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Validation of an Integrated System for a Hydrogen-Fueled Power Park

Merit Review and Peer Evaluation
May 19, 2003
Berkeley, Ca

Phase I Program Goals

Central Question:

Is it Economically Feasible ($0.10/kWh) to Produce Power with a PEM Fuel Cell From Natural Gas?

Investigate:

Natural Gas and PEM Fuel Cells

Combined Heat and Power

Distribute Electrons or Protons?

Residential (multiple dwellings), Commercial, and Light Industrial (50 kW- 250 kW)

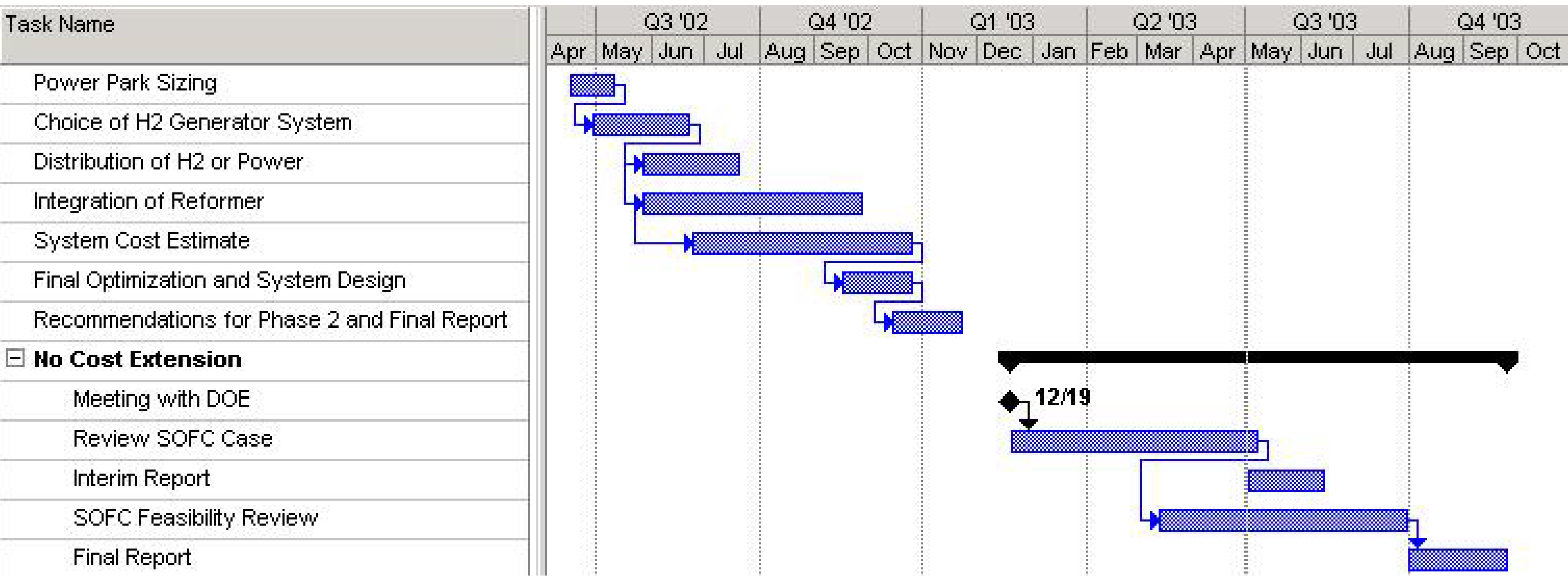
Tools and Techniques

- ASPEN PLUS process simulation
  - Efficiency
  - Waste heat availability
- Develop cost of operation models
  - Capital
  - Fuel costs
  - Installation
  - Operation
  - Maintenance
- Operating mode study (load-following or baseload)
- Today's costs
- Gap analysis

Base System

- 50-200 kW reformer system
  - 100 kW system chosen for base case
  - Steam Methane Reforming
  - Pressure swing adsorption
  - PEM fuel cells
- 3 buildings located 200 yards each from the central reformer with equal loads
- All waste heat can be utilized
- 3-5 kW commercially available PEM fuel cells (linearly scaled to system size)
- Penn State campus assumed for construction estimates

