Forecourt Storage and Compression Options

> **DOE and FreedomCAR & Fuel Partnership Hydrogen Delivery and On-Board Storage Analysis Workshop**
> DOE Headquarters
> 25 January 2006

Mark E. Richards
Gas Technology Institute

Overview

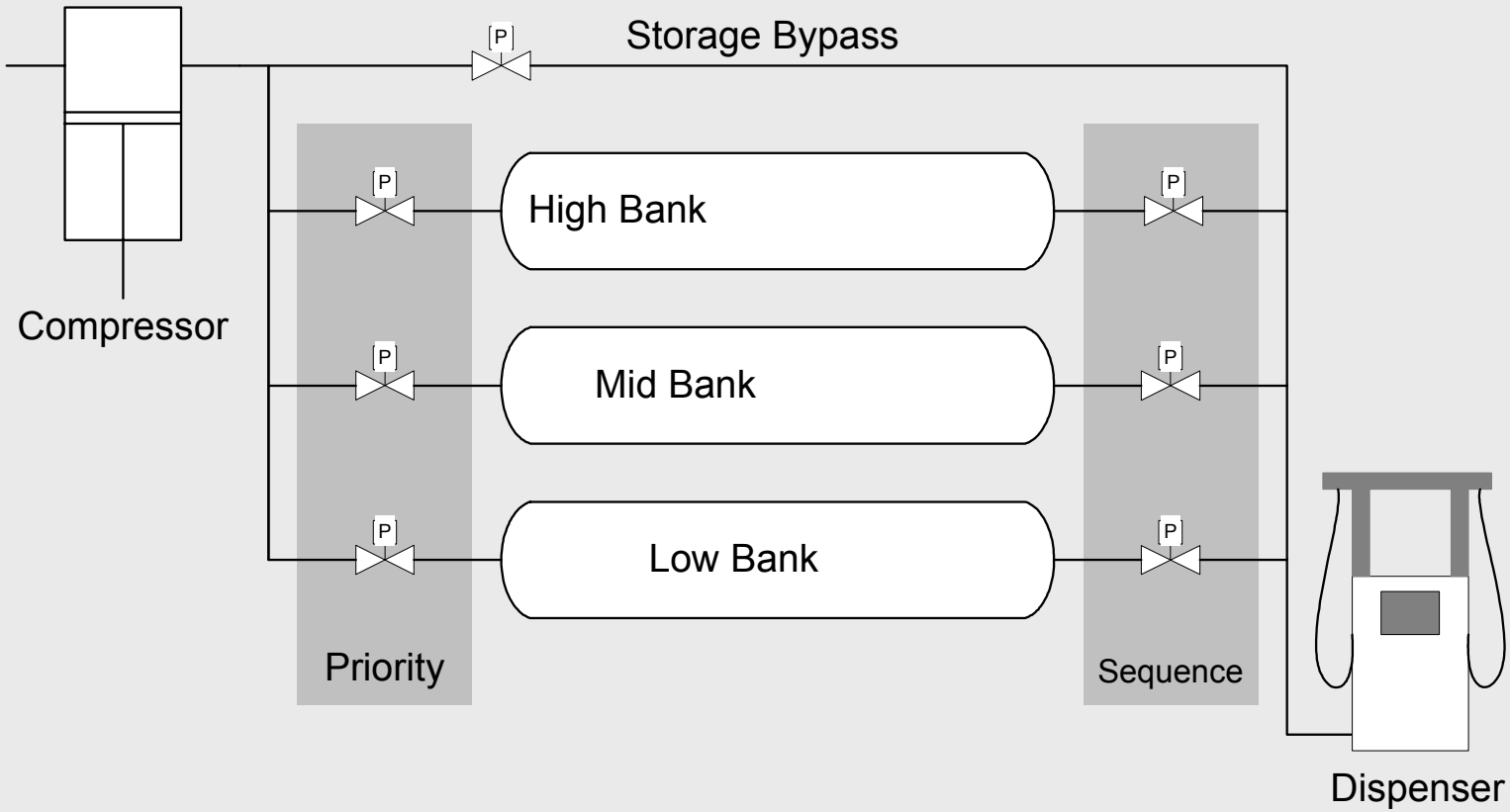
- Project objectives
- Gaseous delivery configurations
- Analysis tool: CASCADE H2 Pro
- Station demand profiles
- Operational analysis results
  - Compressor-storage relationships
  - Vehicle fueling times
  - Temperature effects
- Cost profiles
- Considerations for 70 MPa
- Next steps

