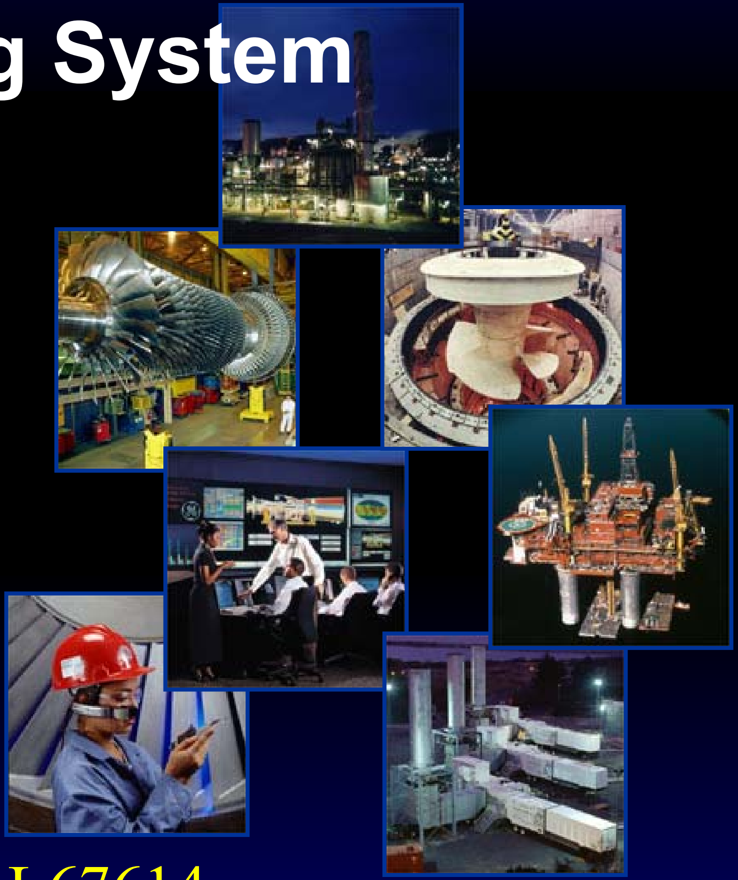
GE

Autothermal Cyclic Reforming Based H_2 Generating & Dispensing System



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Review on DOE Contract # DE-FC04-01AL67614
May 2003

Goals & Approach

DOE Goal

Cost of Delivered H_2 < \$2.50/kg

Phase I (2002) – System Design

- Design
- Assess the technical & economic feasibility

Phase II (2003-4) – Sub-System Development & Integration

- Develop the subsystems
- Reduce cost of components critical to achieving the economic goal

Phase III (2004-5) – Prototype Fabrication & Demonstration

- Fabricate, install, & operate a H_2 refueling station
- Verify the operational performance
- Verify that the cost of producing & dispensing H_2 meets the targets

Schedule & Milestones

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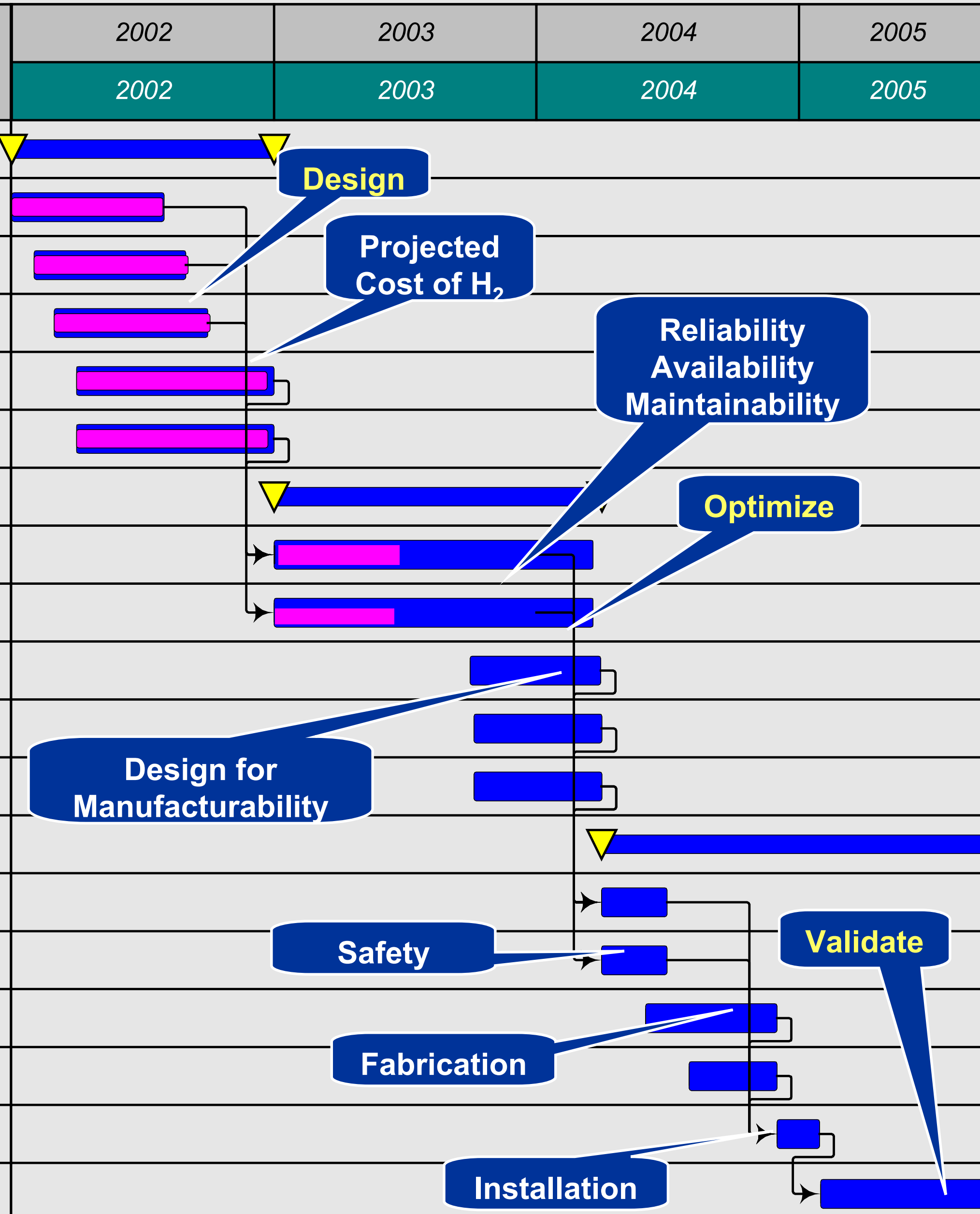
ID	Task Name
1	**Phase I - Design & Analysis**
2	Literature search
3	Functional analysis
4	Conceptual design
5	Economic analysis
6	Business plan
7	**Phase II - Subsystem Development**
8	Bench-scale durability testing
9	Component Development & Testing
10	Design of the Prototype System
11	Economic feasibility assessment
12	Update Business plan
13	**Phase III - Prototype Demo.**
14	Prototype Detailed Design
15	Environmental health & safety
16	Fabrication & procurement
17	Site planning and infrastructure
18	Unit checkout, testing & installation
19	Operation & maintenance at user