Timeline


Task Name
Q3 '02
Q4 '02
Q1 '03
Q2 '03
Q3 '03
Q4 '03
Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct
Power Park Sizing
Choice of H2 Generator System
Distribution of H2 or Power
Integration of Reformer
System Cost Estimate
Final Optimization and System Design
Recommendations for Phase 2 and Final Report
No Cost Extension
Meeting with DOE
12/19
Review SOFC Case
Interim Report
SOFC Feasibility Review
Final Report

Summary of Phase I

- **Findings**
  - **Natural Gas to Electricity using Distributed Reformer and PEM**
    - SMR with PSA Purification
      - Most efficient, 25-33% Overall Efficiency
      - Lower impurities, protect highest cost component
    - Cost is $0.45/kWh (Today) and $0.14/kWh (Future) – 10 year term
  - **Distribute Protons or Electrons?**
    - Electrons Lowest Cost – run electric wires vs. hydrogen pipe
    - Electrons ($50K), Protons ($100k)
  - **Combined Heat and Power Has the Potential to Lower Power Cost by ~$0.01/kWh**
    - CHP Requires Reformer and Fuel Cell Close to Heating Load
    - Large Local Reformer with Local PEM is The Most Viable Case (>250kW)
- **Conclusions**
  - **Small Reformer/PEM System has Low Potential for Distributed Power Generation with Natural Gas Feedstock**
  - **Potential Uses of PEM in Distributed Power Applications**
    - **Hydrogen Pipeline or Low Cost Hydrogen Offgas**
    - **Hybrid Energy Station**
      - Higher Efficiency & Capital Utilization
      - Potential For Cost Competitive Power Generation and Fueling
      - Peak (Electrical Generation), Off-peak (Hydrogen Generation)

Further findings

- Sizing
  - Ideal size would be greater than 800 kW
    - Obtain lower fuel costs (industrial rates)
    - Lower cost per kW for fuel cell and reformer (economies of scale)
- Amenable building types
  - Hospitals
  - Apartments
  - 24 hour store (Wal-Mart)
  - Prison
  - Dormitory
  - Warehouses with cooling requirements

Natural Gas to Electricity Efficiencies

Subsystem	Today	Future	FC Company 1 1-250 kW	FC Company 2 1-250 kW	FC Company 3 1-250 kW
Reformer + Purification	75%	80%	75%	76%	75%
Balance of Plant	90%	90%	100%	100%	90%
Anode Eff	100%	100%	85%	78%	100%
PEM	52%	62%	52%	52%	53%
Electrical Conversion	90%	90%	81%	92%	85%
Total Efficiency	31.59%	40.18%	26.85%	28.36%	30.41%
Total Cost	$14,000/kW	$3,300/kW			

	NG Recip >200kW	Micro turbine 30-500kW	Stirling 30-60kW	Small Turbine >500kW	CCGT >20MW
Efficiency	38%	27%	30%	35%	40%
Cost	$1,000/kW	$3,000/kW	$3,000/kW	$1,200/kW	$850/kW

Combined Heat and Power

- **CHP Requires Reformer and Fuel Cell Close to Heating Load**
  - Hot Water Distribution is Cost Prohibitive
  - Large Local Reformer with Local PEM is Most Viable Case
- **Integrated Heat Recovery (Minimal HVAC Tie-In Costs)**
  - Building HVAC System
    - Hot Water Boiler/Adsorptive Chiller System for HVAC
    - Constant Load - Year Round ~80% efficiency
  - Available Excess Heat is ~90% of the Electrical Output (kW)
  - 70% of Excess Heat can be Recovered
  - Savings Primarily from Fuel Reduction
- **Credit**
  - $0.013/kWh Commercial Utility Rates
  - $0.008/kWh Industrial Utility Rates

