

Hawaii Hydrogen Center for Development and Deployment of Distributed Energy Systems

Richard Rocheleau

Hawaii Natural Energy Institute

School of Ocean & Earth Science & Technology

University of Hawaii at Manoa

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*This presentation does not contain any
proprietary or confidential information*

TVP 1



Overview

Project comprised of 3 stand-alone tasks coordinated under one project.

Timeline

- Start - October 2004
- Finish - December 2006
- 75% Complete

Budget

- Total project funding
 - DOE \$4.1 million
 - Cost share \$1.2 million
- Funding received in FY04
 - \$3.1 million
- Funding received in FY05
 - \$1 million

Barriers

- See next slide

Cost Share Partners

- HI Dept. of Business, Economic Development & Tourism
- City and County of Honolulu
- HELCO/HECO
- The Gas Company
- AirGas
- ClearFuels Technology
- New Mexico Tech
- Hawaiian Commercial & Sugar Co.
- Center for a Sustainable Future
- PICHTR

Other Partners

- Sandia National Laboratory
- Sentech



Barriers

Task 1: Hawaii Hydrogen Power Park

- B, C, E, H, I: Hydrogen infrastructure technology validation
- G, H: Hydrogen safety

Task 2: Hydrogen Fuel Quality Assessment

- A, C: MEA materials and components – durability and performance

Task 3: Renewable Hydrogen Production: Biomass

- W: Cost reduction of biomass gasification
- W: Gasifier product gas cleanup
- W: Basic research on advanced hydrogen purification



Objectives

Task 1: Hawaii Hydrogen Power Park

Develop and operate a test bed to validate and characterize hydrogen technologies in a real world setting

- Integrate a renewable energy source with an electrolyzer, hydrogen storage, and fuel cell to power a building
- Collect performance and cost data
- Conduct outreach to local authorities and the general public

Task 2: Hydrogen Fuel Quality Assessment

Characterize the effect of trace level contaminants on the performance and durability of PEM fuel cells

- Collect pre-commercial data for development of fuel quality guidelines
- Develop mechanistic understanding of degradation due to contaminants

Task 3: Renewable Hydrogen Production: Biomass

Investigate critical steps for H₂ production from biomass

- Evaluate H₂ yield potential of Pearson Technologies' gasification process
- Develop skid-mounted test system for tar reforming and H₂ purification
- Characterize feedstock/feedstock preparation for gasification



Approach

Task 1: Hawaii Hydrogen Power Park

- Leverage infrastructure at Hawaii Fuel Cell Test Facility to evaluate component performance: Stuart electrolyzer, high pressure hydrogen storage system, and 5kW Plug Power fuel cell
- Establish a wind-electrolysis and fuel cell test bed at Kahua Ranch on the Big Island
- Work with SNL modeling group for economic and engineering analysis (TV-2)
- Establish a biofuels-to-hydrogen test bed at HGEC

Task 2: Hydrogen Fuel Quality Assessment

- Leverage DOD investment in Hawaii Fuel Cell Test Facility: test stands and infrastructure
- Work in close collaboration with industry, SAE, USFCC, and DOE working groups to identify critical impurities and test protocols
- Use non-proprietary MEAs to allow post-test analysis



Approach

Task 3: Renewable Hydrogen Production: Biomass

- Leverage multi-million dollar investment by ClearFuels LLC in biomass gasification to ethanol process to assess direct hydrogen production feasibility
- Conduct parametric gasification tests using Pearson Technologies' pilot plant in Aberdeen, Mississippi
- Develop skid-mounted, producer-gas clean-up test bed to include tar reforming and H₂ purification unit operations to allow use with other biomass facilities in Hawaii to evaluate H₂ yield potential and assess remaining issues



Technical Accomplishments/Progress/Results

Task 1: Hawaii Hydrogen Power Park

Component Evaluation

- Electrolyzer characterized at steady state at several power levels
- Fuel cell characterized throughout operating range
- Data collected and analyzed by HNEI and Sandia National Lab (see SNL presentation TV-2)

Kahua Ranch - Wind-Hydrogen-Fuel Cell Test Bed

- System and infrastructure design completed, installation underway
- 10 kW Bergey wind turbine being modified to produce 48 VDC output
- 48V Industrial lead acid battery system donated as wind energy absorber
- Load-following, pressurized PEM electrolyzer (175 psi minimum) ordered from EH Inc.