Autothermal Cyclic Reforming

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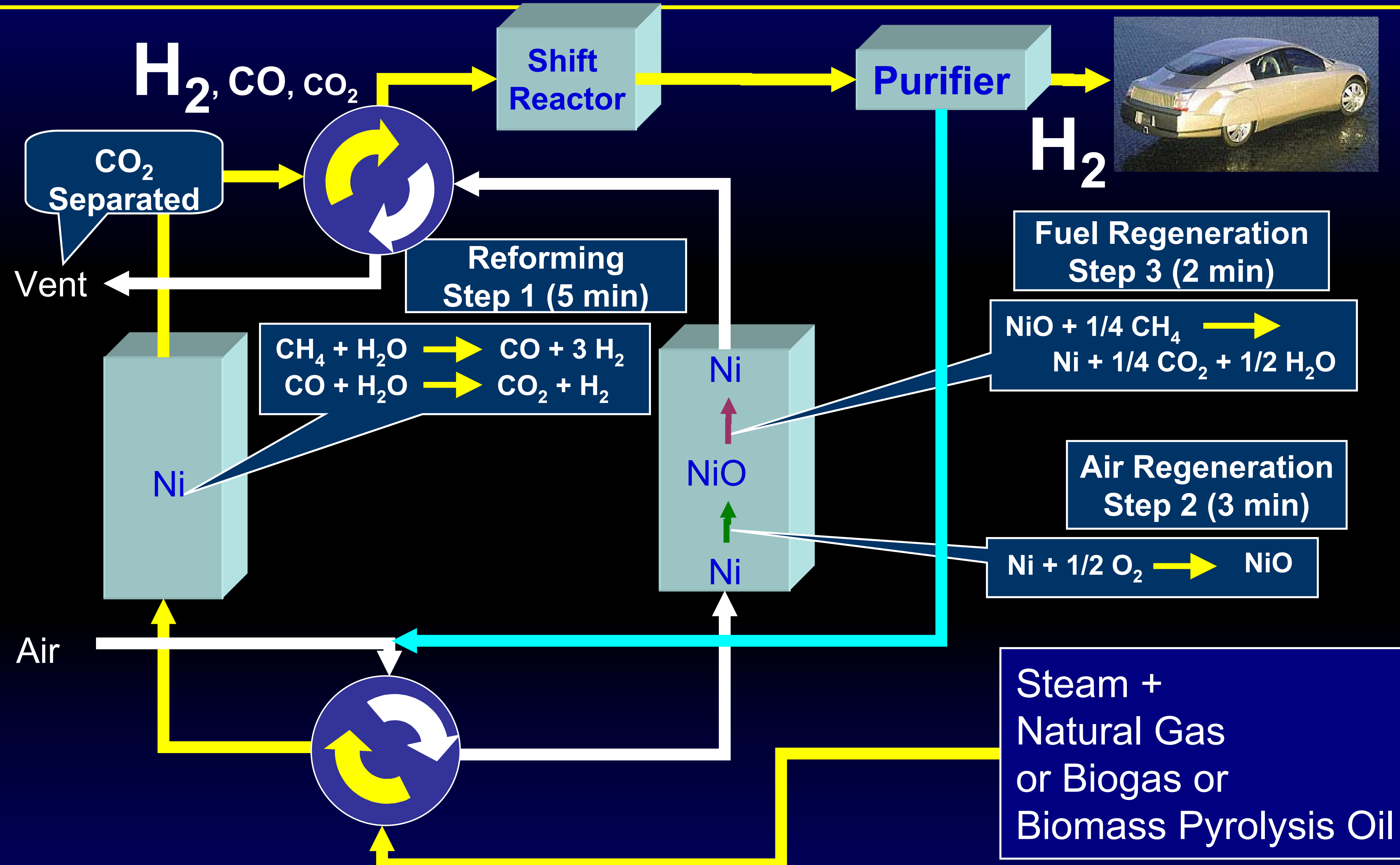

ACR offers lower capital cost & inherent CO_2 separation

High Pressure vs. Low Pressure Reforming

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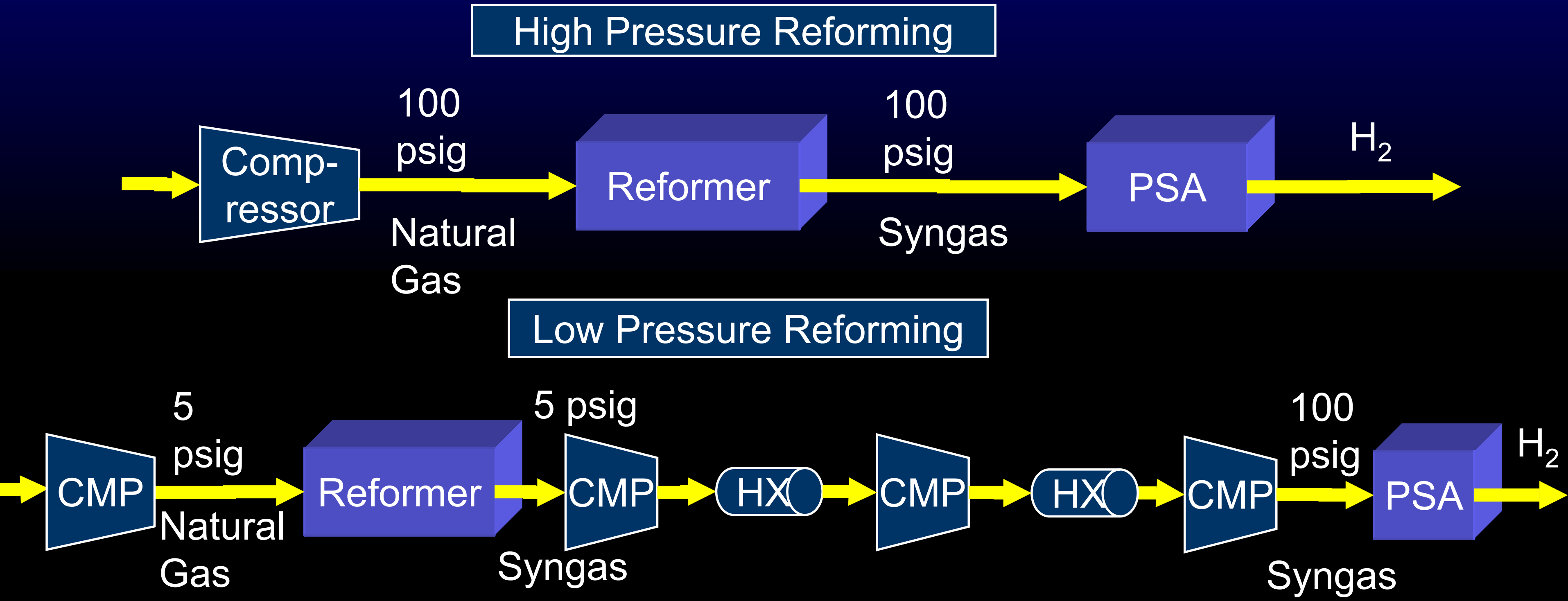

Thermal Efficiency = HHV of H_2 Produced / HHV of NG Fed

PSA – Pressure Swing Adsorption

High Pressure vs. Low Pressure Reforming Comparison

Configuration	High-Pressure Reforming	Low-Pressure Reforming
Thermal Efficiency (Excludes Electricity) = HHV of H_2 Produced / HHV of Fuel Fed	70-80%	70-80%
Electricity Consumed / HHV of Fuel Fed	0.5-1%	3-4%
Efficiency (Includes Electricity) = HHV of H_2 Produced / (HHV of Fuel Fed + Electricity Required /Efficiency of Grid Electrical Generation-35%)	68-78%	65-74%
Advantages	❑ Higher Efficiency ❑ Lower Overall System Capital Cost ❑ Higher Reliability (Eliminates Syngas Compressor)	❑ Lower Capital Costs for Reformer Reactor Only

