HYRADIX™

Hydrogen Generation Systems

Auto-Thermal Reforming Based Refueling Station at SunLine

2005 DOE Hydrogen Program Review

Arlington, VA

May 24, 2005

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This presentation does not contain any proprietary or confidential information.

Project: **TVP6**

Overview - Project Timeline

- Project began: January 2003
- Project competed: August 2004
- Percent complete: 100%

Overview - Partners

- HyRadix Inc.

HYRADIX™
Hydrogen Generation Systems

- SunLine Services Group / SunLine Transit

SunLine TRANSIT AGENCY

- DOE/State of Illinois

- South Coast Air Quality Management District of California

South Coast Air Quality Management District
AQMD
the clean air people

Overview - Budget

- Total project funding: $1,126,000
  - DOE share: $563,300
  - Contractor share: $212,700
  - SCAQMD share: $350,000
- FY-04 funding: $243,300

Overview - Project Objective

Demonstration of Auto-Thermal Reforming based refueling station

DOE Objectives

- Demonstrate H_2 fueling station for HCNG and H_2 vehicles
- On-site auto-thermal reforming of natural gas
- Cost analysis vs. target of $3/gge in 2008
- Evaluate fill rates of fuel cell bus and car
- Public education of hydrogen and fuel cells

Overview – Barriers Addressed

C. Hydrogen Refueling Infrastructure

This project primarily addresses factors from the *Hydrogen Refueling Infrastructure* technical barriers as noted in the Technology Validation section of the *Hydrogen, Fuel Cells & Infrastructure Technologies Program*

- Interface technology to fast-fill tanks requires reliable demonstrations
  - SunLine has gained significant experience with and understanding of rate-of-fill factors and the optimization of a cascaded storage and dispensing system for servicing different types of vehicles.
- The high cost of hydrogen
  - The hydrogen generator used for this project represents a big step forward in reducing the cost of hydrogen production.
    - *Feedback from this project is providing further cost reductions for HyRadix.*

Overview – Barriers Addressed

C. Hydrogen Refueling Infrastructure

- Low availability of hydrogen production systems
  - This project demonstrates one of the first hydrogen refueling stations in the US using small scale reforming technology for on-site hydrogen generation. This project helped lead to a hydrogen generator that is now commercially available.
- Integrated facilities with footprints small enough…
  - Implementation of a compact skid-mounted hydrogen generator. This project also furthered the participants understanding of siting and configuration criteria for future refueling station design