Project Objective

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

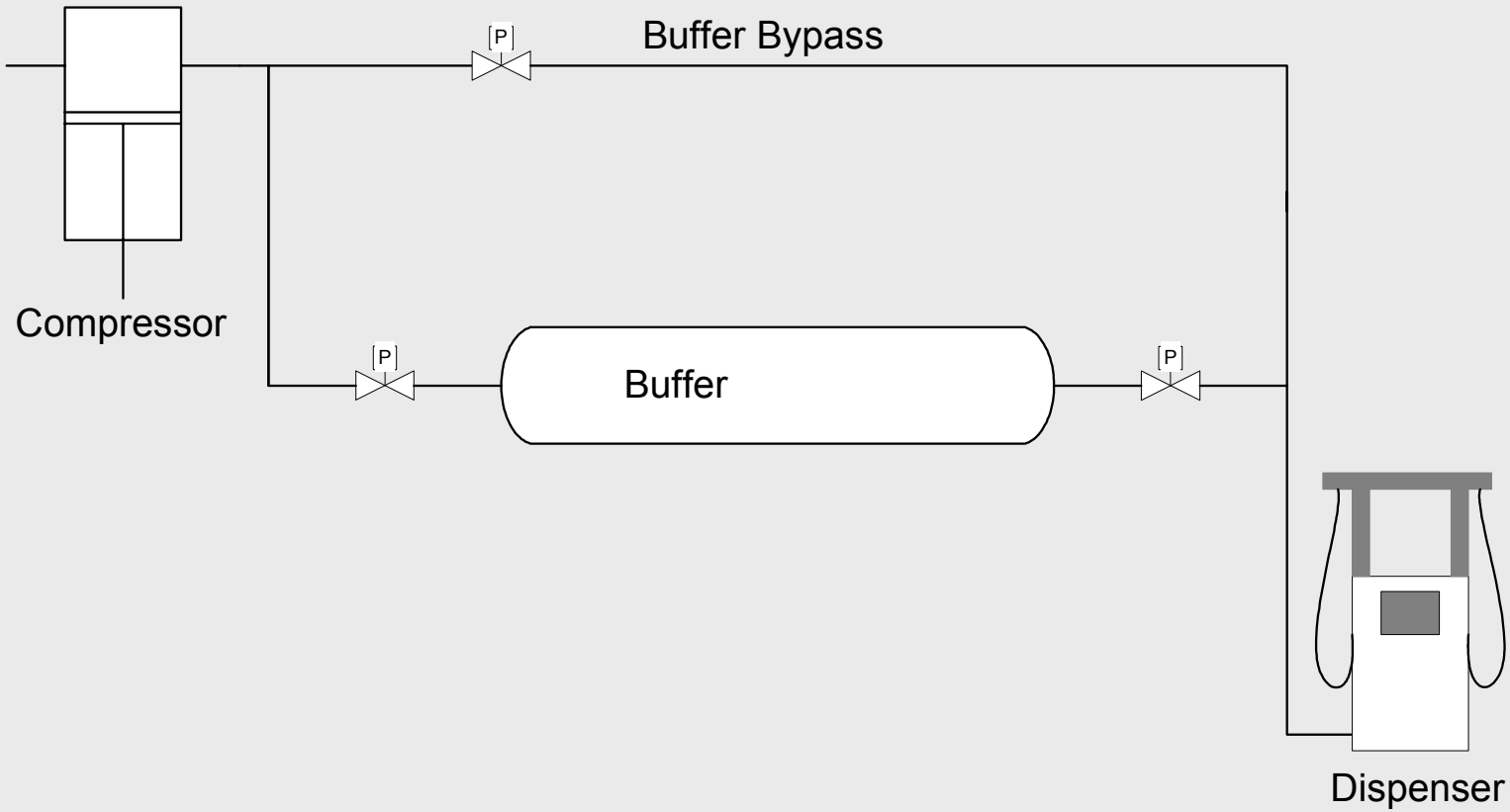
Cascade Fill

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



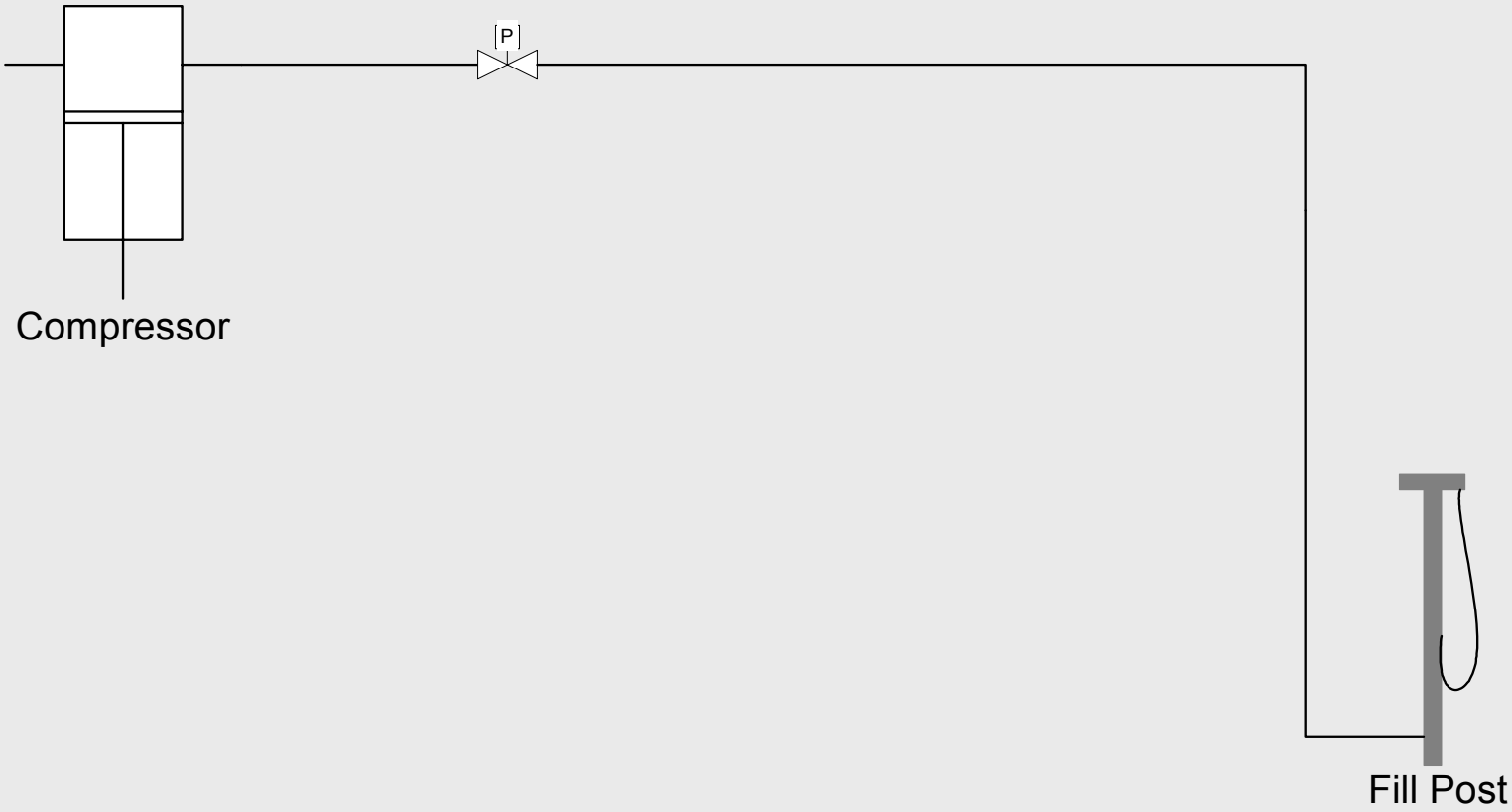
Buffer Fill

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

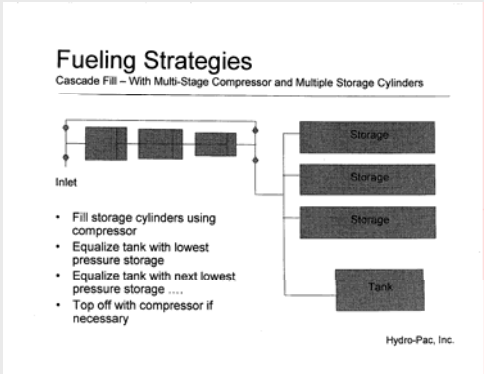


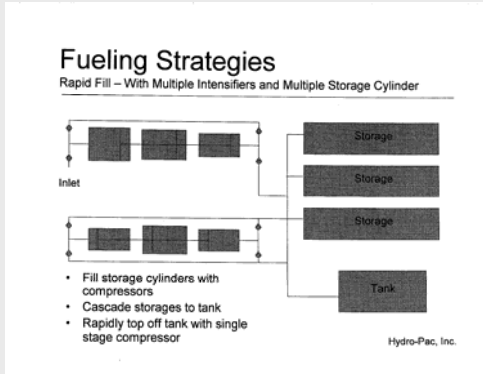
Time Fill

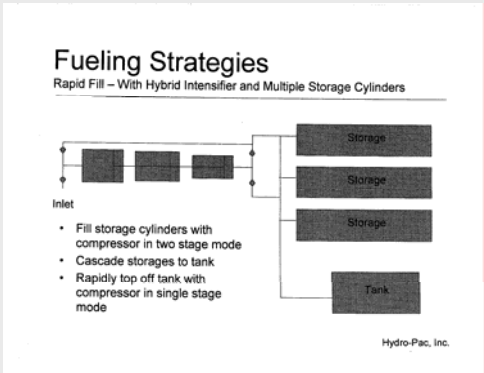
- Vehicles return to property for several hours
- Total fill cycle will usually requires 8+ hours

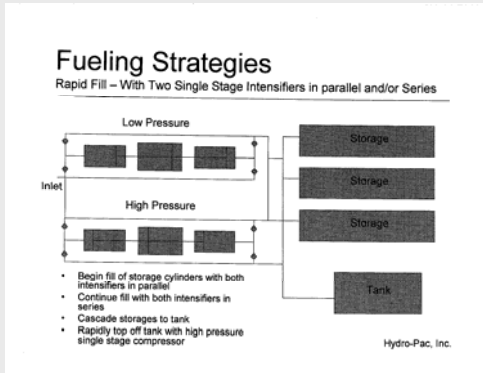


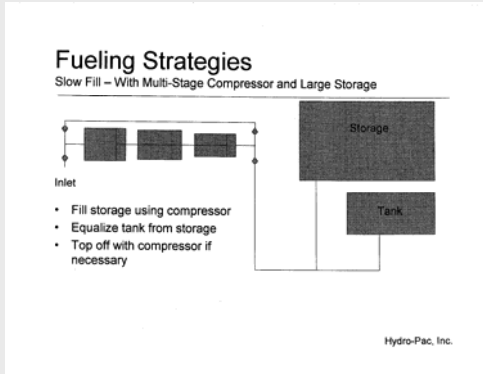
Potential Configurations

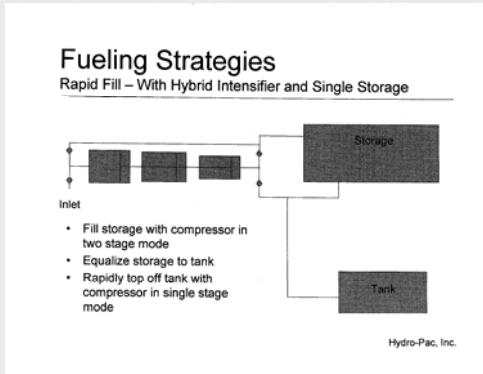


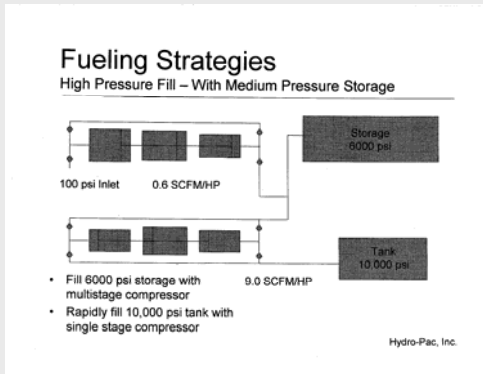








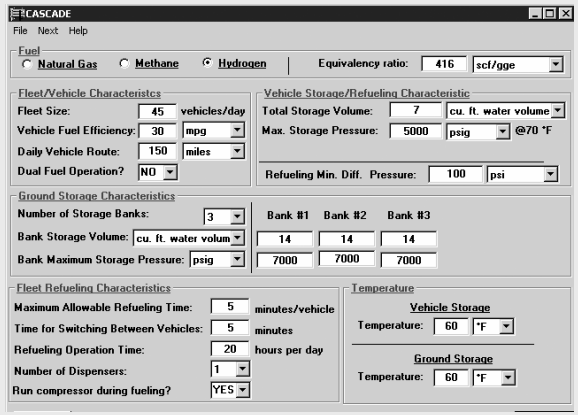




Hydrogen Station Sizing: CASCADE Program

- 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 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 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