High Pressure ACR is more cost effective

Reformer Design

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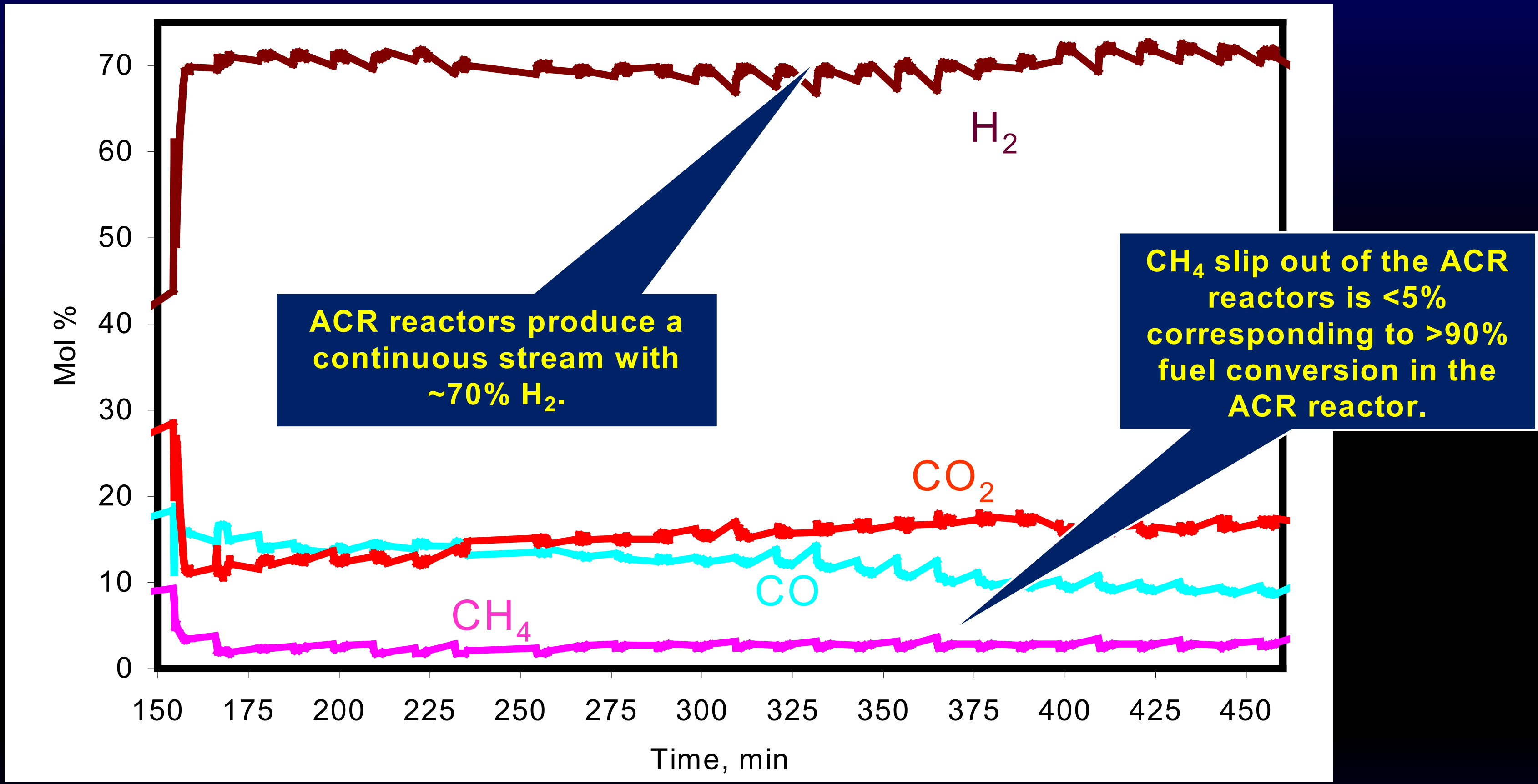


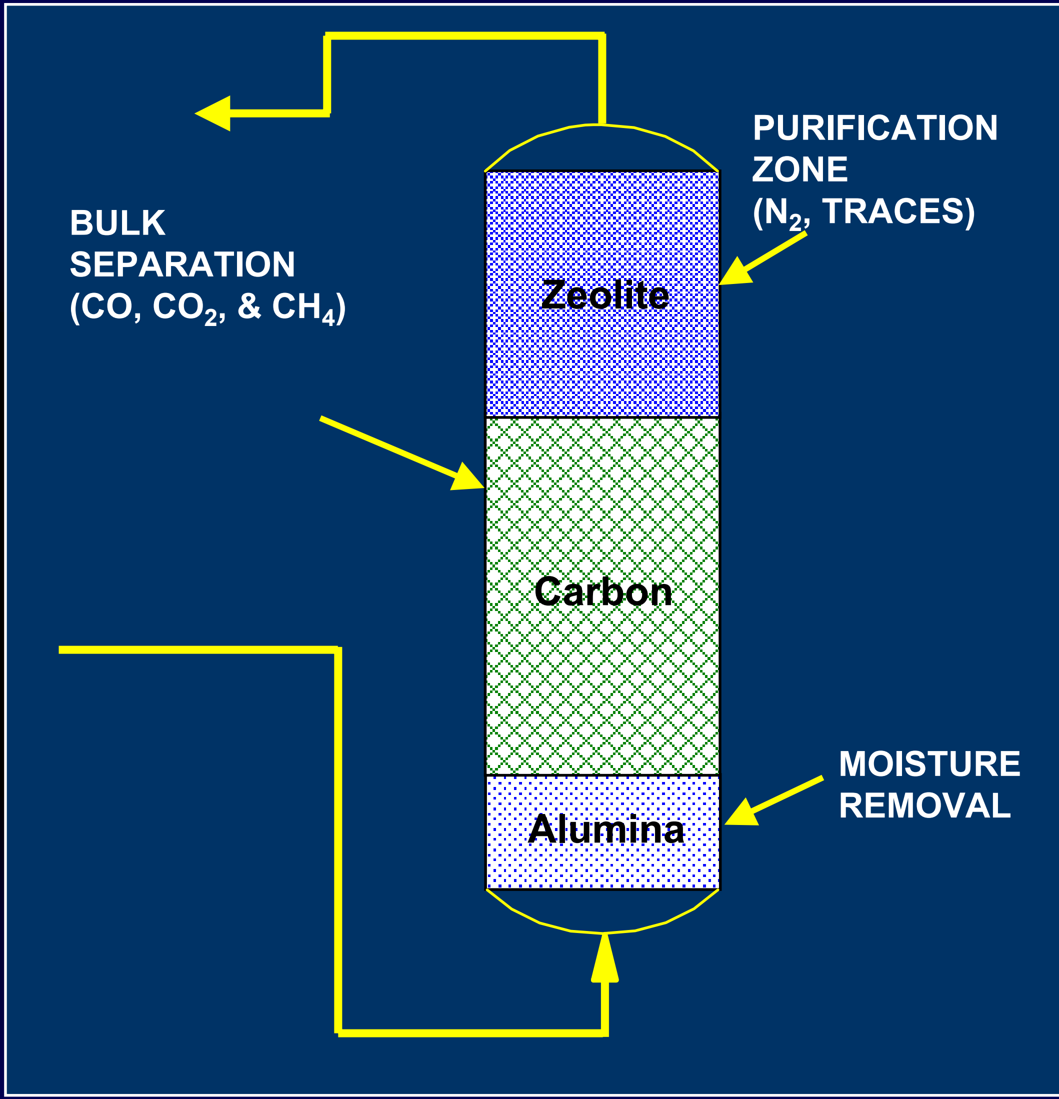
- Detailed design completed
- Low pressure reformer operated successfully
- Moving to high pressure reformer design and fabrication

150 kW thermal NG unit

ACR was operated successfully for extended periods of time

Multi-Bed Praxair PSA Design

- 3-bed process
- Accepts continuous feed from ACR and delivers uninterrupted hydrogen product
- Cyclic Reformer simplifies Cyclic PSA considerably, due to ease of integration by matching cycle times of Reformer and PSA
- Tail Gas from PSA can be used for fuel regeneration
- Product Hydrogen Specifications
  - » < 5 ppm CO
  - » < 10 ppm CO_2
  - » < 10 ppm CH_4
  - » < 10 ppm H_2O
  - » ~ 1,000 ppm Nitrogen
  - » ~ 99.99 % Hydrogen



