Power Parks System Simulation

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Objectives and Relevance

Objective

- Develop a flexible system model to simulate distributed power generation in power parks that use H_2 as an energy carrier

Power parks combine power generation co-located with a business, an industrial energy user, or a domestic village

- H2 generators -- reformers, electrolyzers
- H2 storage -- high-pressure vessels, hydrides,
- Electricity generation -- fuel cells, H2-engine, micro-turbine
- Renewable sources -- Photovoltaic, wind turbine, biomass gasification
- Vehicle refueling

Deliverable

- Tool to construct simulations of H_2 systems, including power parks, to analyze performance (thermodynamic efficiency and cost)

Method of Approach, Milestones

Software Design

Use Simulink software as platform for transient simulations

- Simulink provides:
  - Graphical workspace for block diagram construction
  - ODE solvers for integration of system in time (not quasi-steady approximation)
  - Quick-look output from simulation
  - Control strategies and iterative loop solutions

Create a library of Simulink modules to represent components

- Component models based on fundamental physics to the extent practical
- Example:
  - Coupled Chemkin software routines as Simulink functions
  - Thermodynamic properties of gas mixtures used in energy balances
  - Equilibrium composition used for catalytic reforming and combustion burners
- Library components can be quickly re-configured for new system concepts
- Generic components from library can be customized using data on the performance of specific unit

Method of Approach, Milestones

Project Plan for FY03:

		FY2003				FY2004			
Item	Task	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4
1.	Develop additional modules for power park components.	*	*	*	*	*	♦		
2.	Configure systems to model existing power park sites			*	*	*	*	♦	
3.	Evaluate system performance of the power park.			*	*	*	*	*	♦
4.	Implement a control algorithm to optimize power park.					*	*	*	♦

* Continuous development
♦ Milestone for completion

Simulink library modules, *Progress*

Library of Simulink modules includes:

- Reformers: steam methane and autothermal (partial oxidation)
- Fuel cell system
- Compressor (mechanical)
- High-pressure storage vessel
- Electrolyzer
- Photovoltaic Solar Collector

Module descriptions:

- Steam-methane reformer (SMR)
  - Reformer T determined by balance of heat transfer from combustion of reformate stream after H_2 separation
  - SMR module uses several sub-modules that call Chemkin
- Fuel cell system
  - Module uses H_2 flow rate and requested electric power
  - Sub-module uses data table for efficiency-power relation

Simulink library modules, *Progress*

Module descriptions (con't):

- Compressor
  - Raises pressure of H_2 to fill storage vessel
  - Computes power required for ideal multi-stage compression
- High-pressure storage vessel
  - Accepts H_2 flow rate and integrates H_2 stored
  - Computes pressure using Sandia's real-gas equation-of-state for H_2
- Photovoltaic Solar Collector
  - Model for average solar radiation
    - Flux is analytic function of longitude, latitude, altitude, and time
  - PV module uses a solar-electric conversion efficiency
    - Function of panel area and slope or tracking capability
    - Can be adjusted to match a specific collector design
- Electrolyzer
  - Convert electric power into flow of H_2 using efficiency
    - Initial model specifies efficiency consistent with SunLine data

Simulation of power systems, *Progress*

PV system simulates H_2 production at SunLine Transit

- Solar radiation modeled over calendar year
- PV arrays produce power to run electrolyzers
- H2 stored for vehicle refueling

Power system modeled after City of Las Vegas refueling facility

- SMR operates at steady state – sized to supply fuel cell and vehicles
- Fuel cell stack uses H_2 to generate power to utility grid
- H_2 is compressed and stored in high-pressure vessel for vehicles
- Vehicle usage model depletes storage tanks

Transient simulation evaluates:

- Local efficiencies of individual components
- System thermal efficiency includes
  - H2 generated (and stored for use by vehicles or fuel cell)
  - Electric power from fuel cell (or other power conversion devices)
  - Compressor power required to store H_2