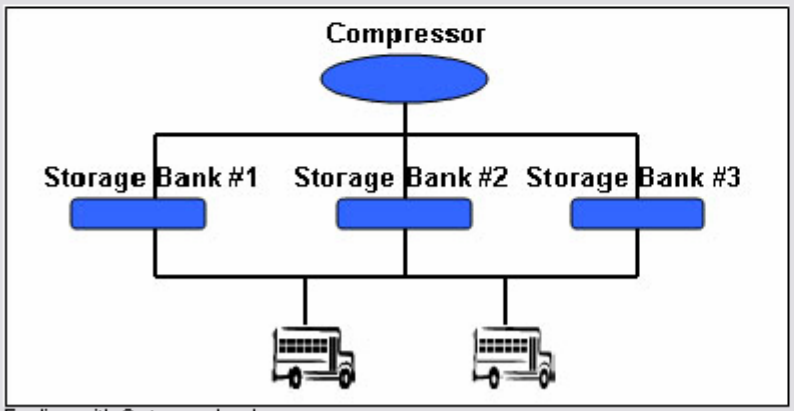
Number of Storage Banks: 3

	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



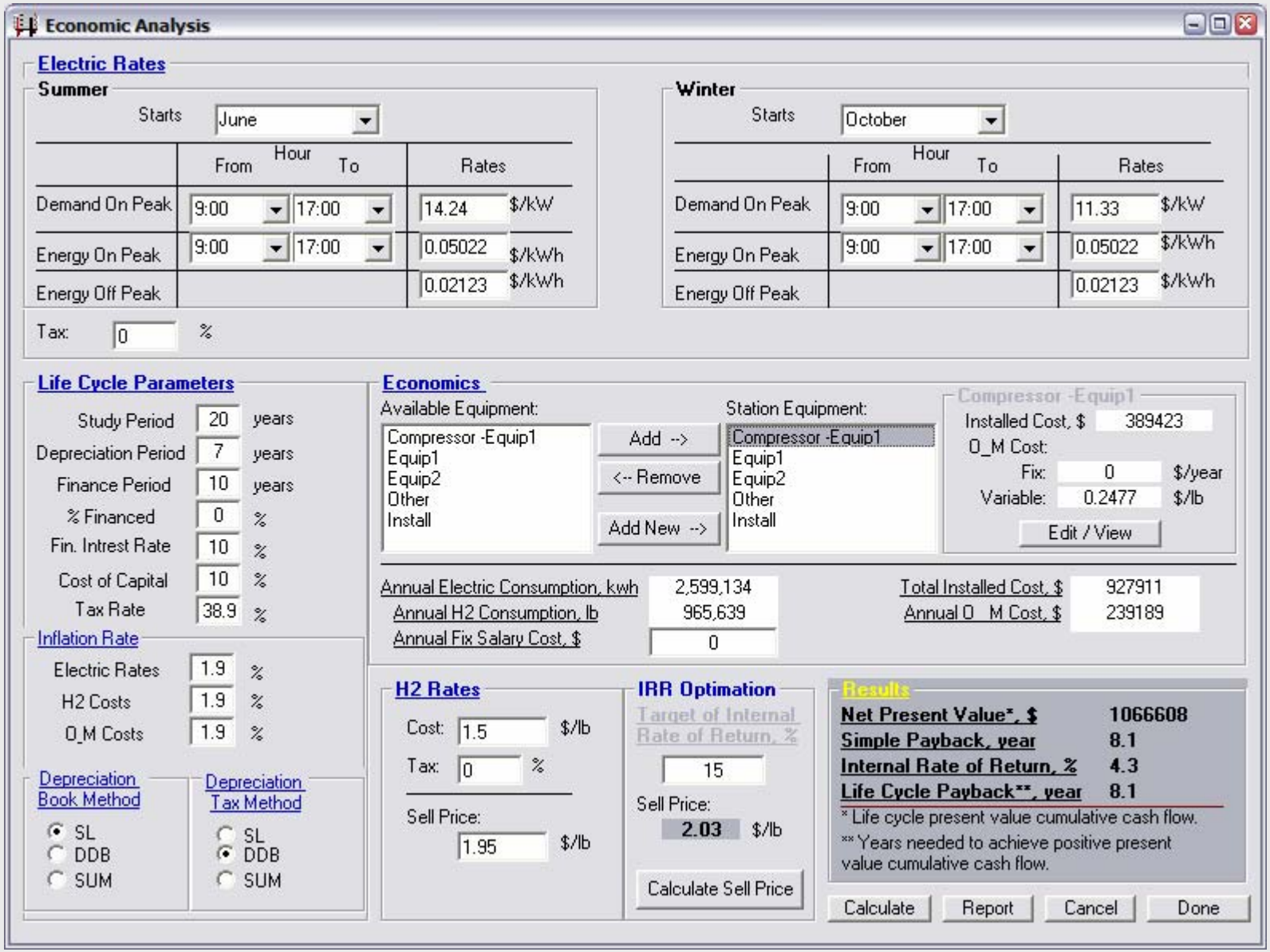
Fueling with 3 storage banks.

Fueling Station Characteristics

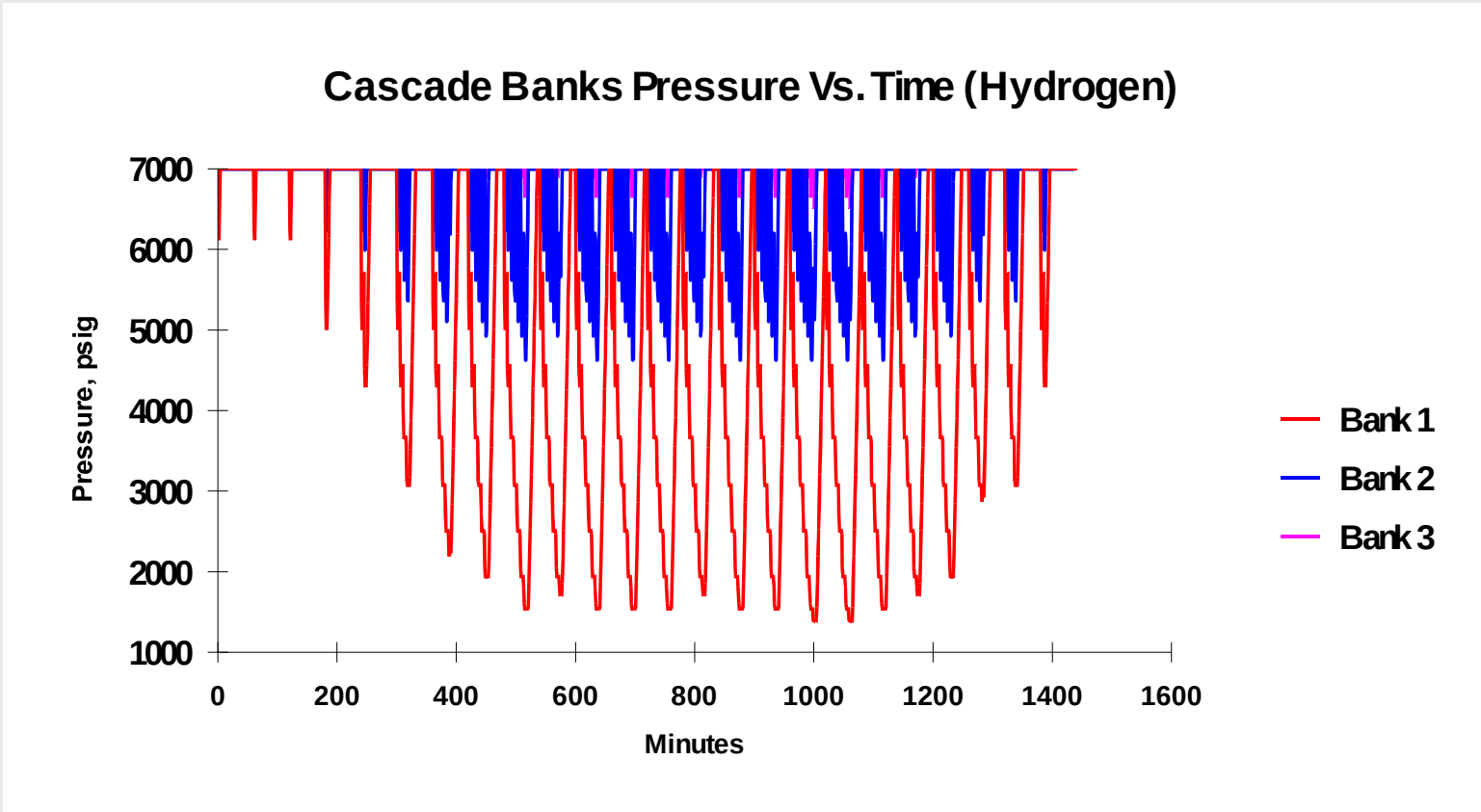
Time for Switching Between Vehicles:	3	minutes
Dispenser Rating Point Pressure:	7000	psig
Dispenser Rating Point Flow Rate:	8	lb/min
Dispenser Min. Diff. Pressure:	100	psi
Number of Dispensers:	2	
Run compressor during fueling?	YES	