Synergy in integrating cyclic PSA with cyclic reformer

Conceptual 3-Bed PSA Skid Assembly

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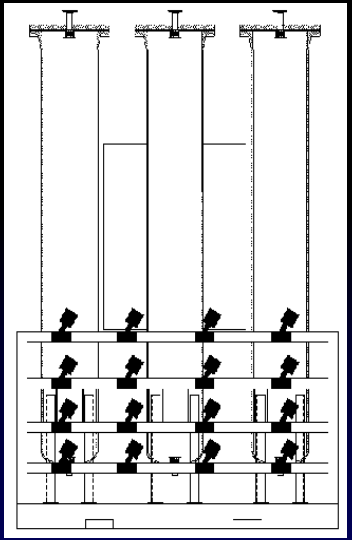
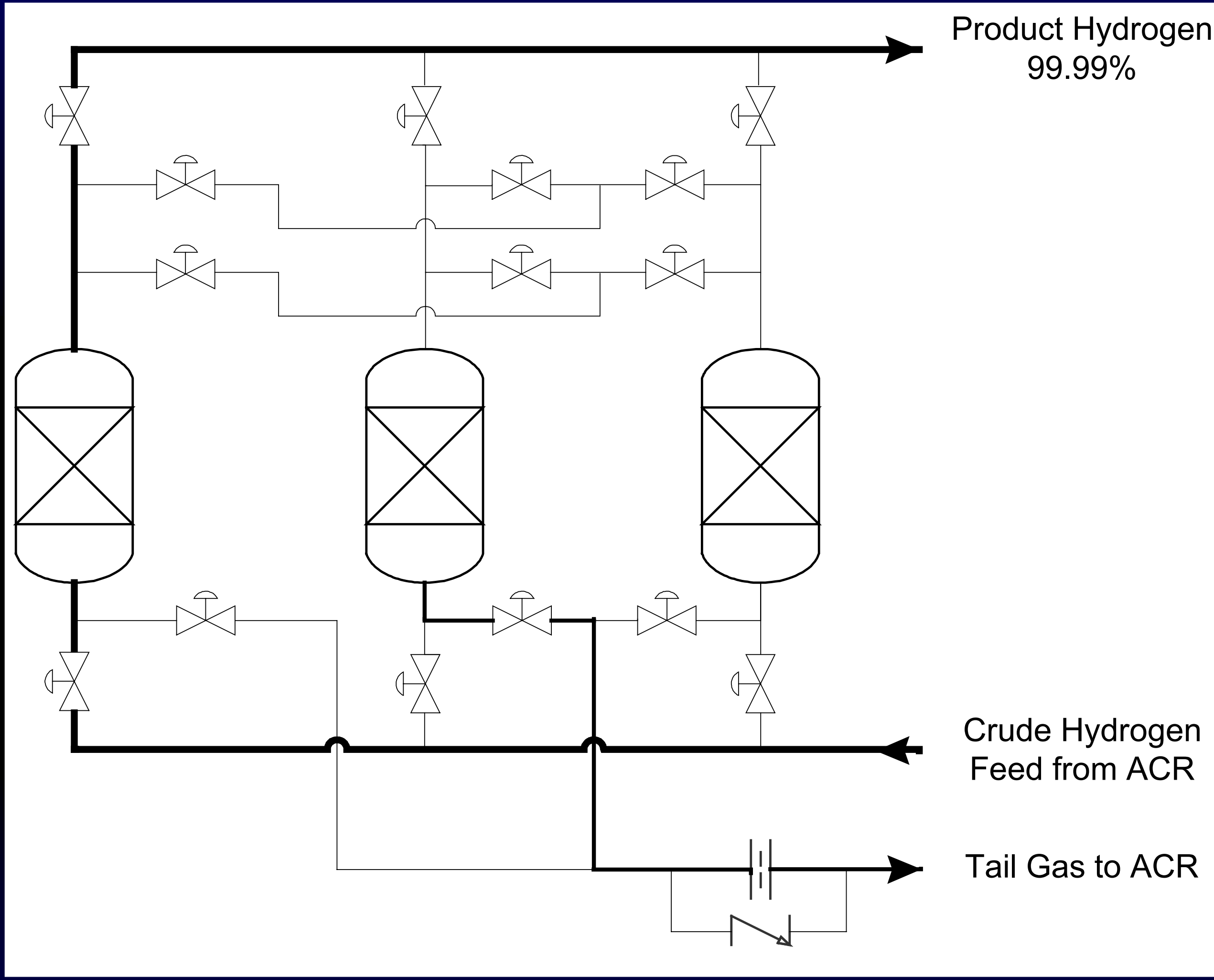
- Designed for easy valve maintenance
- Employs low cost conventional components
- System costs are highly competitive





Cost Competitive Design

Hydraulically Driven H_2 Compressor

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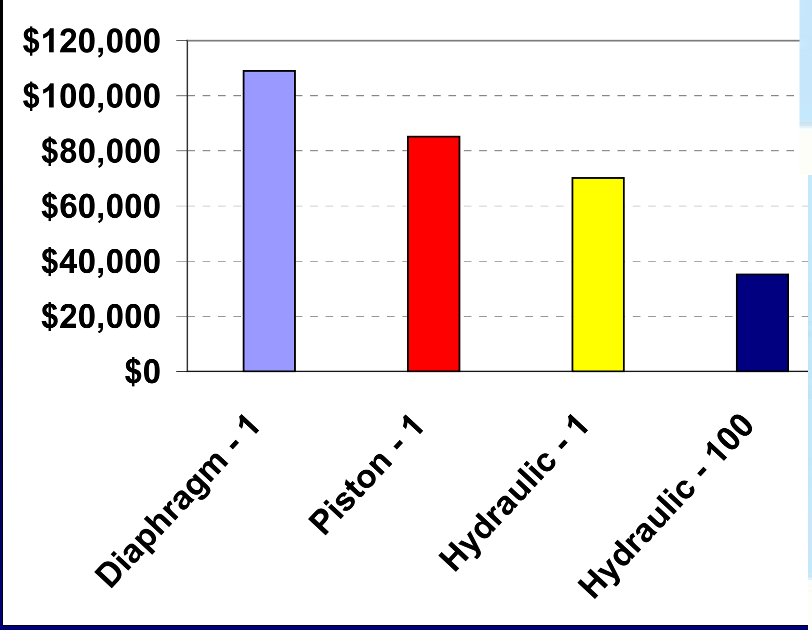
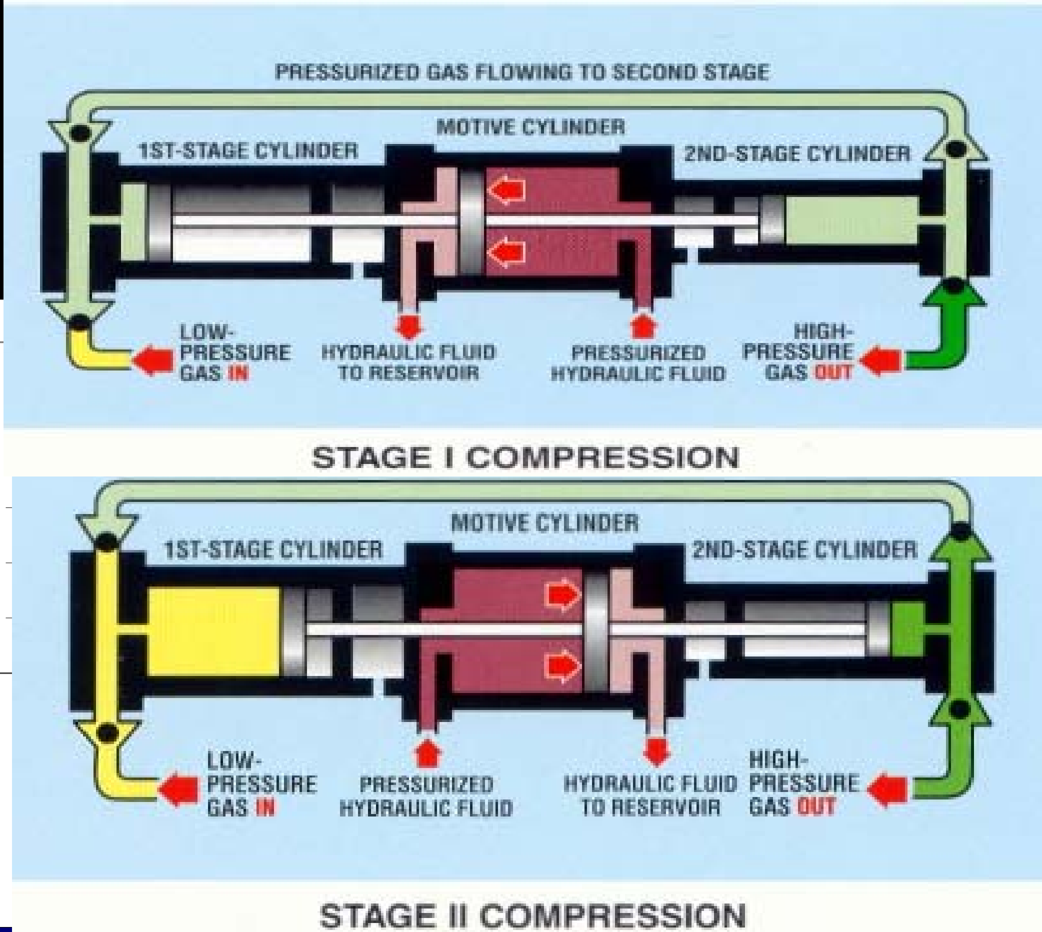
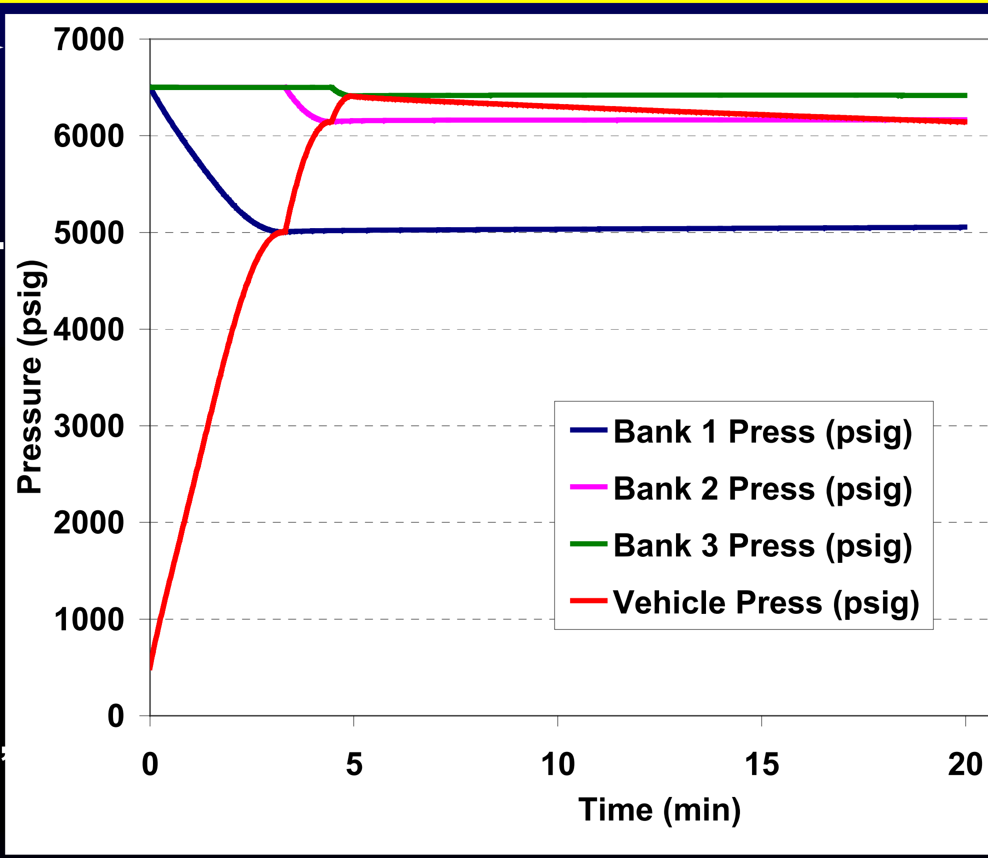
- Oil-free nonlubricated design
- Long slow stroke results in longer packing and check valve life, and much higher compression ratios in each stage
- Piston design allows easy replacement of high pressure seals
- Variable inlet pressure capabilities
- Praxair has prior experience with Hydro-Pac in high pressure nitrogen and argon applications