Simulink provides:

- Solution variables displayed numerically & graphically
- Numerical output stored in Matlab vectors for post-processing

Proposed Future Work and Milestones

Task 1

Continue to add and refine components to Simulink library

- Battery, H2 storage as liquid or metal hydride, wind turbines

Task 2

Collaborate with researchers at existing power parks

- SunLine Transit, City of Las Vegas, and other DOE sites

Task 3

Perform long-term studies of distributed H_2 production

- Include economics of generating H_2 and power
- Expand existing analysis to examine thermodynamic *availability*

Task 4

Implement a control system to optimize performance

- Direct power flow and size components to minimize H_2 cost

Cooperative Efforts

Collaborations:

- U C Berkeley – Energy and Resources Group (ERG) – Tim Lipman, Carl Mas
  - economic analysis of H_2 systems
- SunLine Transit Agency – Using data for PV energy and electrolyzer performance
- City of Las Vegas Refueling Station – Will use data from reformer and fuel cell
- University of Alaska, Fairbanks -- Dennis Witmer (Remote Area Power Program)

Publications:

- Lutz, A E, Bradshaw, R W, Keller, J O, and Witmer, D E, "Thermodynamic Analysis of Hydrogen Production by Steam Reforming," *Int J of Hyd Engy*, 28 (2003) 159-167.
- Lutz, A E, Bradshaw, R W, Bromberg, L and Rabinovich, A, "Thermodynamic Analysis of Hydrogen Production by Partial Oxidation Reforming," submitted to *Int J of Hyd Engy*, 2003.
- Lutz, A E, Larson, R S, and Keller, J O, "Thermodynamic Comparison of Fuel Cells to the Carnot Cycle," *Int J of Hyd Engy*, 27 (2002) 1103-1111.

Response to FY 2002 review

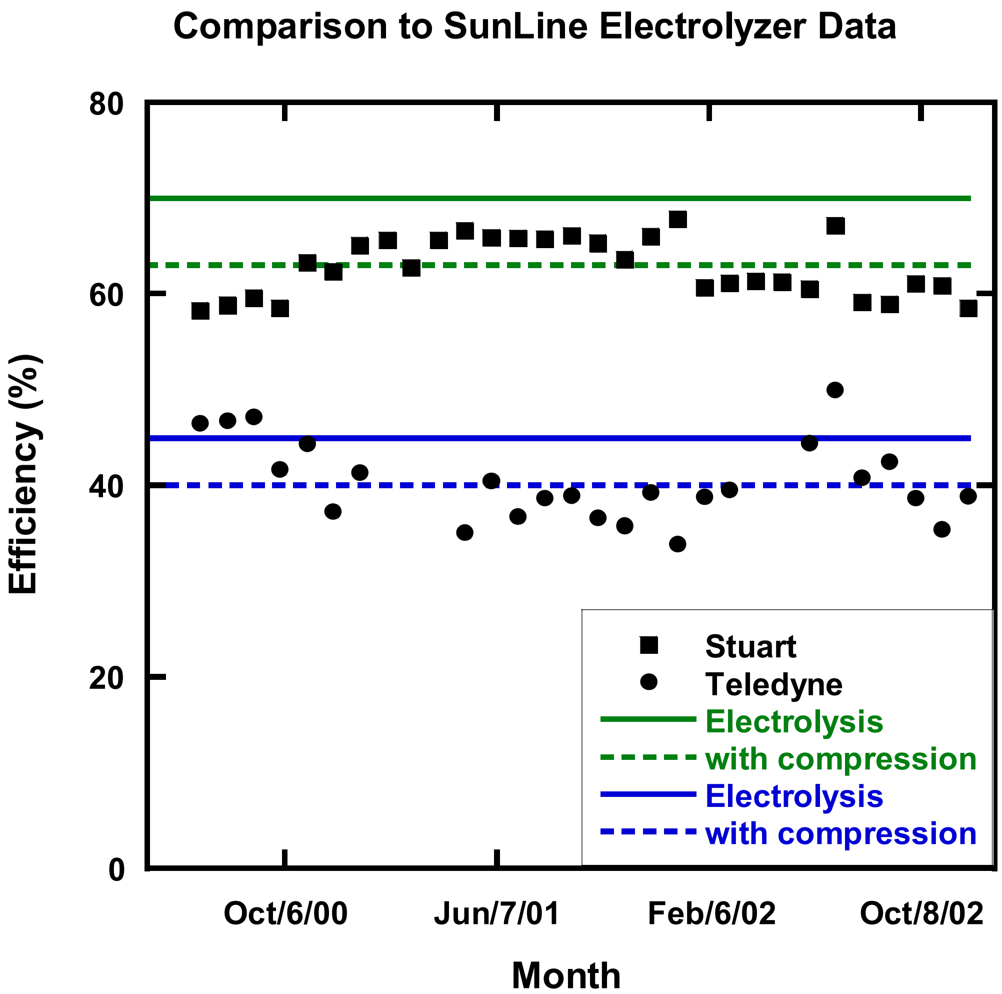
- **FY2002 Ranking**
  - **Project ranked tied for 5th place in category with score 91/100** **(Storage, Utilization, Safety, Analysis and Technology Transfer)**
- **Reviewer's suggestion:**