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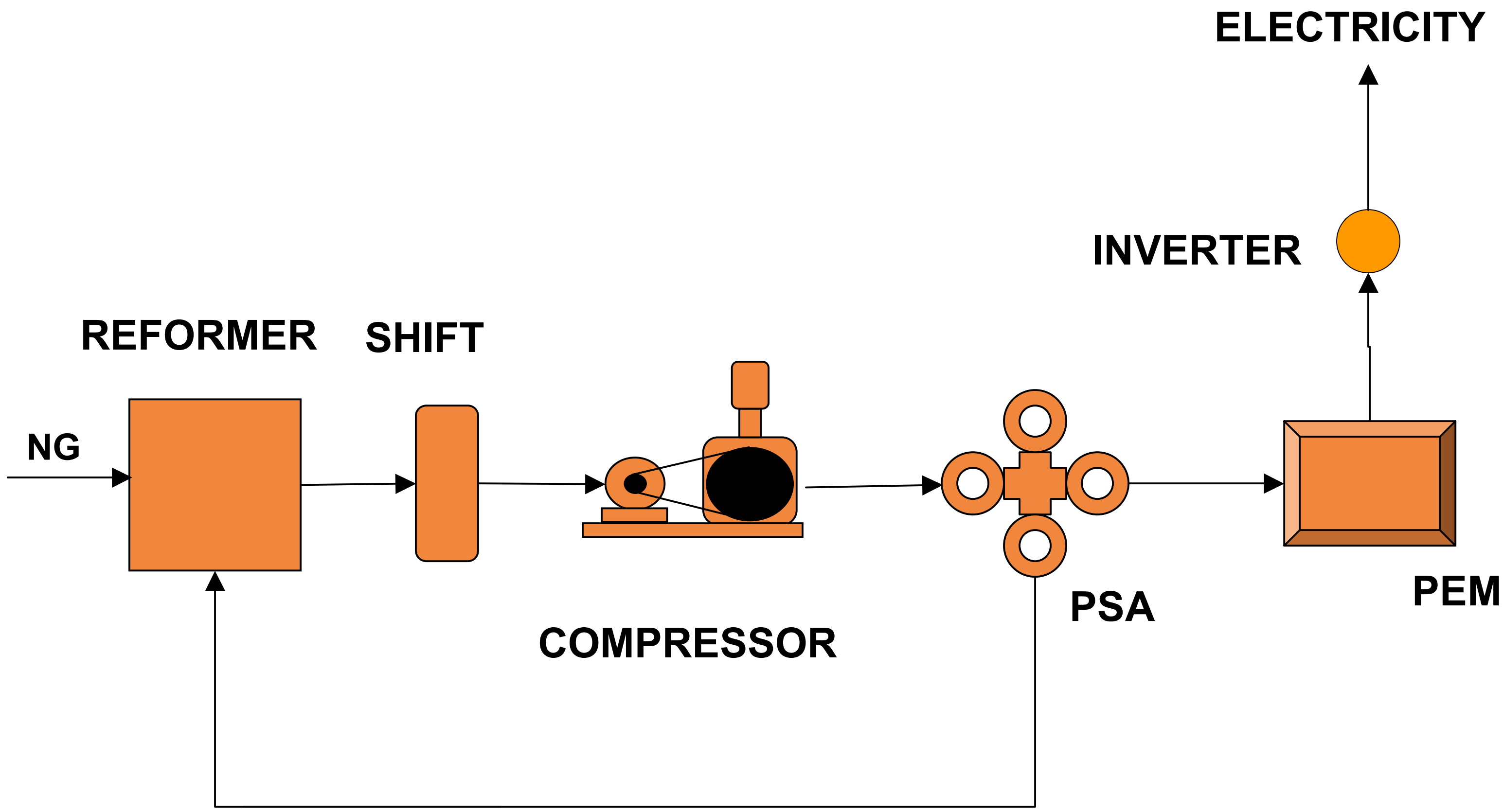
Integrated System



Overall Efficiency (LHV): 25-33%

Efficiency = Electricity/Natural Gas (LHV)