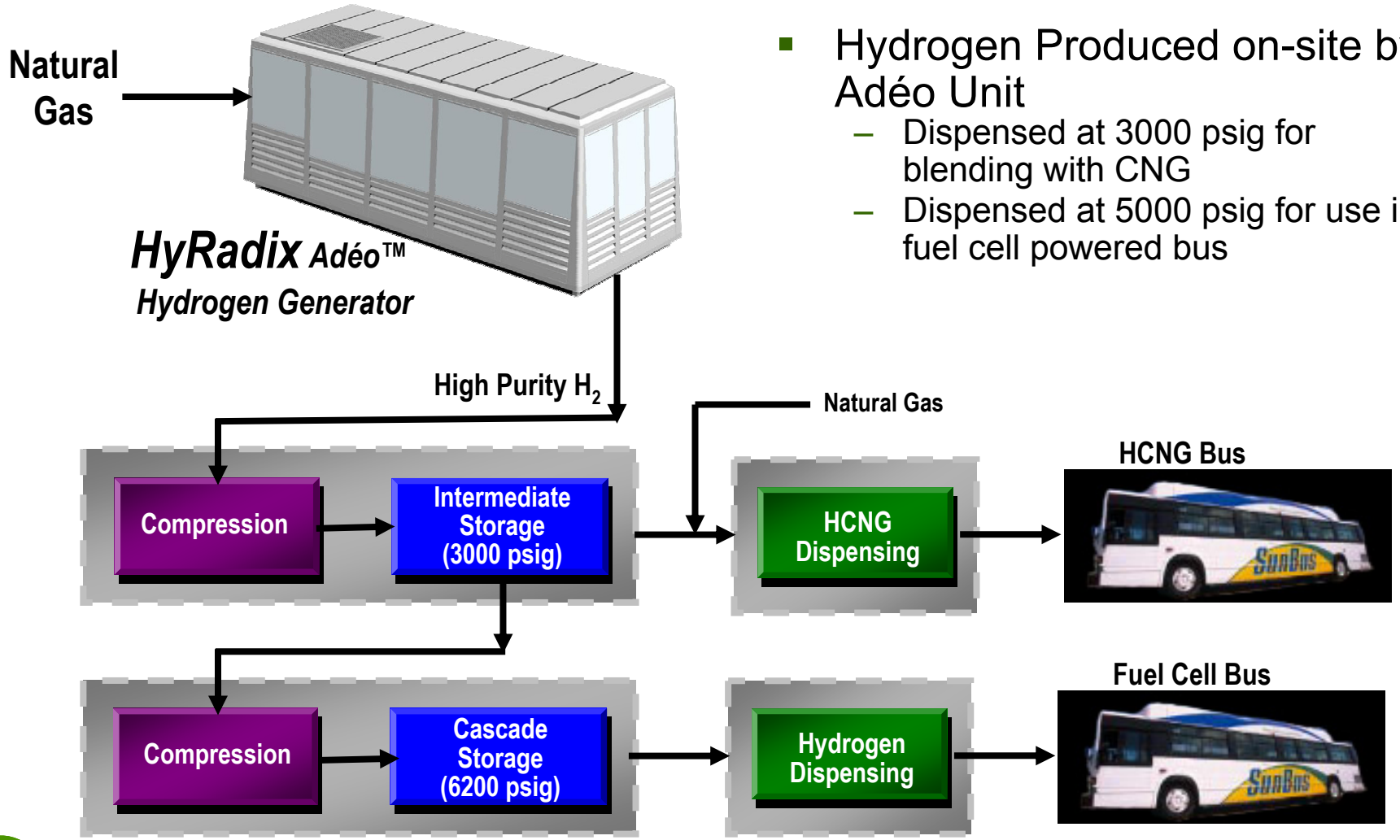
Project goals

Hydrogen Purity	>99%
H_2 Production Rate	90% of 100 Nm^3/hr
Compression & Storage	6250 psig
Dispensing	5000 psig
Refueling rate	15 min per bus 3-5 min per car

Approach

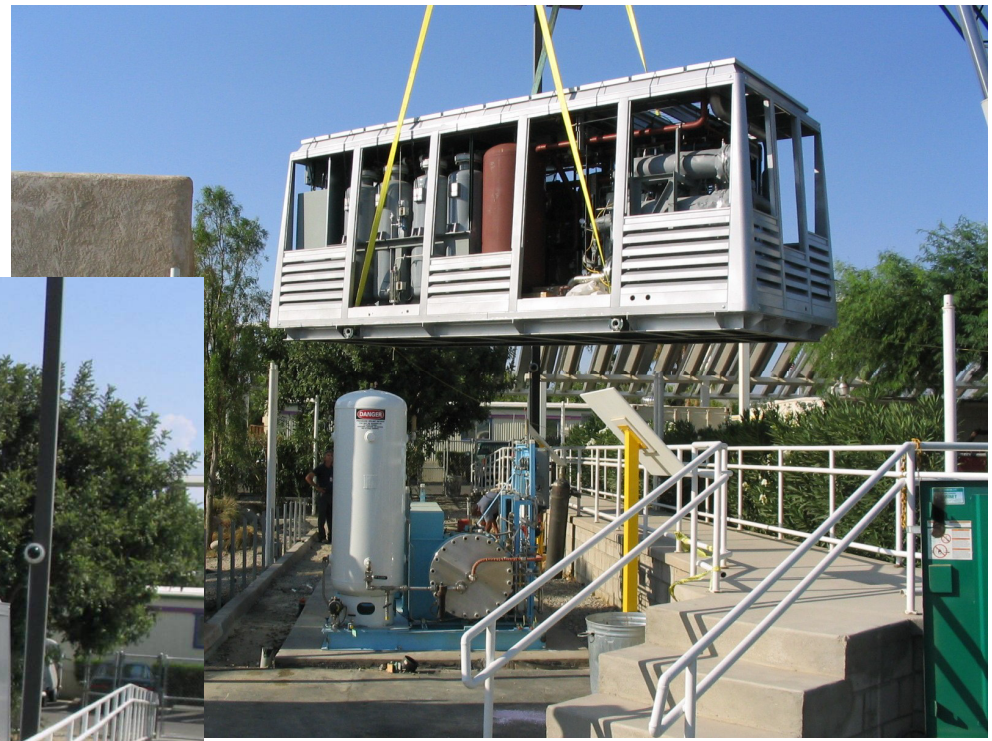
- On-site natural gas fueled Hydrogen Generator
  - Catalytic Auto-Thermal Reforming (ATR) technology
  - Advanced sulfur removal technology
  - High performance Pressure Swing Adsorption (PSA) system for purification of ATR reformate.
- Multi pressure storage for cascaded hydrogen dispensing
  - Duel fueling capability; H_2 only / HCNG
- Demonstration & Education:
  - Refueling of HCNG buses in commercial operation
  - Refueling of H2 Fuel Cell and ICE vehicles at a public access facility
  - Provide public tours of the facility

