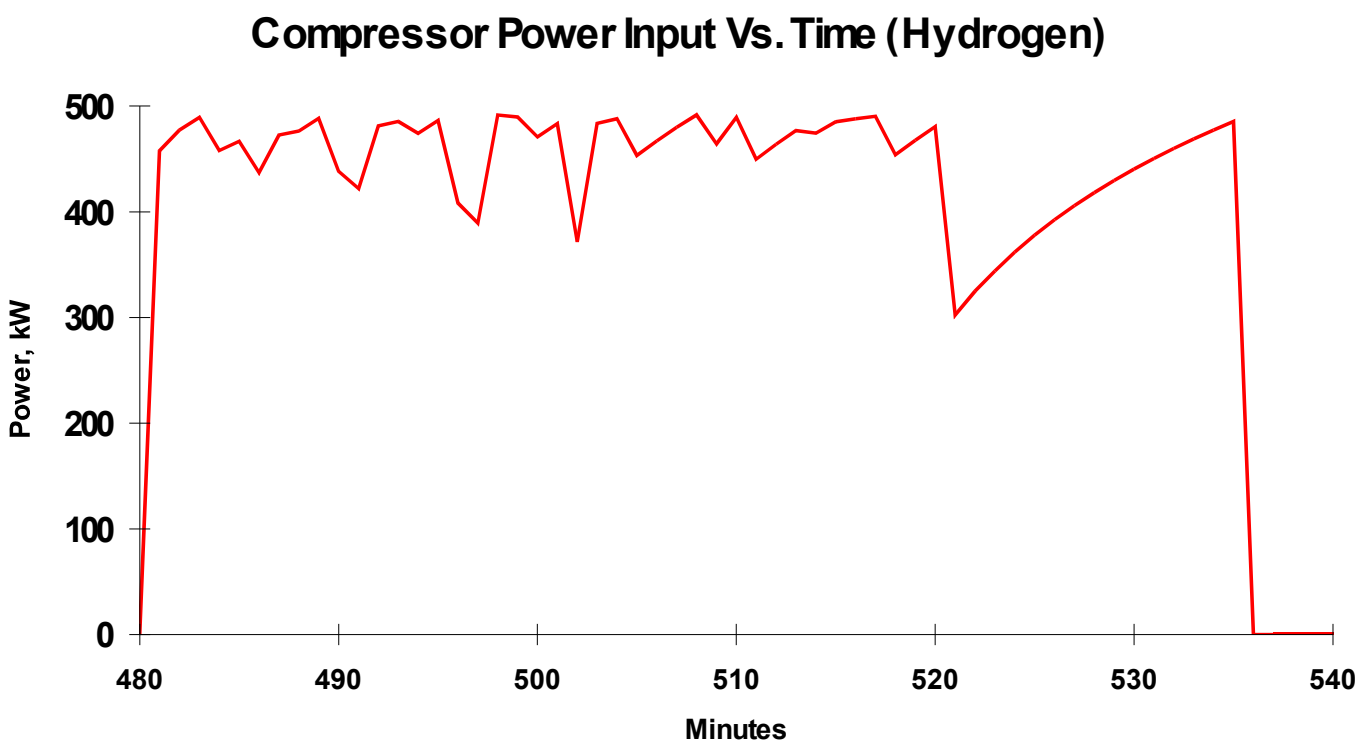
Cascade Pressure



Cascade Pressure
One Hour



Compressor Power
One Hour

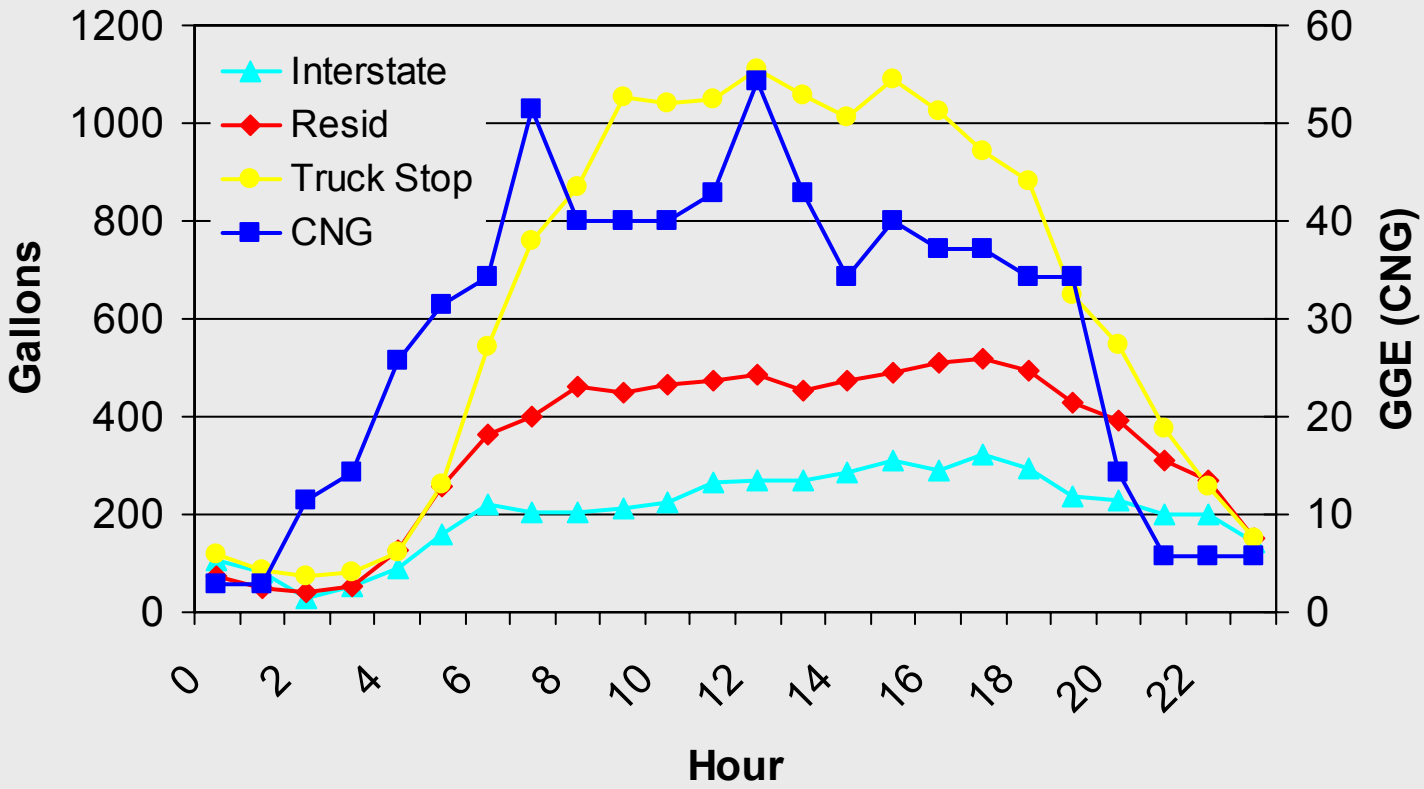


Sample Analyses

- Different demand profiles normalized to 1200 kg per day
  - Gasoline data courtesy of ConocoPhillips
    - Truck stop, interstate station, large residential station
  - Compressed natural gas (CNG) station