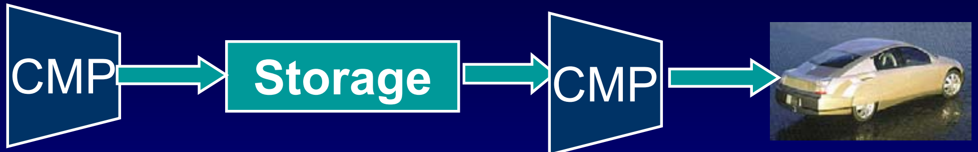


Vehicle Filling - @ 5000 psig

- **Cascade Dispensing**
  - Direct tank to tank pressure transfer through a series of pressure transfers from 3 banks.
  - One bank may be filling while other is being emptied.



- **Fill Pump Dispensing**
  - Filling method requires 1/3 the amount of storage.
  - Each vehicle can be "topped off" to the same target pressure within 5 minutes.
  - Requires the use of two packaged compressors with low utilization on the fill pump.



Vehicle Filling - Cascade Dispensing

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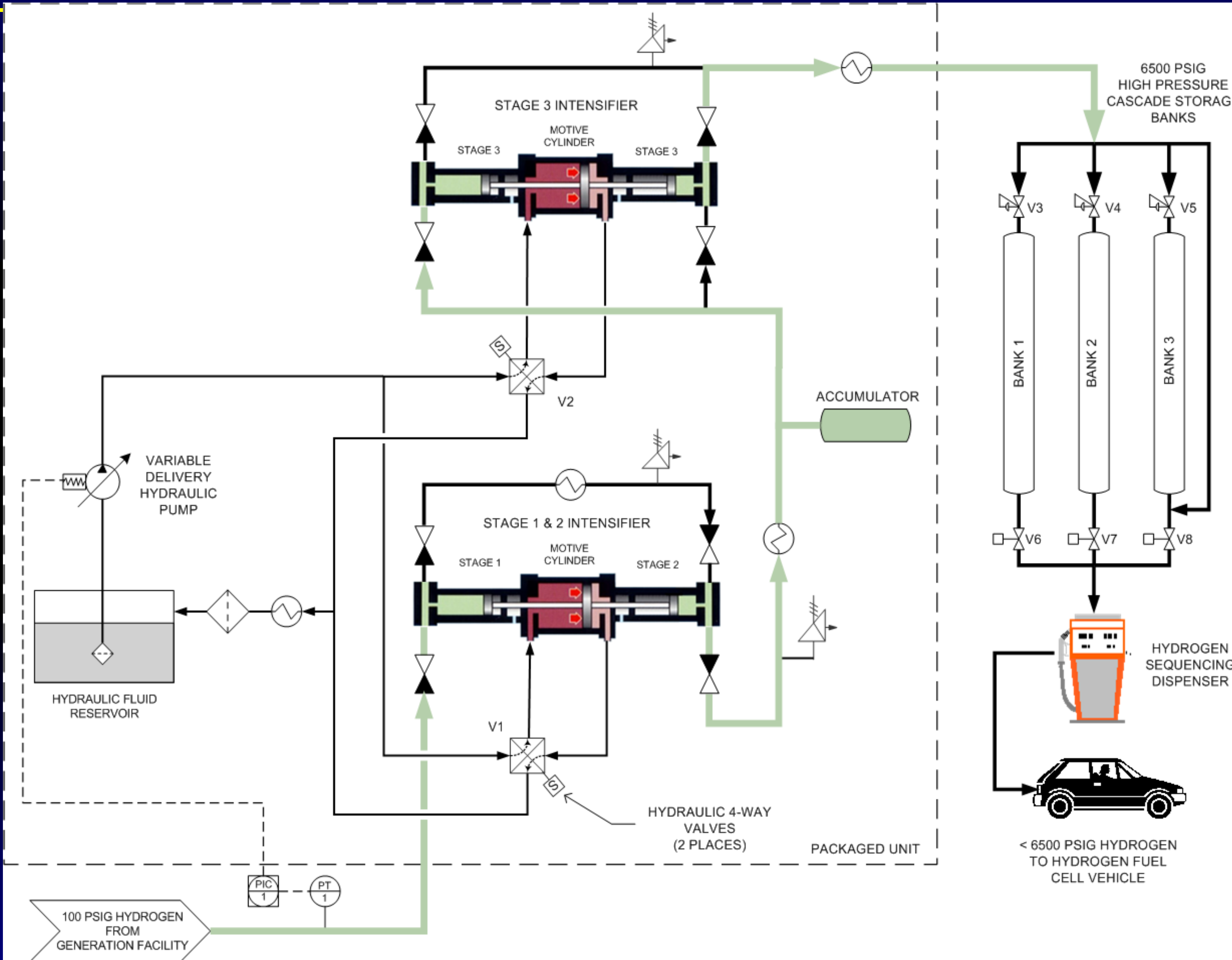