Edit Station Load Profile / Schedule

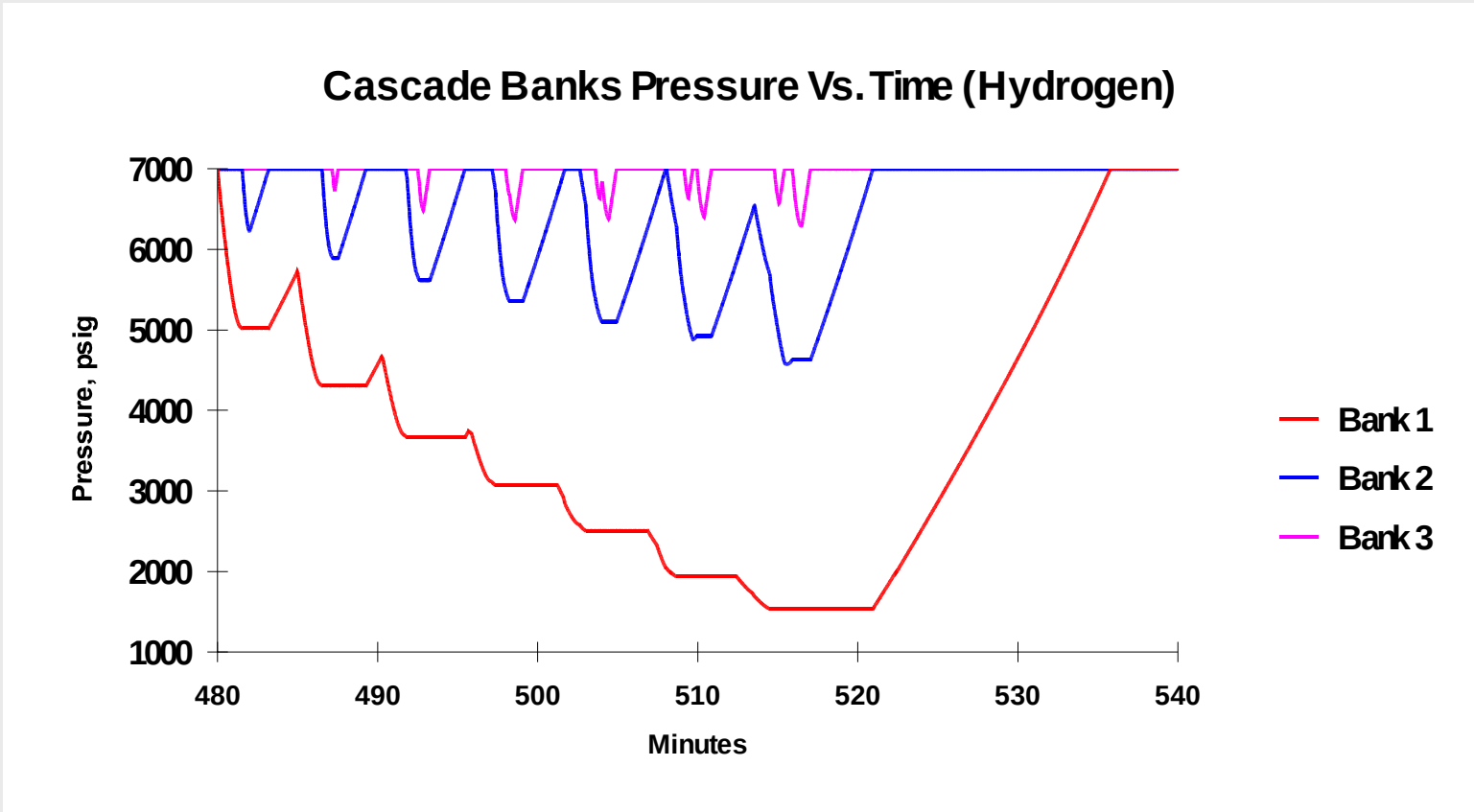
Help Next


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

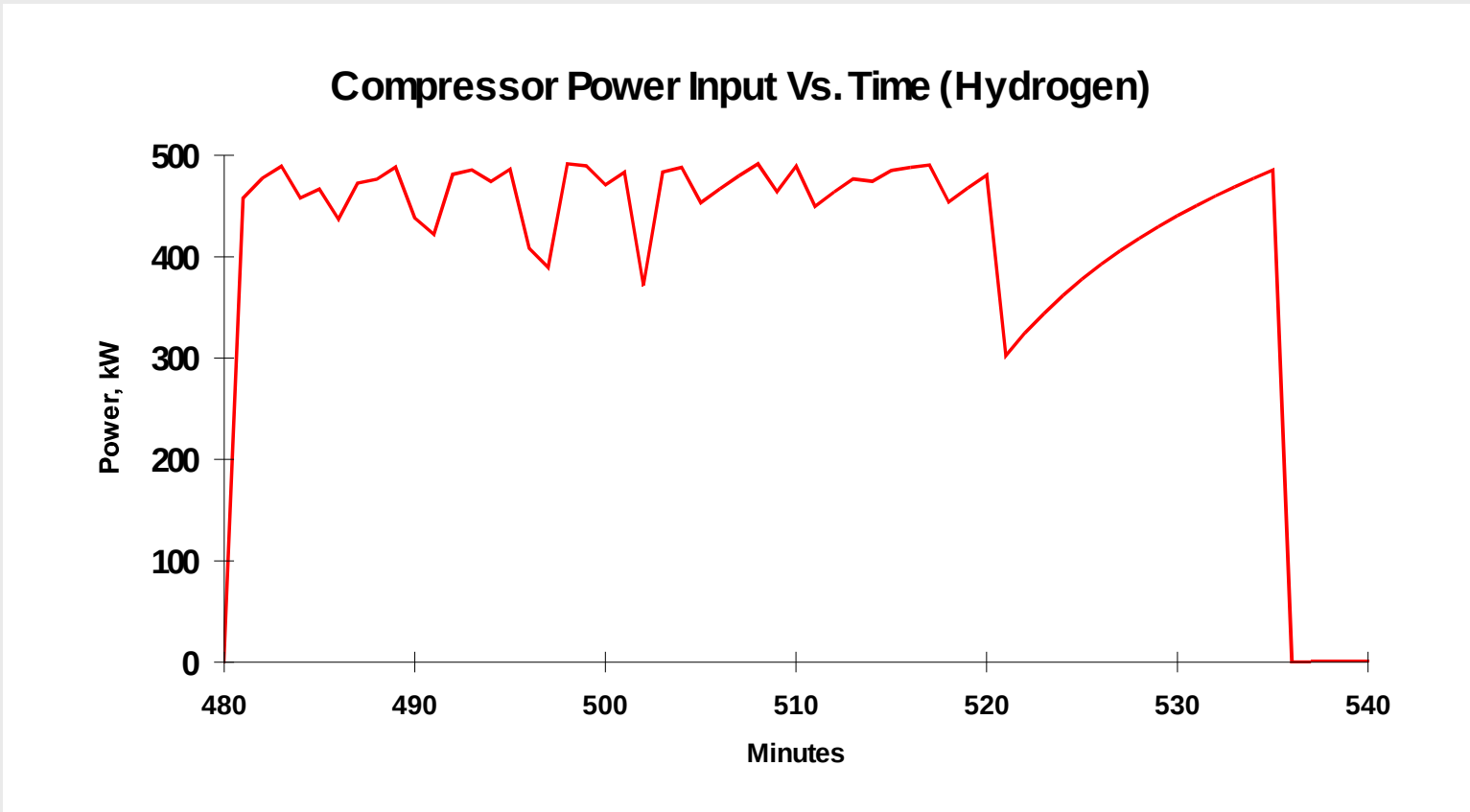
Cascade Pressure



Cascade Pressure
One Hour