Hydrogen Fueling Station at SunLine



- Hydrogen Produced on-site by Adéo Unit
  - Dispensed at 3000 psig for blending with CNG
  - Dispensed at 5000 psig for use in fuel cell powered bus

Installation of Demonstration Adéo Unit



SunLine Transit Agency
Palm Springs, CA
100 Nm^3/h

Technical Accomplishments

Operating Experience

- Demonstrated operation of ATR reformer
  - Acceptance Test Passed in April 2004
    - *10 days continuous operation*
    - *Capacity >90 Nm^3/hr H2*
    - *Purity >99%*
- Real world validation
  - Production of hydrogen in a revenue generating application
  - Successful integration and automation of production, compression and storage
  - Cost of hydrogen is less than delivered tube trailers
  - Ongoing fueling of FC buses, H2 ICE bus, and HCNG buses in revenue generating service
  - Occasional fueling for most major automotive OEM FC vehicles
    - *Refueling stop for Southern California test drives*

Technical Accomplishments

Operating Experience

- Demonstrated low risk of contamination from ATR based reformer
  - Operated the plant from 99.9% to 99.999% purity
    - Verified that the only impurities in this range are N_2 & Ar
    - CO, CO_2, CH_4 & other contaminants remain below detection limits.
- Fully automated hydrogen generator
  - Unattended operation with remote monitoring capability

Technical Accomplishments

Operating Statistics

- Start-up Time
  - Cold Start: 3 hrs
  - Warm Start: 1½ hrs
- Emissions (Exhaust)
  - CO: < 0.03 % (below detection limit of the instrument)
  - CH4: 6-15 ppmv
  - NOx: 0-3 ppmv
  - SOx: < 1 ppmv (below detection limit of the instrument)

- Power Consumption

Feed Nm3/h	Peak Power kW	Energy / Feed * kWh / Nm^3
20	17.70	0.885
35	21.50	0.614
40	25.00	0.625
43	27.20	0.633
44	29.00	0.659
45	29.70	0.660