Stationary Storage

NGV2-3 Composite Cylinders - $54,000

ASME Steel Cylinders- $51,000

Refueling Station System Footprint Summary

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60 kg H_2/day
3 consecutive fills

1

60 kg H_2/day
1 consecutive fill

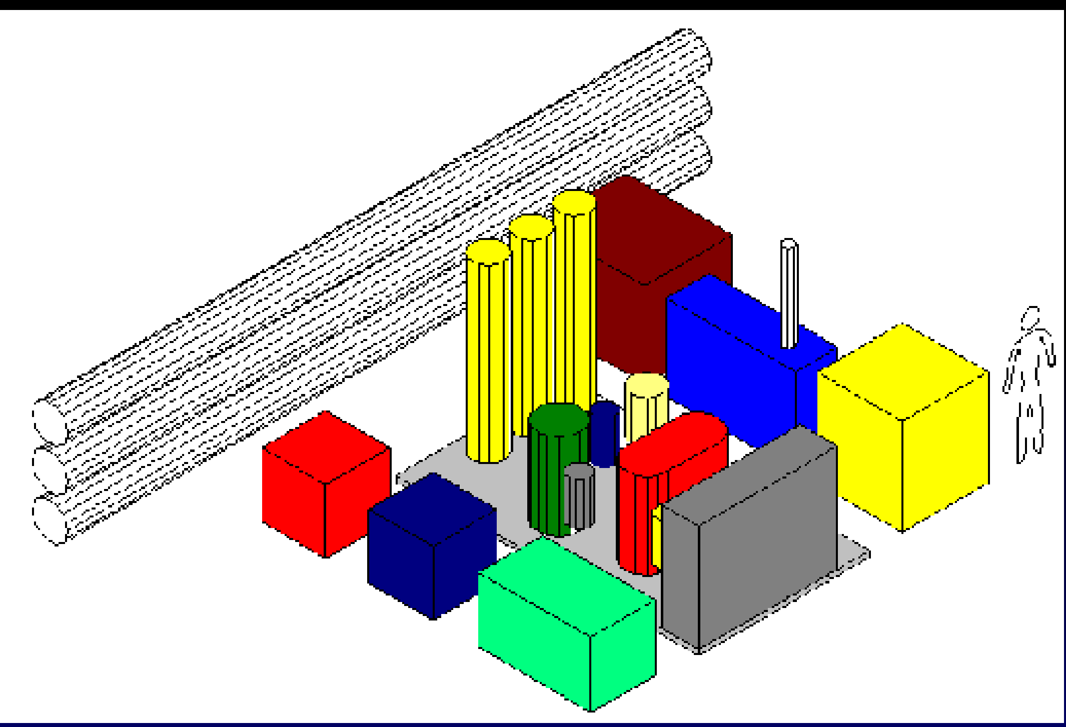
2

15 kg H_2/day
3 consecutive fills

3

15 kg H_2/day
1 consecutive fill

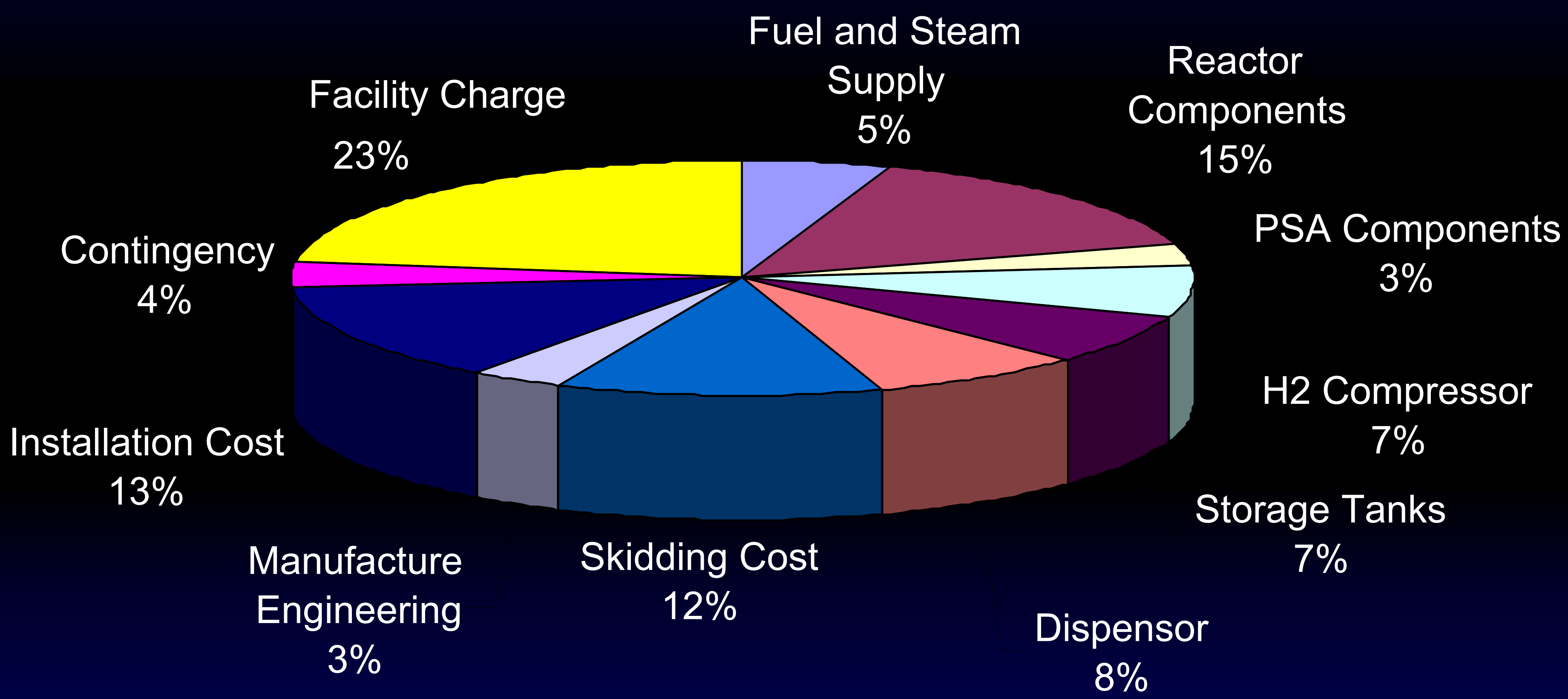
4



Hydrogen storage tanks are the largest subsystem component

Capital Cost Breakdown

120 kg/day H_2 Commercial @ 100 Units/year



Market Assessment - Commercial Price Targets