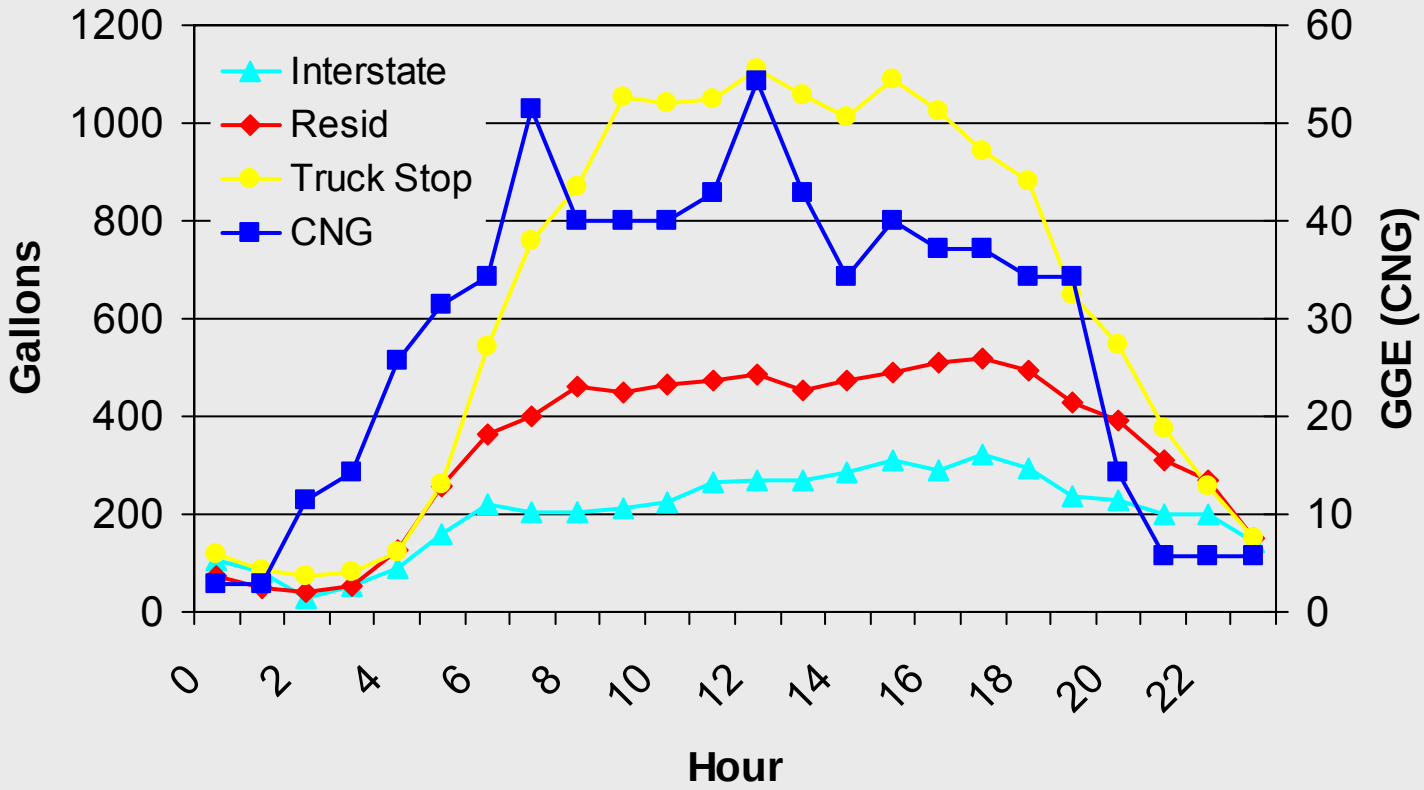


Compressor Power
One Hour



Station Demand Profile

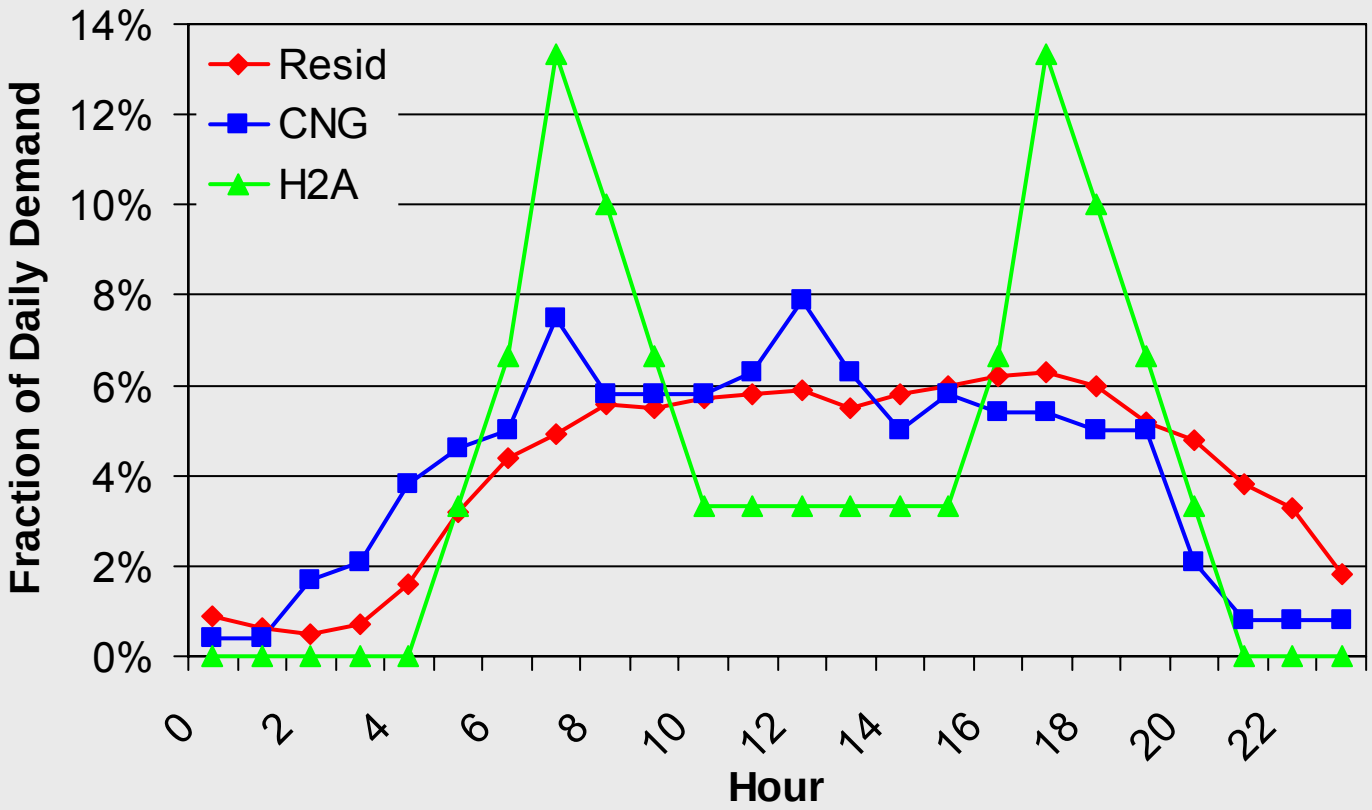
- Gasoline: 5000 to 15000 gal/day
  - Average station is about 3300 gal/day
- CNG: 700 gal/day