Station Demand Profile

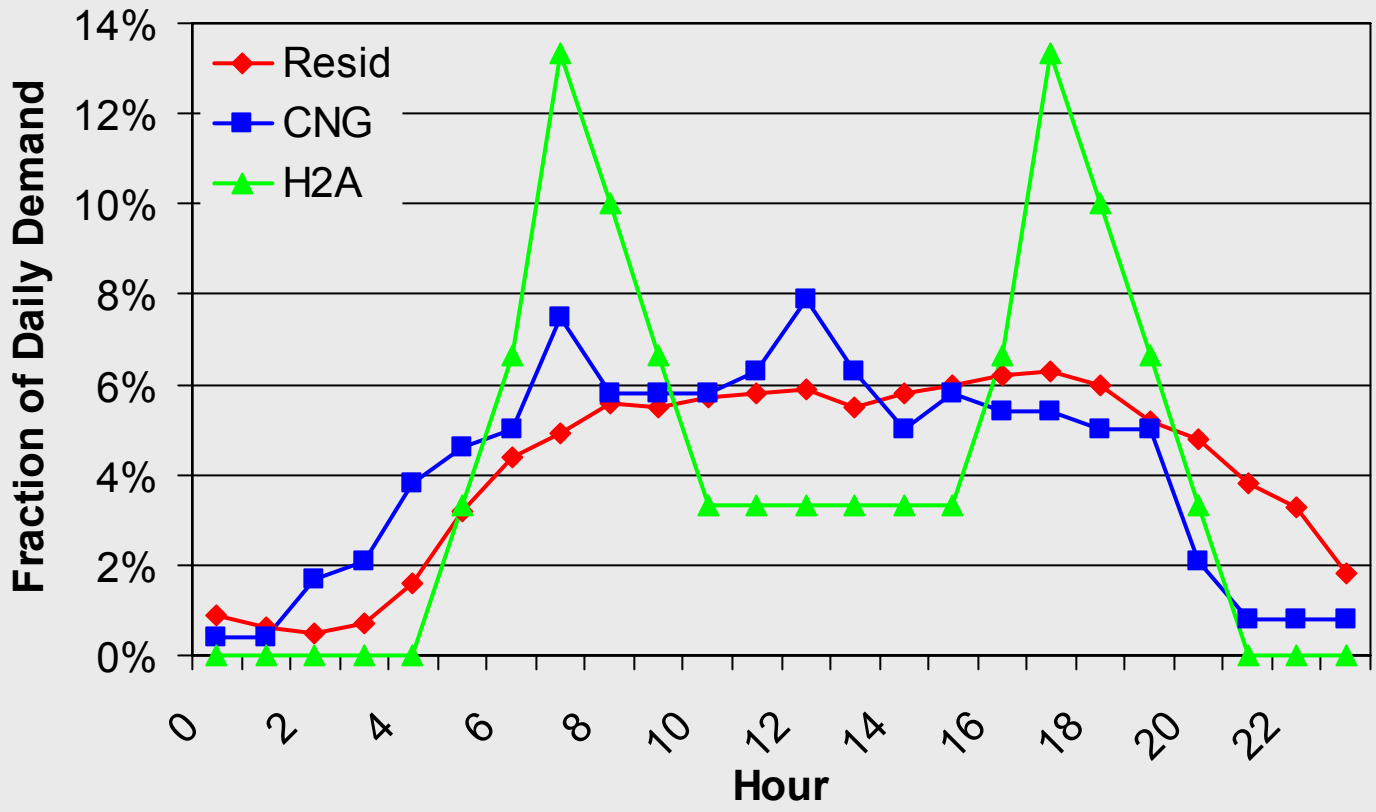
- Gasoline: 5000 to 15000 gal/day
  - Average station is about 3300 gal/day
- CNG: 700 gal/day