"We encourage further collaborations and modeling of actual power park sites such as Las Vegas, SunLine, etc."

- **Collaborations with power park sites:**

1. **Established collaboration with SunLine transit**
   - **Using performance data on electrolyzers and PV collectors**
   - **Model comparison appears on following slides**
2. **Continuing to participate on teleconferences with City of Las Vegas, Air Products, Plug Power, and DOE to follow progress**
   - **Attended opening of facility in November**
   - **Will use reformer and fuel cell performance data when it becomes available**

Electrolyzer Simulation



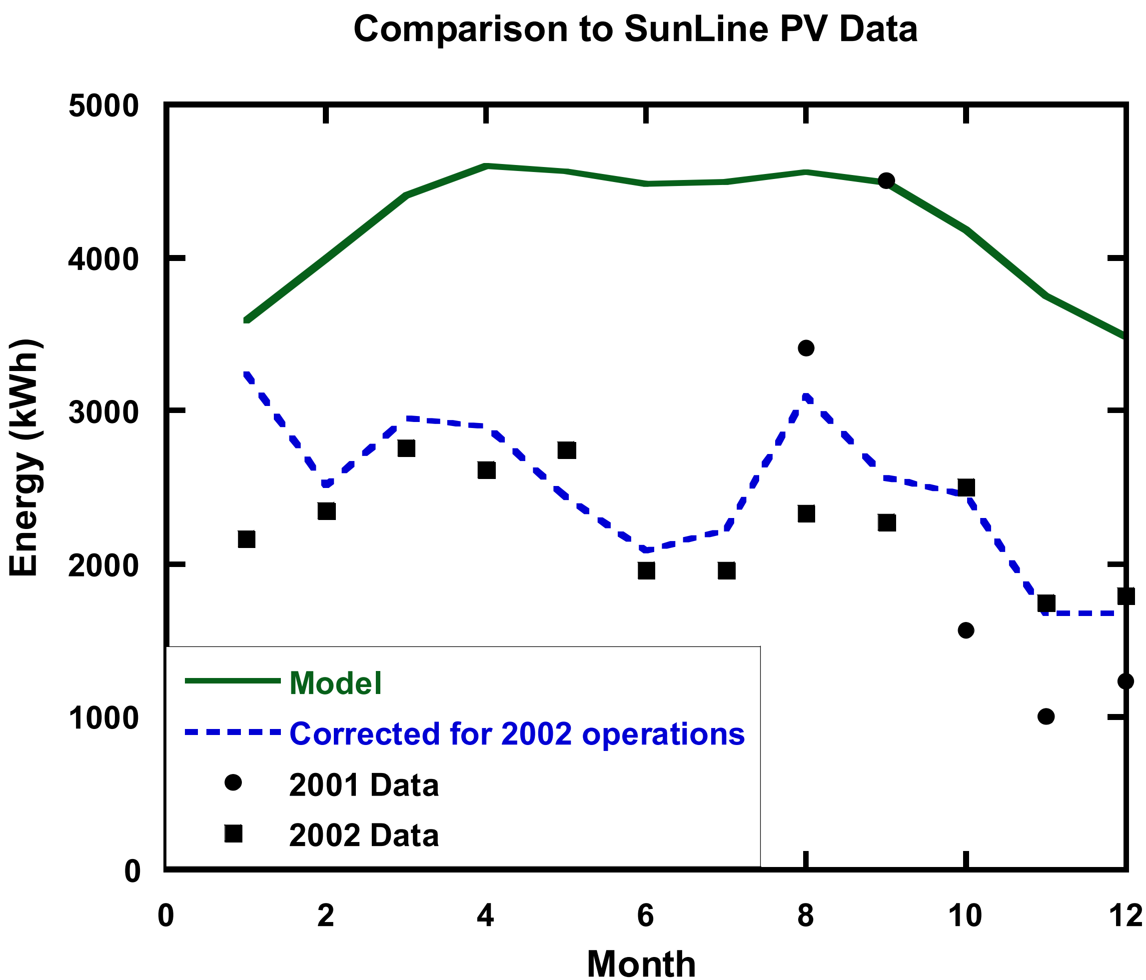
Model comparison

- Electrolyzer + compressor to compare with SunLine data
- Estimate efficiency of electrolysis step to match average H_2 delivery efficiency

SunLine electrolyzers:

- Stuart Energy (Phase 3 unit)
  - Low-p cell output (1 psig)
  - Compression: 4-stages at 50% efficiency to 5000 psi
- Teledyne Energy Systems
  - High-p cell output (100 psig)
  - Higher purity H_2 supply
  - Compression: 2 stages at 20% efficiency to 3600 psi

Photovoltaic collector simulation



- **Model simulation**
  - Run yearly variation
  - Integrate daily collection