Gasoline data courtesy ConocoPhillips

H2 Station Demand Profile

> Normalized Residential, CNG, and H2A profiles

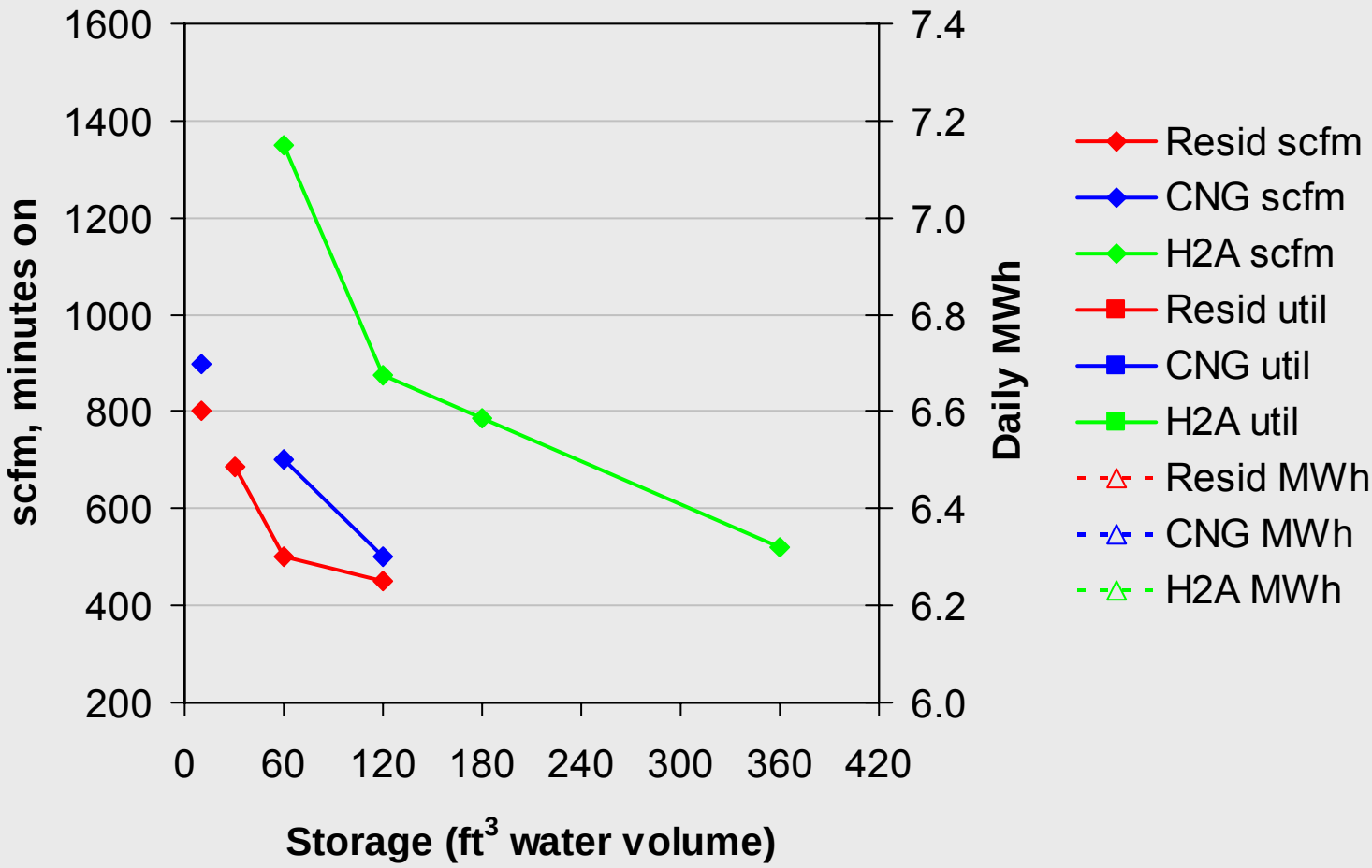


H2 Station Sizing

- 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

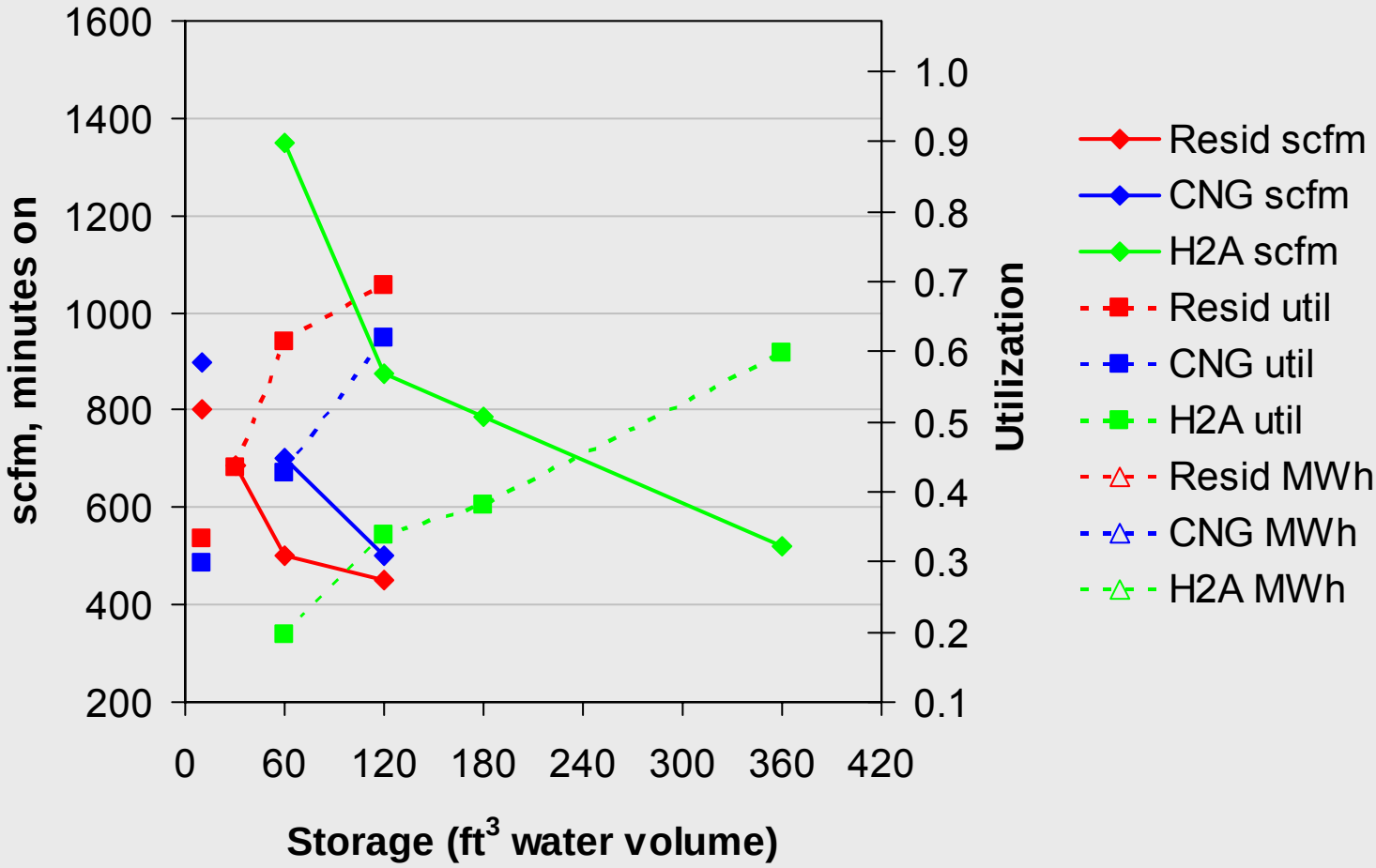
Compressor-Storage Relation

Compressor Size



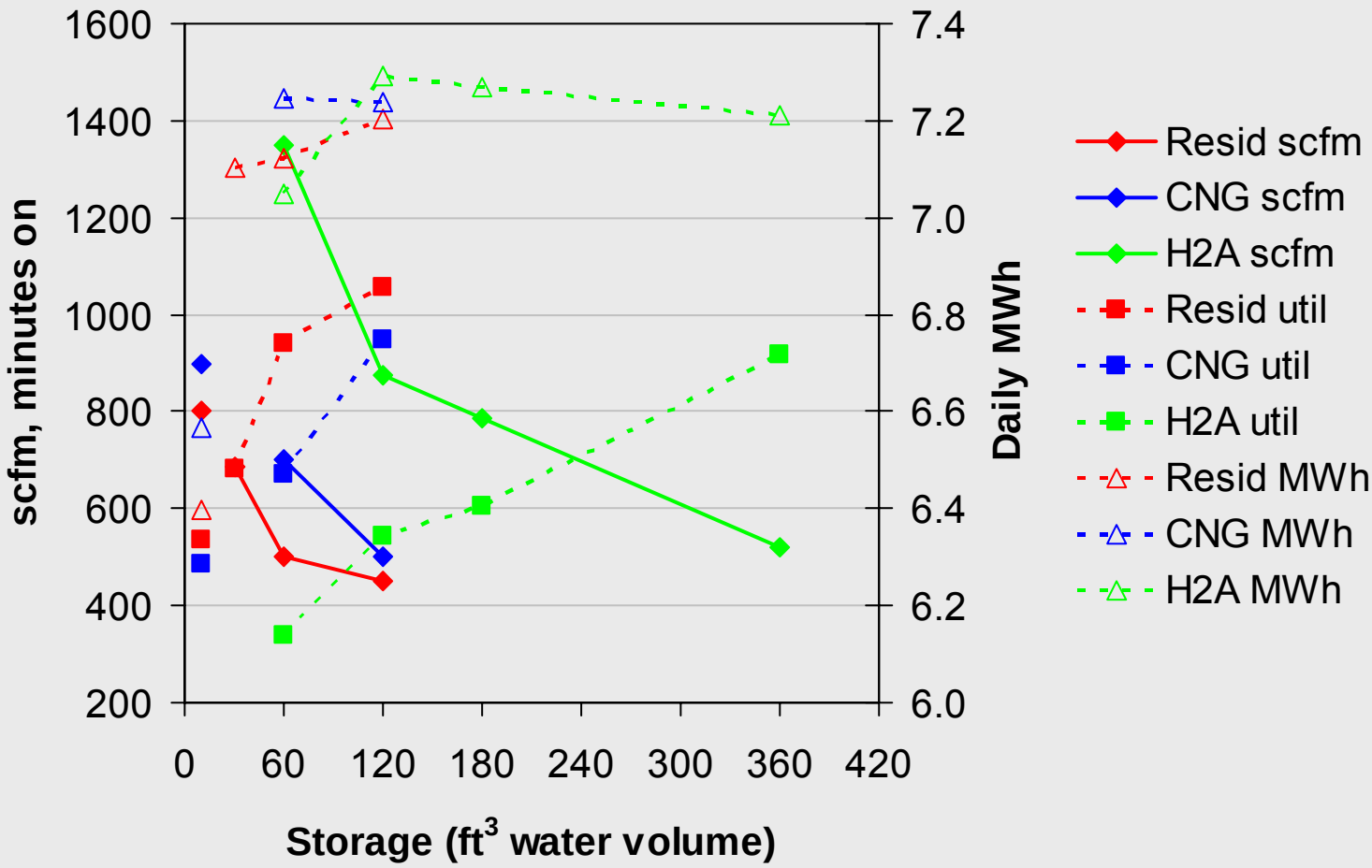
Compressor-Storage Relation