Gasoline data courtesy ConocoPhillips

H2 Station Demand Profile

> Residential, CNG, and H2A profiles normalized to 1200 kg/day

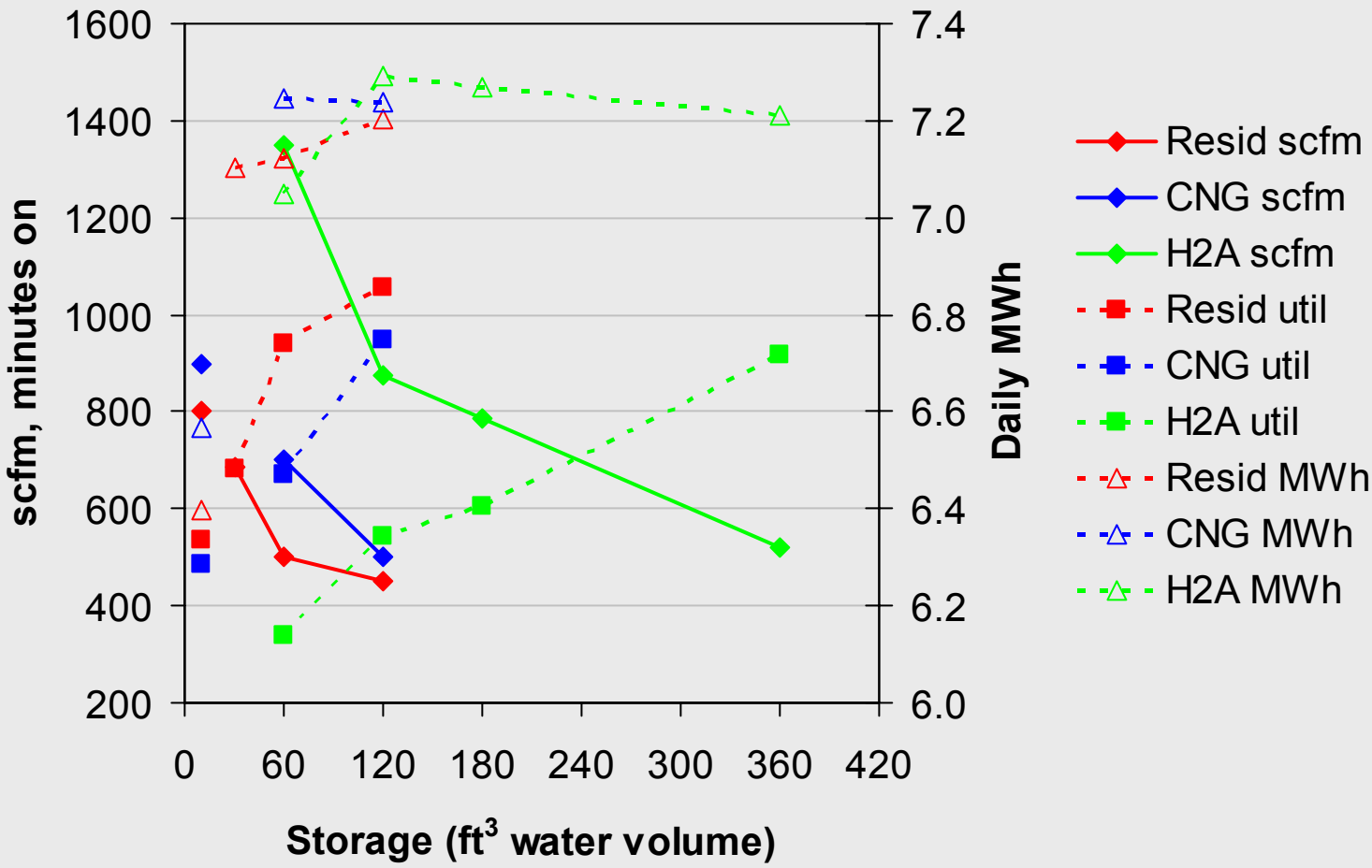


H2 Station Sizing

- Used CASCADE to determine required compressor output for various cascade capacities for each load profile
  - Single bank cascade (10 ft^3 water volume)
  - Three bank cascades
    - 30 to 360 ft^3 water volume
- All simulations used 3-2-1 capacity ratios
  - Low bank (first used by vehicle) the largest
  - Marginal performance improvement relative to 1-1-1 ratio