* Product / Feed Ratio is approximately 2/1 at design purity

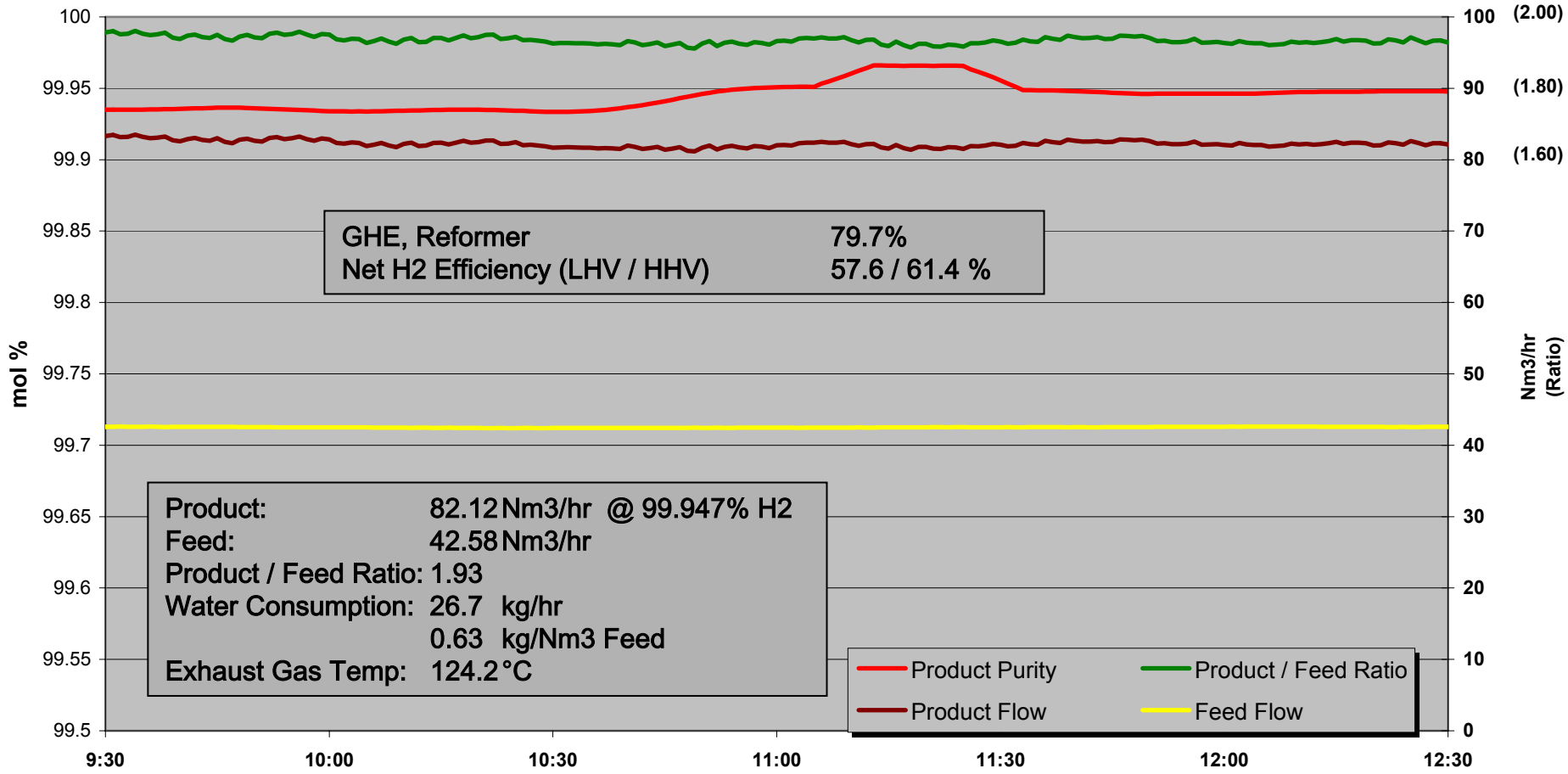
Technical Accomplishments

Operating Statistics

- One full year of operation (April ’04 – April ’05)
  - 4500 hrs of run time on reformer
  - All H_2 dispensed has been produced by the reformer; back-up supply has not been used
    - *Moderate usage pattern has been helpful in allowing problems to be solved without impacting commercial operations*
  - Consistent hydrogen quality
    - *Hydrogen generator is normally operated to produce 99.999% hydrogen*
    - *Contaminants are consistently undetectable during routine sampling*