  - Sum monthly to compare to SunLine data
- **Solar radiation model**
  - Analytic function of longitude, latitude, altitude
- **PV panel model**
  - Area = 360 m^2, slope 23°
  - Adjust solar-electric conversion efficiency = 7 %
- **Correct monthly sums to SunLine's operations**
  - Operating days / month
  - Sunny days / month

Vehicle H_2 consumption survey

Vehicle	Storage Mode	Internal Volume (l)	H_2 (kg)	Mileage (mpgge)	Range (miles)
Ford Model U	**10,000 psi**	180	**7**	**45**	**300**
Ford P2000 – ICE	**3600 psi**	**87**	**1.5**	**31.4/46.7**	70
BMW 750hL – ICE	**Liquid**	**140**	9.9	22	**218**
Ford Focus FCV	**5000 psi**	**186**	4.3	47	**200**
Toyota FCHV	**3600 psi**	**136**	**3.2**	57	**182**
Honda FCX	**5000 psi**	**157**	**3.8**	45/58	**170/220**
Chrysler Natrium	**$NaBH_4$**	**200**	10	**30**	**300**
GM HydroGen3	**Liquid**	**68**	**4.5**	55	**250**
GM HydroGen3	**10,000 psi**	86	**3.1**	55	**170**
GM Hy-wire	**5000 psi**	88	**2**	40	**80**

- Data collected from journals, press releases, and private communication
- Bold font indicates data that is specified, other values are computed
- Gaseous storage values computed using Sandia's real-gas equation-of-state
- External volume of container depends on storage mode and design