Modeling Assumptions

- **Non-Load Following, Baseload System (95% Utilization)**
- **After Tax Return: 10% (DCF basis)**
- **Overhead: 20% of capital**
- **Insurance and Property Taxes: 2.5% of capital**
- **Taxes: 35% Federal, 3% State and Local**
- **Inflation: 2.5%**
- **Book and Economic Life: 10 Years**
- **Capital, Utilities, and Maintenance: per vendor quotation**
- **Utilities (10 year avg commercial rate - 2000 dollars)**
  - Natural Gas $5.65/MMBTU (HHV)
  - Electricity $0.0822/kWh

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Effect of Technology Advancement on Cost of Power

Cost of Power	**Today** **$14,000/kW**	**Future*** **$3,300/kW**
Capital Recovery	$0.349	$0.083
Ops and Maintenance	$0.008	$0.008
Fuel and Power	$0.093	$0.075
Total Cost	**$ 0.45**	**$ 0.17**

***10,000 units/year and 40%Efficiency**

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Similar Findings

- **DTI - Cost Analysis of Stationary Fuel Cell Systems Including Hydrogen Co-Generation-1999**
  – $0.44/kWh @ 36% efficiency@ 20% part load
  – $7,011/kW at 100 units production
  – $3,230/kW at 10,000 units production

- **Idatech – 2002 AICHE Spring Session**
  – >$0.36/kWh @ 30.4% efficiency
  – >$10,000/kW Cost

Modeling Cost Sensitivities

Base Price $0.67/kWh

Variable	Basis	Sensitivities	Cost Adjustment	Future Cost
Natural Gas Price	$5.65/MMBTU	$3.37/MMBTU	-$0.032	$0.64
Life	5 Year	10 Year	-$0.221	$0.42
		15 Year	-$0.290	
Reformer Cost	$11,000/kW	$6,000/kW	-$0.124	
		$4000/kW	-$0.174	
		$2,800/kW	-$0.204	$0.22
Fuel Cell Cost	$3,000/kW	$1,000/kW	-$0.050	
		$500/kW	-$0.062	$0.16
		$200/kW	-$0.069	
		$50/kW	-$0.073	
Efficiency	33%	40%	-$0.021	$0.14

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What's Needed To Achieve The Goal of Competitive Power ($0.10/kWh)?

- **25% Increase in Overall Efficiency**

AND

- **4000% Increase in Fuel Cell Life**
  - 3,000 hr Guarantee Today
  - Fifteen Year Term

AND

- **500% Increase In Power Output**
  - Near Term 150kW
  - Larger Systems (>800kW for Industrial Gas Rates)
  - Natural gas utilities will not typically combine smaller accounts to achieve higher volume lower cost gas. Many of the costs incurred are based on distribution, metering, etc.

AND

- **95% Reduction in Cost of PEM Fuel Cell and 75% Reduction in Cost of Reformer System**
  - Mass Production (>10,000 units/year)
  - Must be driven by : Government Credits, Rebates, Military, Government Buildings, Emissions Legislation, Automobiles, Buses, or other Transportation

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Does PEM Have A Place in Distributed Generation?

- **Low Cost Existing Hydrogen Source**
  - Pipeline
  - Offgas Hydrogen

- **Energy Station**
  - Reformer/Dispenser/PEM
  - Other

Conclusions and Recommendations

- **Small Reformer/PEM System**
  - Low Potential for Distributed Power Generation with Natural Gas Feedstock
  - Intangible Benefits
    - Low Noise & Emissions
    - Solid State
    - Utility infrastructure reduction
  - Don’t Recommend a Phase II Demonstration
- **Pipeline/Offgas PEM System**
  - Economic in Limited Geographic Region
  - Potential H_2 Pipeline Demonstration
- **Hybrids**
  - Distributed Generation
  - Energy Station
  - Recommended further Phase I Review

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Collaboration

- Reformer Vendors
  - Various Vendors
  - Provided heat and material balance information and cost information
- Purification System Vendors
  - Various Vendors
  - Provided recovery, operating reqts, and cost
- Fuel Cell Vendors
  - Various Vendors
  - Provided efficiency, life, and cost information
- University
  - Penn State, Dr. Wang
  - Princeton, Dr. Ogden and Dr. Kreutz
- LBNL – Joe Huang (building load profiles)

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www.airproducts.com