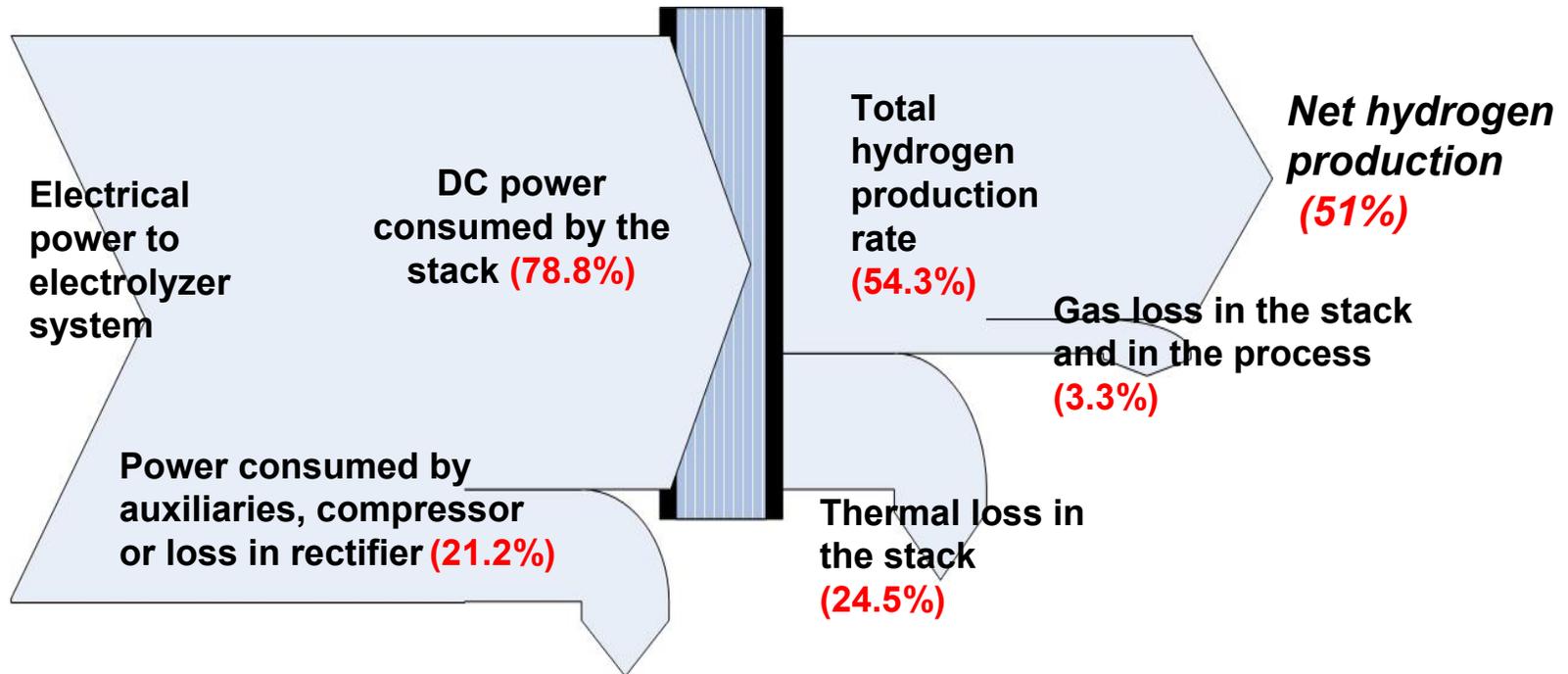
Hawaii Gateway Energy Center (HGEC) - Biofuels to H₂ Test Bed