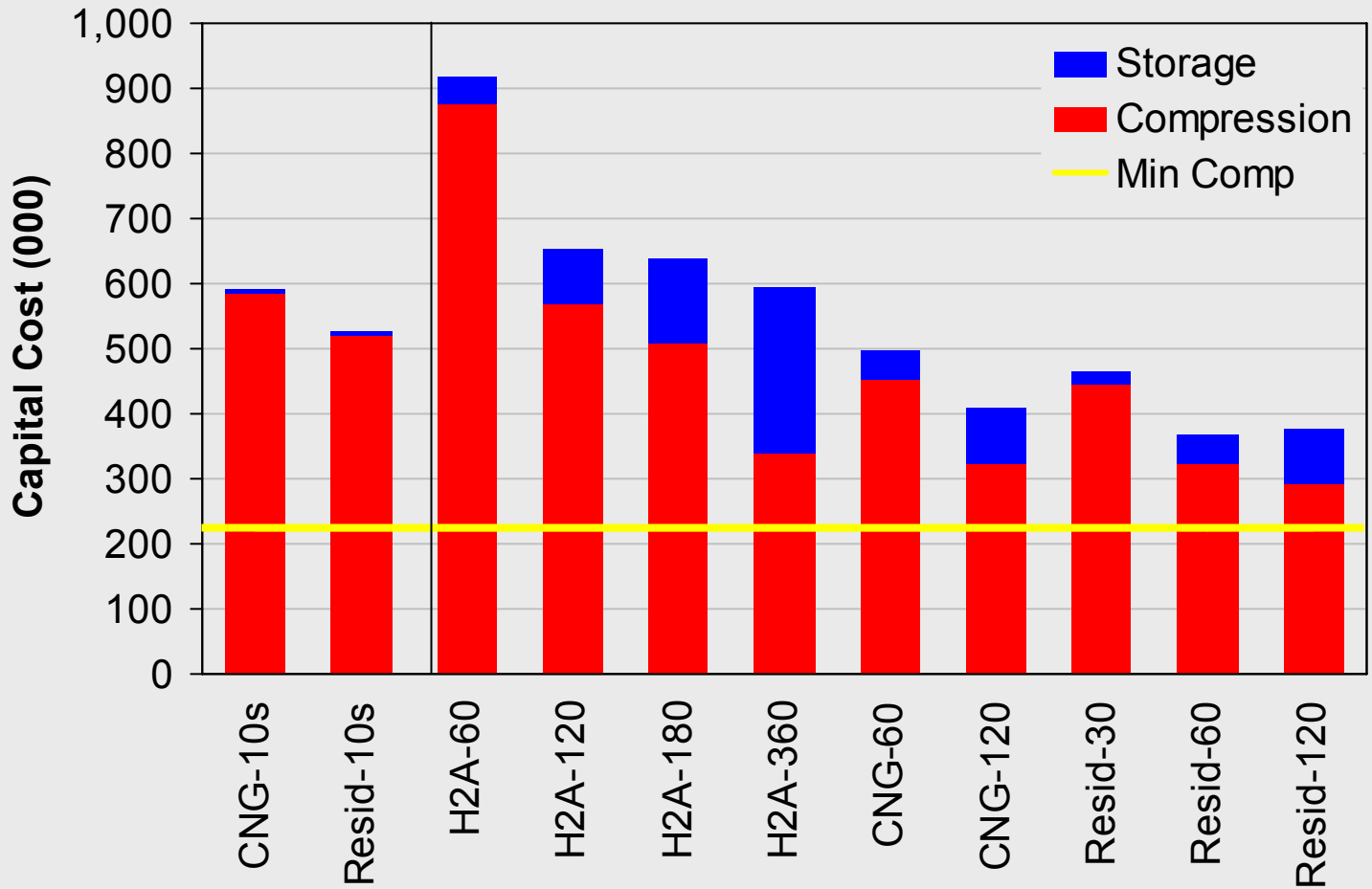
Compressor-Storage Relation

Compressor Size, Utilization, and Energy



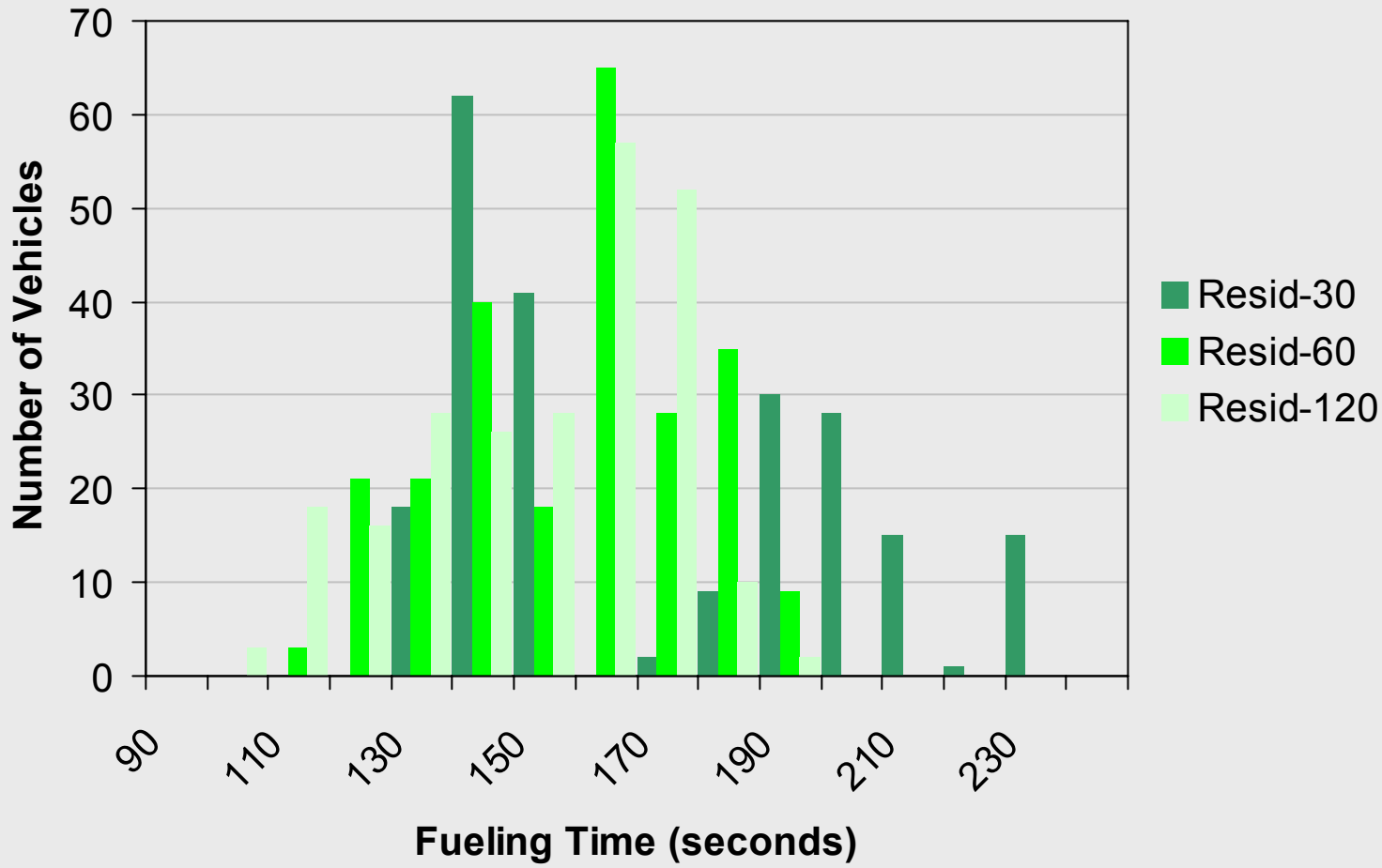
Compressor-Storage Costs

H2A Assumptions: $4500/(kg/hr), $818/kg



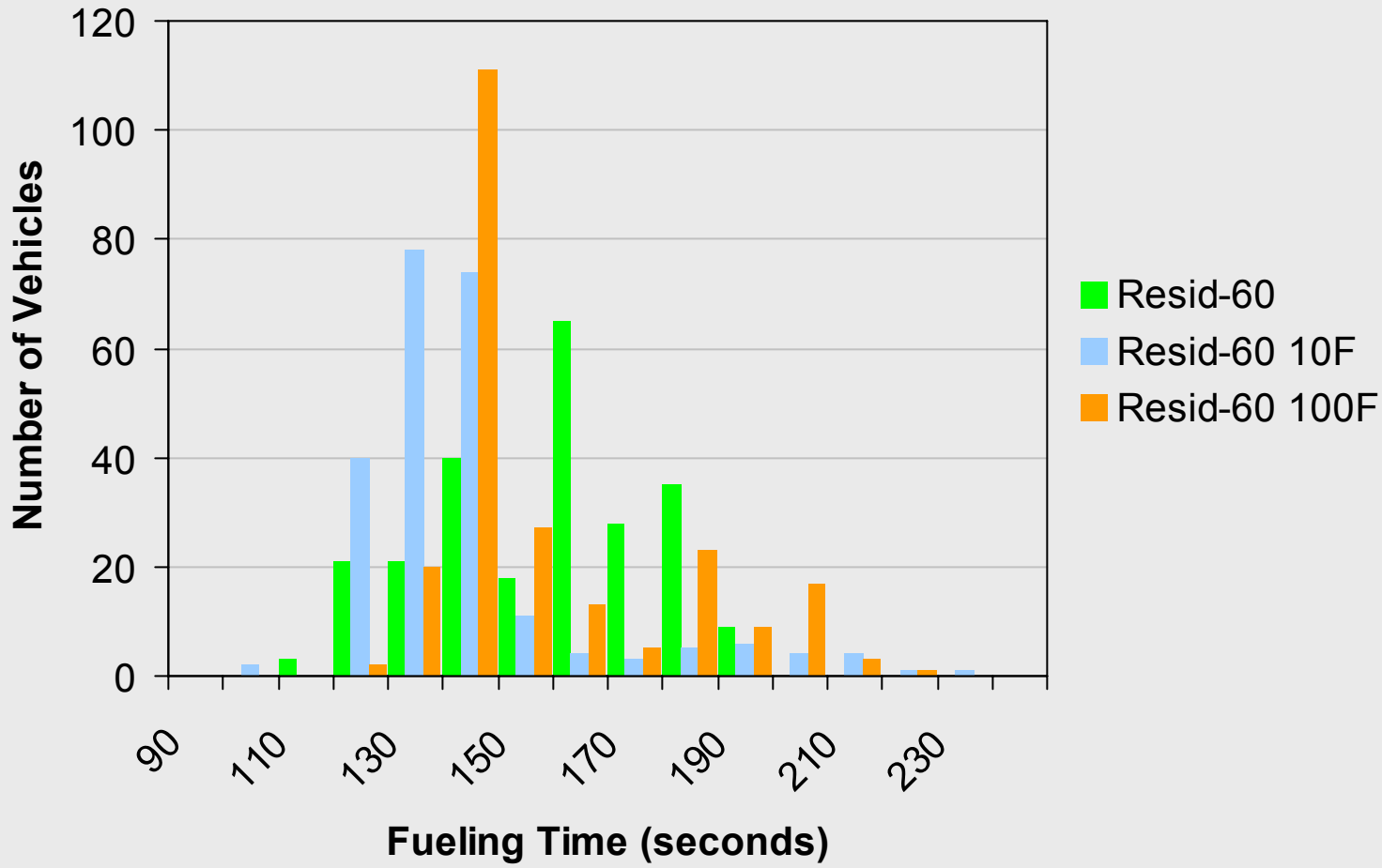
Vehicle Fueling Times

Resid Profiles



Vehicle Fueling Times

Resid Profiles, Ambient Temperature Effects



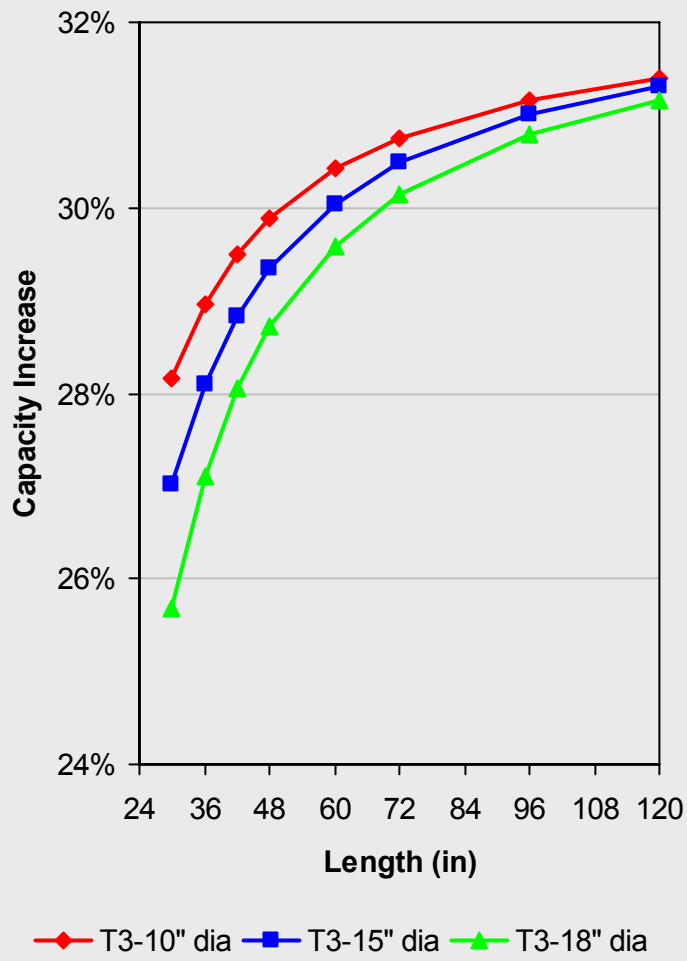
Vehicle Fueling Times

	CNG Res		CNG		Resid		
	10s	10s	60	120	30	60	120
Mean	243	264	136	144	173	149	145
σ	34	28	22	24	42	19	20

	CNG		
	60	60: 10F	60: 100F
Mean	136	134	148
σ	22	21	23

70 MPa Considerations

- Diminishing returns for vehicle storage
  - 35 to 70 MPa yields 67% increase for gas properties
  - Same outer volume constraint: 25 to 31%
- Increased specific costs of fueling equipment
- Difficulties in limiting vehicle tank temperature during fueling



Future Work

- Complete configuration analyses
- Complete cost data collection
- Perform economic analyses
- Examine additional tradeoffs
  - Cryo pump vs. compressor
  - Under ground vs. above ground
  - Advanced composites vs. steel
- Potential inclusion of impacts of 70 MPa fueling scenarios

Summary

- CASCADE H2 PRO is designed to be a simple, yet powerful, tool for:
  - Assisting designers in analyzing complex station equipment interactions
  - Providing valuable performance and economics assessments
- Version 1.0 is currently undergoing testing and review
  - Expected to be available for purchase in the second half of 2006
- Initial analyses indicate some H2A assumptions may need revision

Contact Information

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