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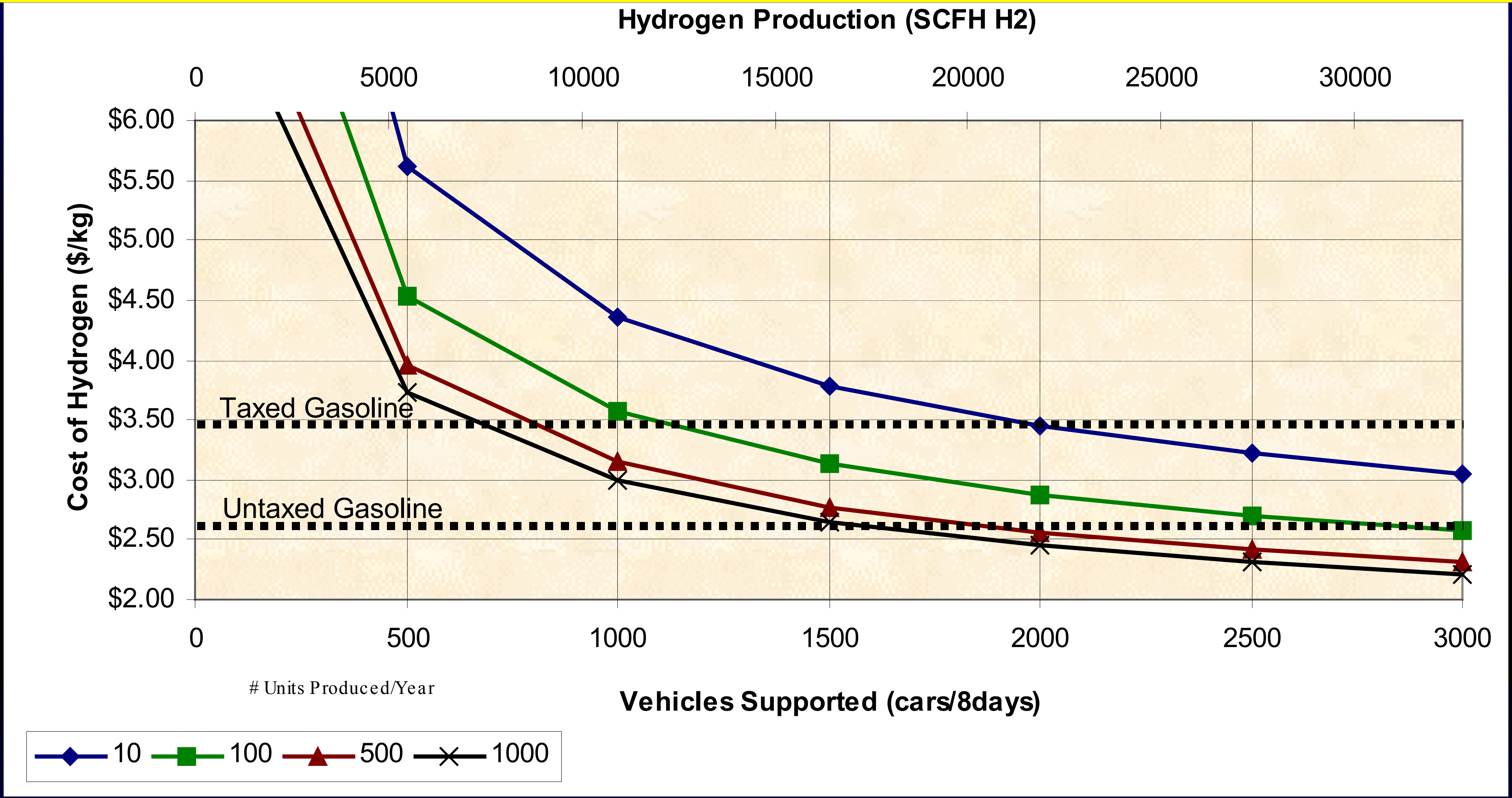

- **Price Targets**
  - **DOE Hydrogen Targets: $2.50/kg non-taxed; $3.30/kg taxed**
  - **Gasoline Equivalent Price: $2.62/kg untaxed; $3.49/kg taxed**
- **DOE price targets Met at 15,000 scfh taxed; 5,000 scfh non-taxed**
- **Commercial Plants require Steady flow, High utilization, Long term contracts**

Near and Long Term Market Cost Factors

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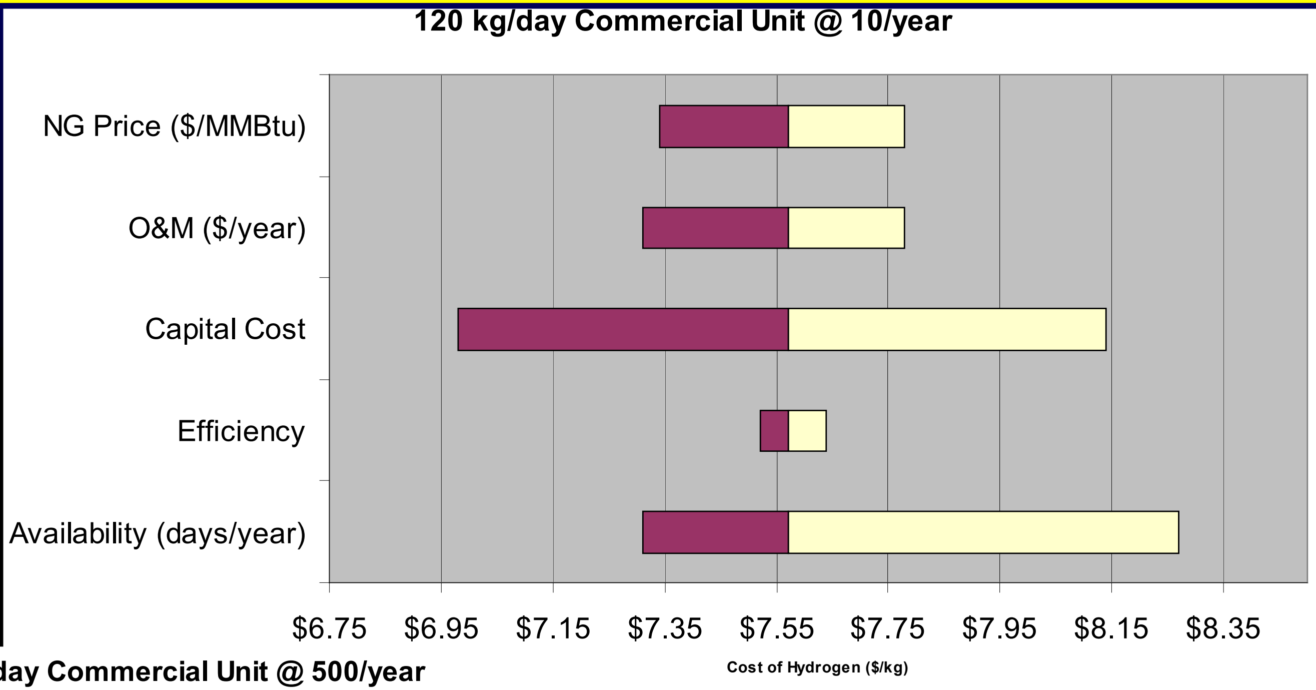
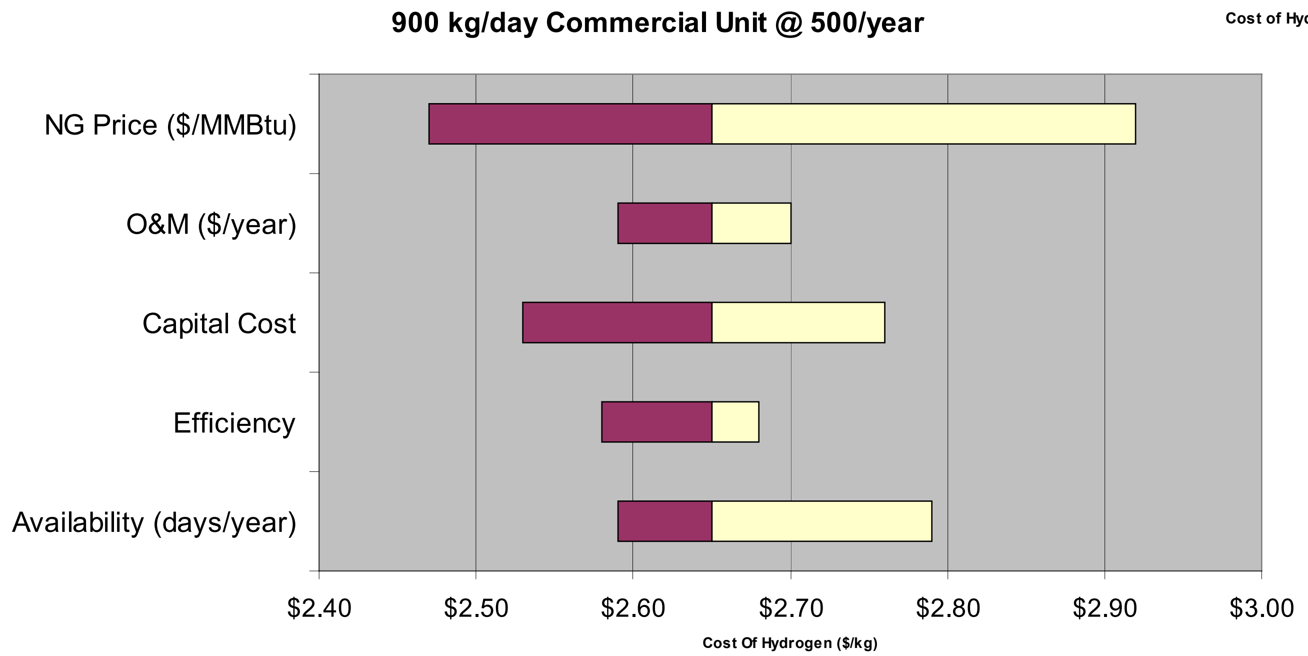
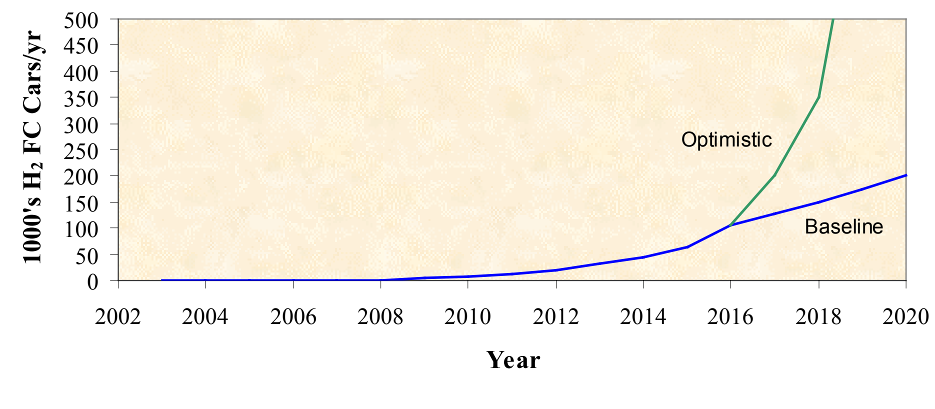
Short Term Market:
Capital Cost
Availability
O&M