Compressor Utilization

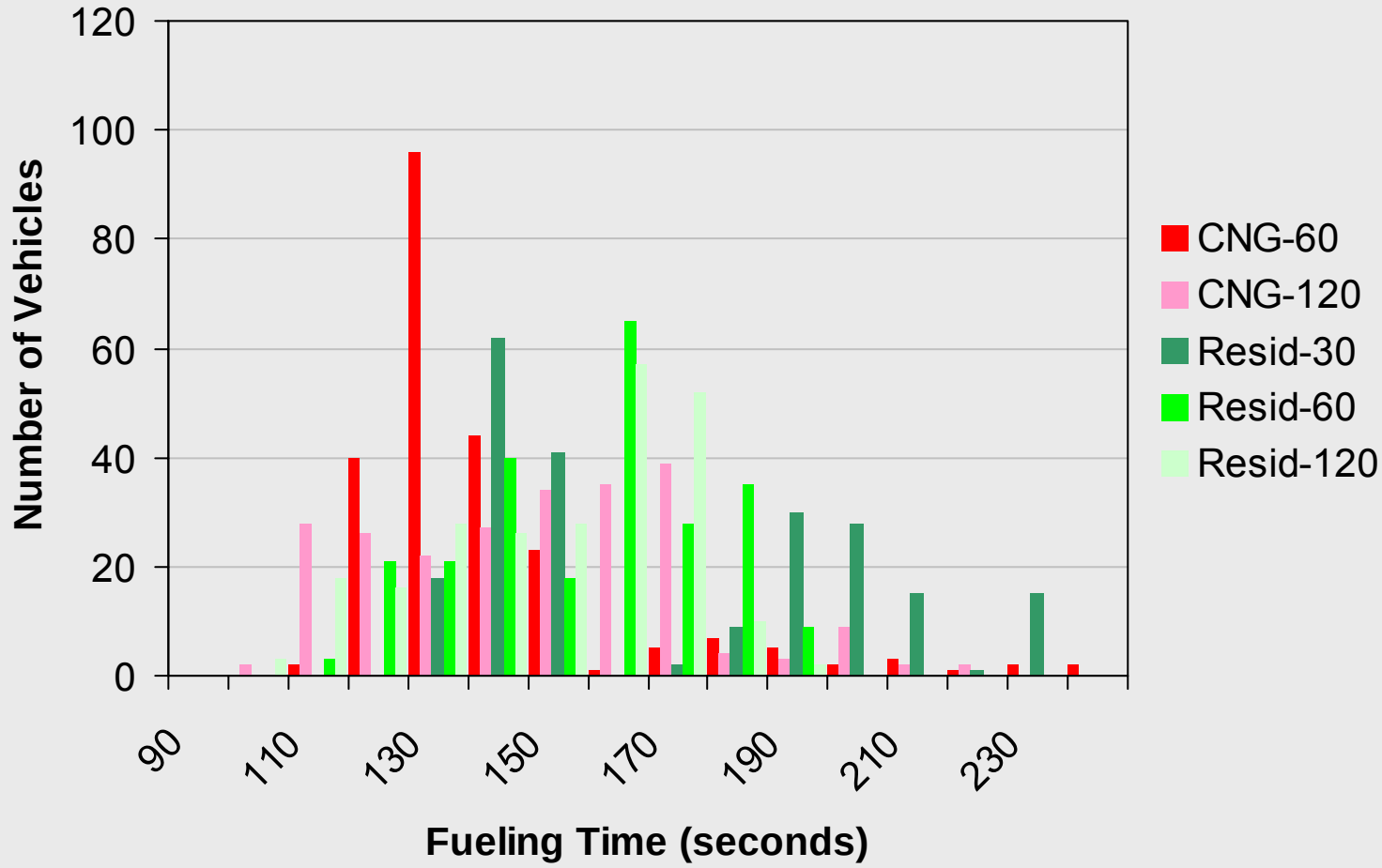


Compressor-Storage Relation

Compressor Energy

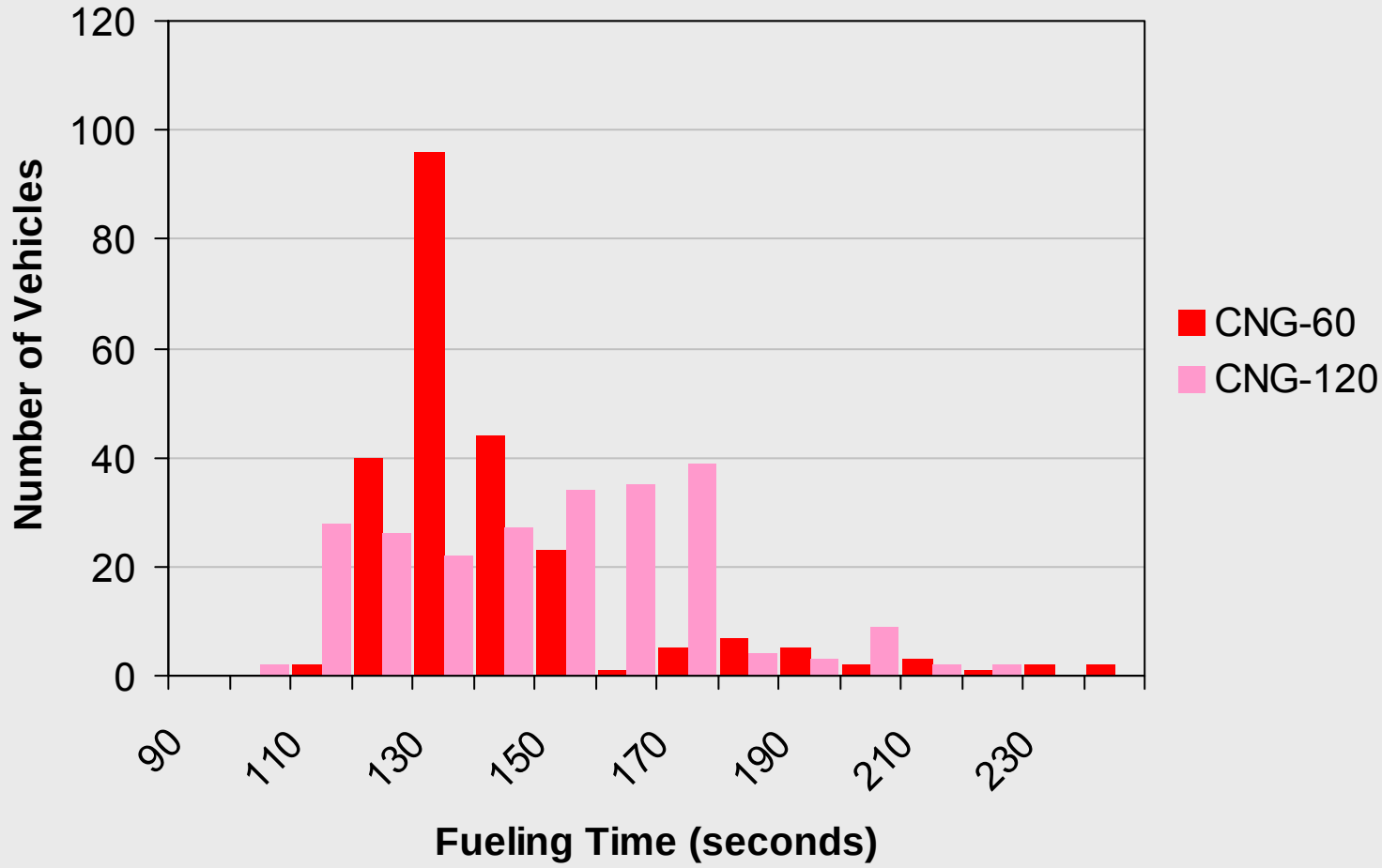


Vehicle Fueling Times
Cascades



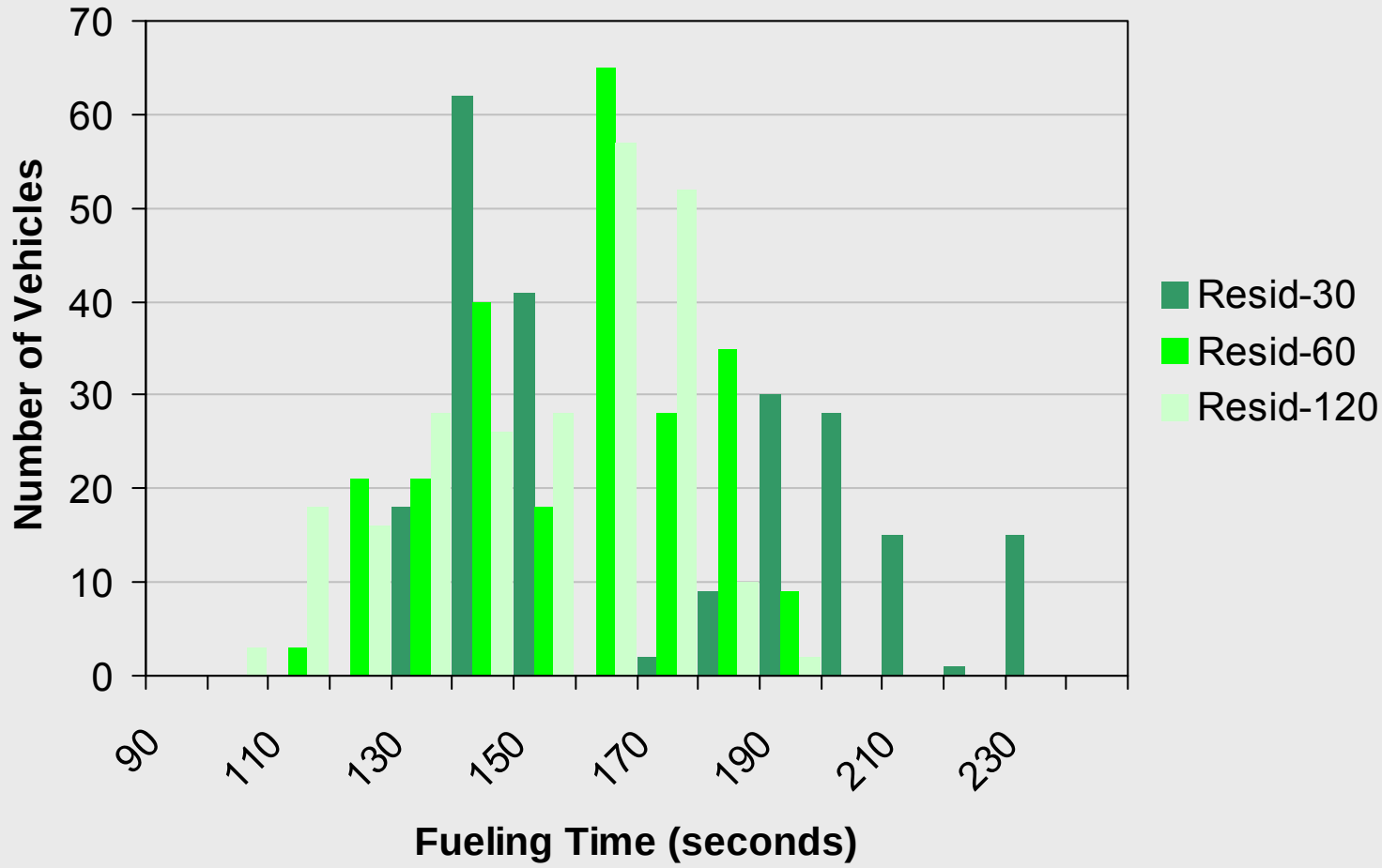
Vehicle Fueling Times

Cascades, CNG Profile



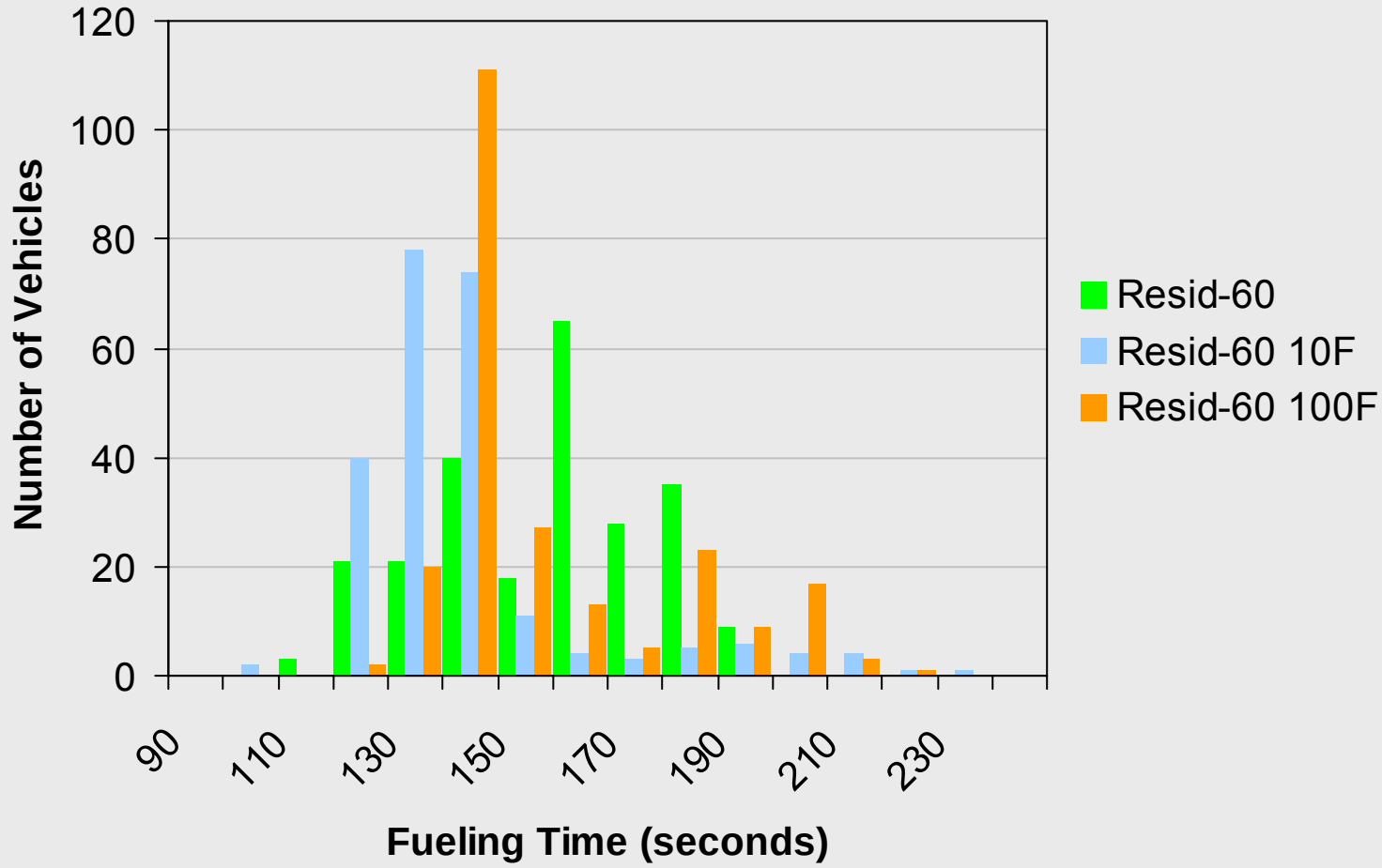
Vehicle Fueling Times

Cascades, Resid Profile



Vehicle Fueling Times