Technical Accomplishments

Operating Data



Technical Accomplishments

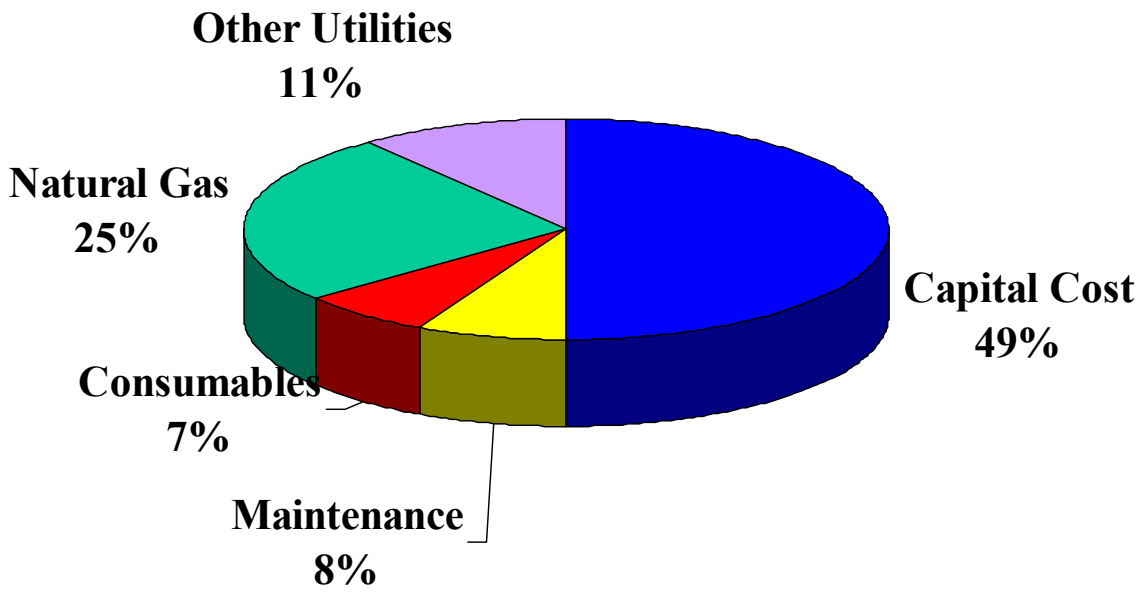
Problems Encountered

Category	Affected Equipment	Un-planned Shut-downs?	Causes	Resolution / Comments
Rotating Equipment	Water Pump	Yes	Blown fuses due to electrical shorts.	Re-oriented junction boxes to prevent vibration damage to wiring
Process Equipment	Heat Exchangers	Yes	Experienced failure of heat exchangers during first commissioning	Re-designed and replaced the exchangers. Re-commissioned the plant in Apr-04
Support Utilities	Electrical	Yes	Voltage Surges causing faults in variable frequency motor drives	Added electrical line filtering to incoming supply
Instruments & Controls	Water level switches	Yes	Fabrication debris in system piping Over sensitive shut-down logic	Improved intermittent flushing of water system and modified fabrication specifications for future units. Improved fault tolerance of water controls
	Solenoid valves	Yes	Fabrication debris in system piping	Cleaned and repaired valves / Modified fabrication specifications for future units.
	Solenoid valves	Yes	Valve sticking due to residue build-up	Modified condensing arrangement to prevent the cause.
	Thermocouples	No	Failures due to vibration	Modified thermowell design – failures have stopped.

Dispensed Hydrogen Cost

(100 Nm^3/h)

NG @ $4.50/MMBTU
Electric @ 8.5¢/kWh
Capital rec. factor 15%
On-stream factor = 85%



Total cost of production = $3.68/kg

Responses to previous year comments

- Request for more performance data
  - Additional performance data is included with this poster presentation
- Potential for degradation of H2 purity
  - Routine sampling shows no degradation of purity.
    - *Any degradation in performance would result in reduced efficiency rather than reduced purity*
- More information on future development and how this technology will be introduced in the expansion of the H_2 infrastructure
  - Information follows…

Future Goals

Adéo Hydrogen Generator

- Efficiency improvements
  - High performance PSA with improved recovery
  - Continued optimization of process design and heat integration
- Cost reduction
  - Process simplification
  - Economies of Scale
  - Parts count reduction (DFMA)
  - Key Vendor participation
- Market introduction
  - HyRadix is commercializing this hydrogen generator technology into the industrial H_2 market as well as refueling applications
    - *To build sales volume faster and reduce costs towards the president's H_2 Fuel Initiative goals*
  - Continued participation in H_2 refueling demonstrations and early commercial applications

Since the completion of this project much of this work has already been done

Hydrogen Safety

- The most significant hydrogen hazard associated with this project is…
  - An ignition of a hydrogen-air mixture
  - This could be caused by an un-intended combustible gas mixture in the surrounding atmosphere (including inside the enclosure).

Hydrogen Safety

- Our approach to deal with this hazard is…
  - Purging and inerting requirements including an interlock to prevent start-up without a suitable purge
  - Containment: Pressure containing components meet ASME & ANSI B31 requirements
  - Class 1 Div 1 area classification per NFPA 497
  - Enclosure geometry and ventilation prevent accumulation of combustible gas mixtures

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