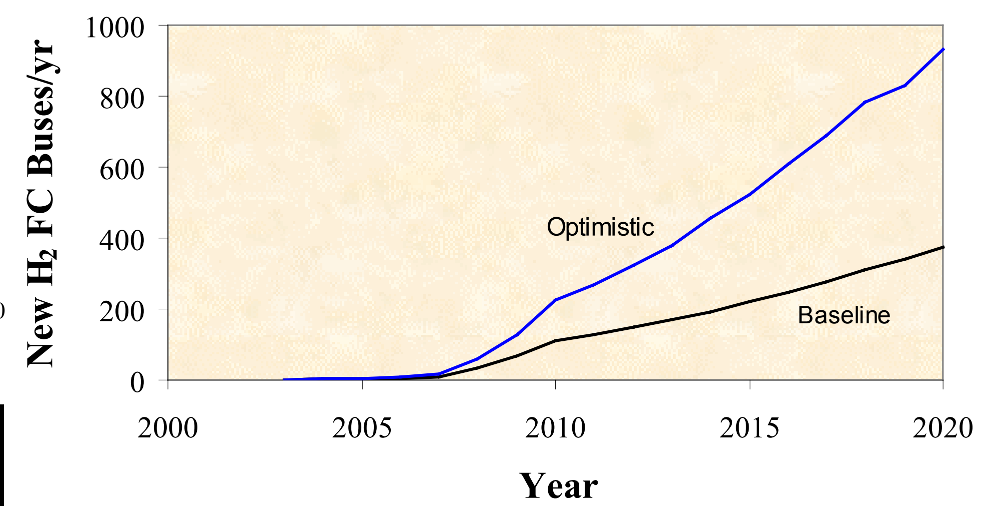




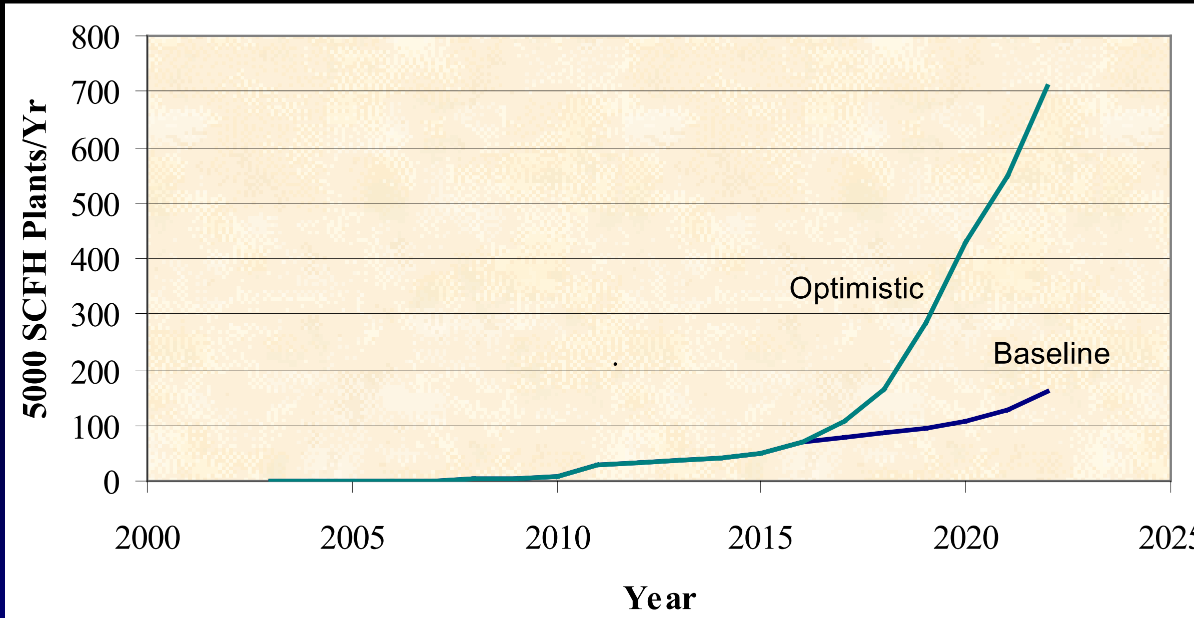
Long Term Market:
Efficiency &
NG Price

Market Projection





- 25% market share to any one individual supplier
- Various size unit could be manufactured ranging from 1000 - 15,000 scfh
- Opportunity summary based upon an expected average size of 5,000 scfh
- Conservative estimates are used for each market sector



Business Case Analysis

- Assumed 6 year R&D Period
- Current:
  - Break even year: 17
  - NPV @10%: $6,000K
- Target:
  - 30% capital cost reduction with R&D
  - Break even year: 15
  - NPV @10%: $29,000K
- If larger hydrogen generation and dispensing units are mass produced, the $2.50/kg cost target can be met. Further R&D for 30% capital cost reduction can make the business model viable
- It is expected that it would require as long as 15 years to make the business profitable. Government legislation could help accelerate this

Further R&D & government legislation is required to make business model viable

Comments, Future Work, Acknowledgements

Last Year Reviewer Comments

- After all chemical reactions you get CO_2 16%, at 800C. However, not quite sure how this process progresses.
  - Included a slide with better explanation of chemical reactions. Data shown is with out CaO. CO_2 is lower if CaO is used.
- Is there enough data to scale up an ACR.
  - Easily scaleable. Practical experience in scaling from 30 kW to 100 kW to 150 kW

Future Work

- **Subsystem Testing: Test components on test stand & Catalysts in bench-scale**
- **Modify Economic Model to Match System Development**
- **Prototype Design**
- **Design for Reliability**

Acknowledgements

- **DOE: Mark Paster, Pete Devlin, Sig Gronich, Kathi Epping, Jill Jankouwski, Ron Fiskum**
- **CEC: Avtar Bining, Art Soinski, Mike Batham**
- **AQMD: Gary Dixon**
- **CARB: Steven Church**