Cascades, Resid Profile, Ambient T Effects



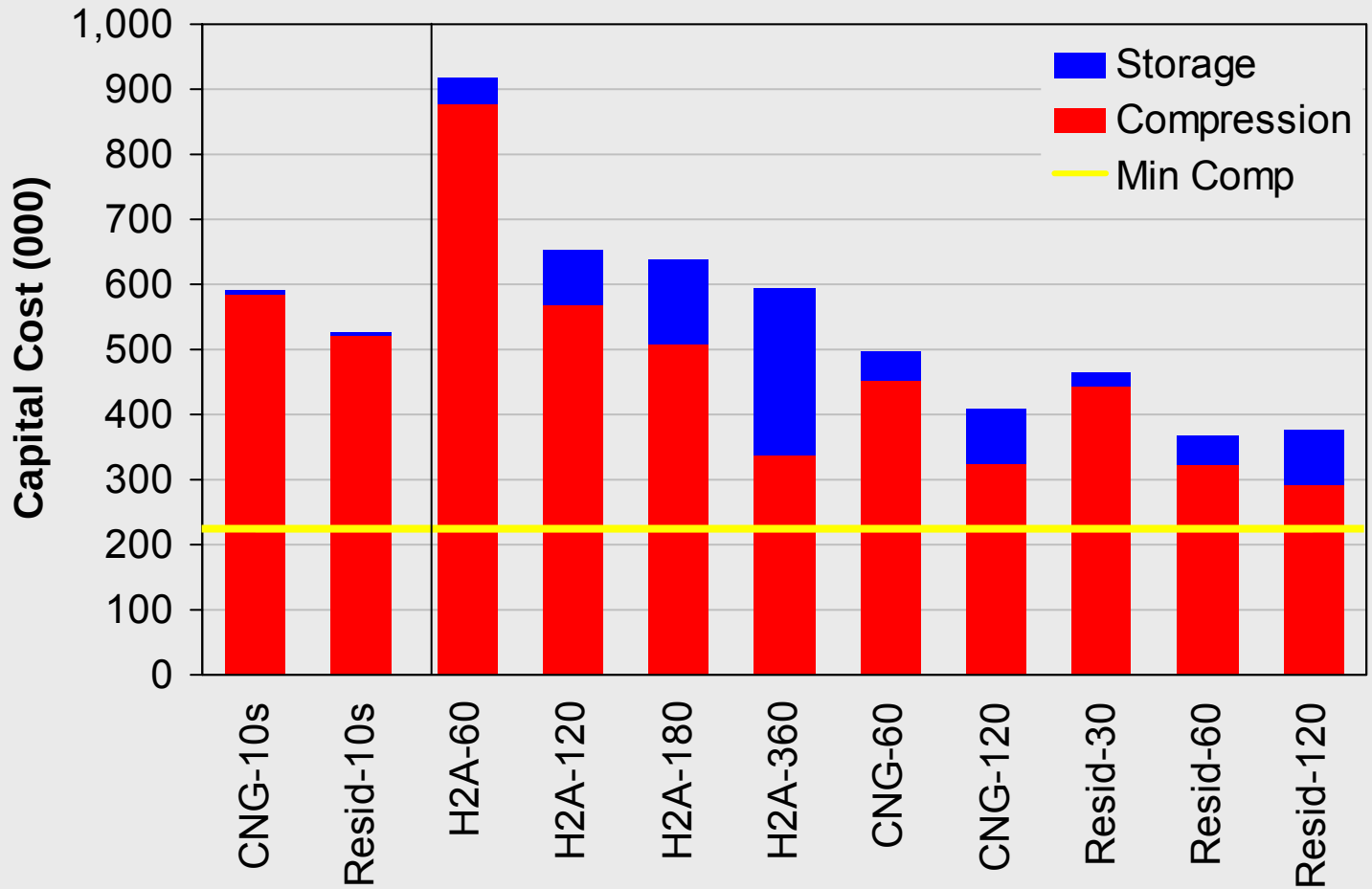
Vehicle Fueling Times

	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

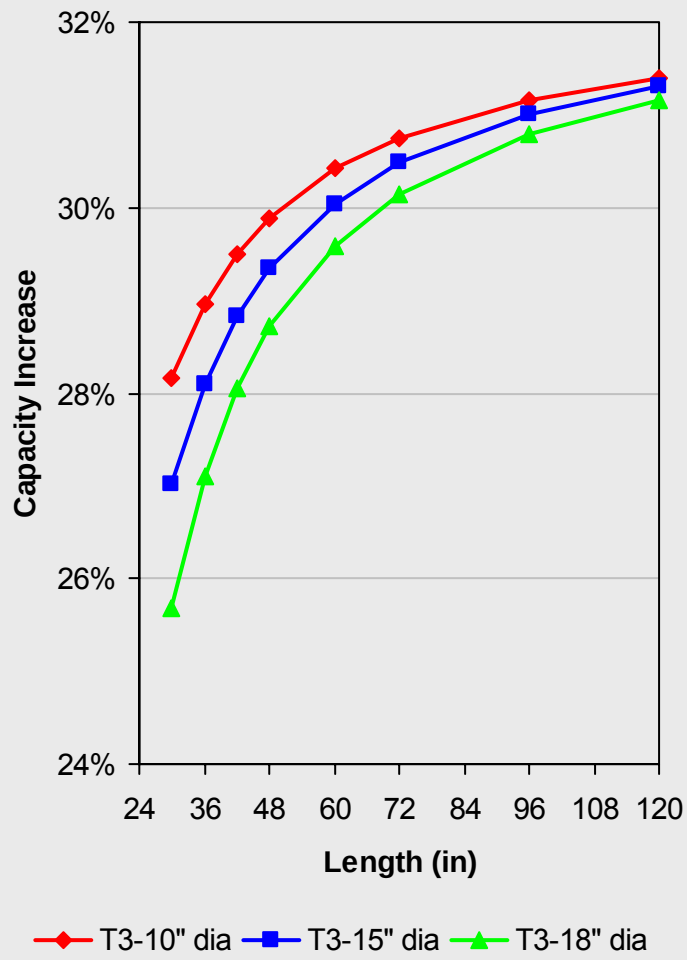
Compressor-Storage Costs

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



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



Next Steps

- 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