- Facility Rental Agreement negotiated with NELHA for use of HGEC



Electrolyzer Energy Balance

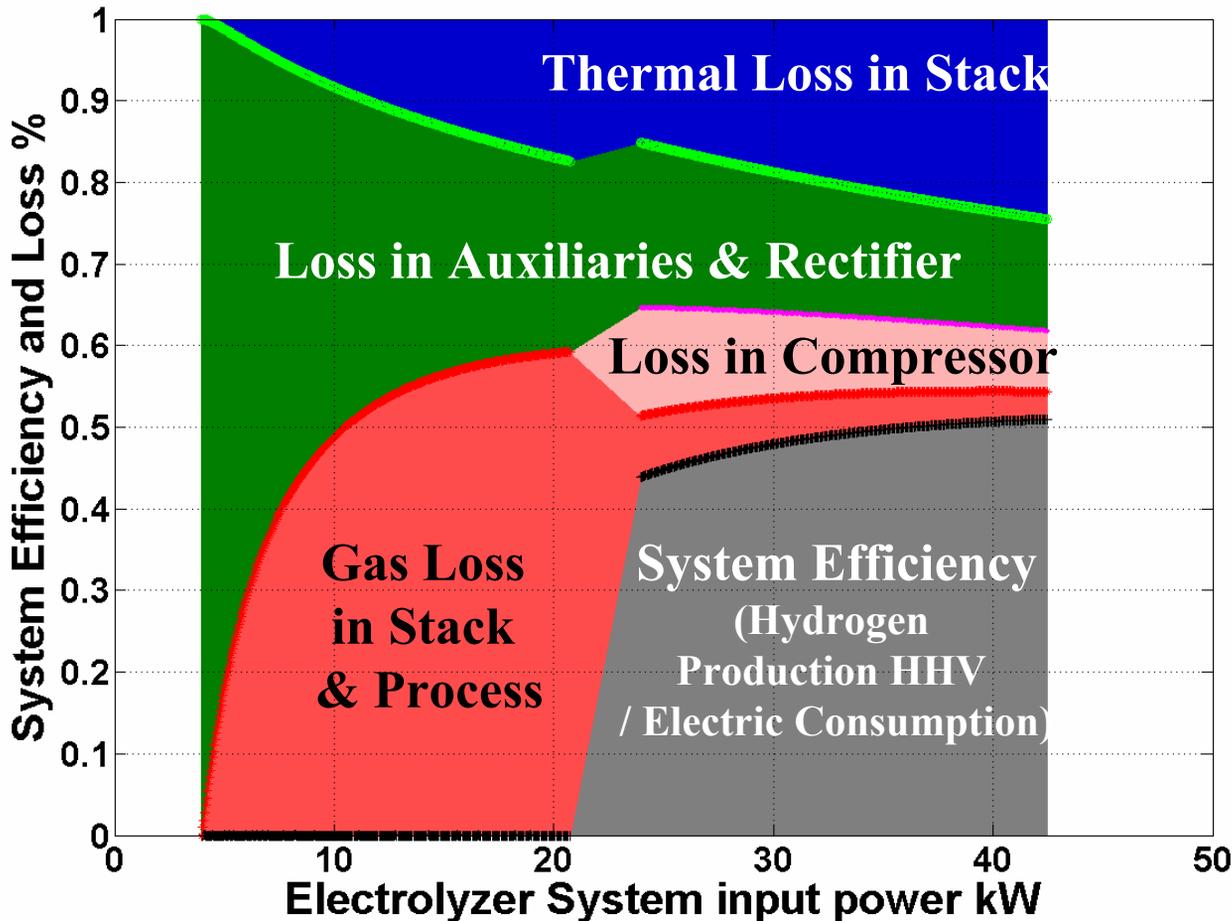
Efficiencies at steady state operation at maximum input power (42 kW_{electric})
Stuart Energy, Model TTR 225, alkaline technology, rated output 225 SCFH



- All H₂ efficiencies based on higher heating value (HHV)
- Efficiencies and losses relative to input AC power
- Net H₂ production - 7kWh/Nm³
- Auxiliary losses include compression to 3000 psi
- Gas loss and auxiliary consumption critical for improved performance



Electrolyzer Efficiency as Function of Input Power

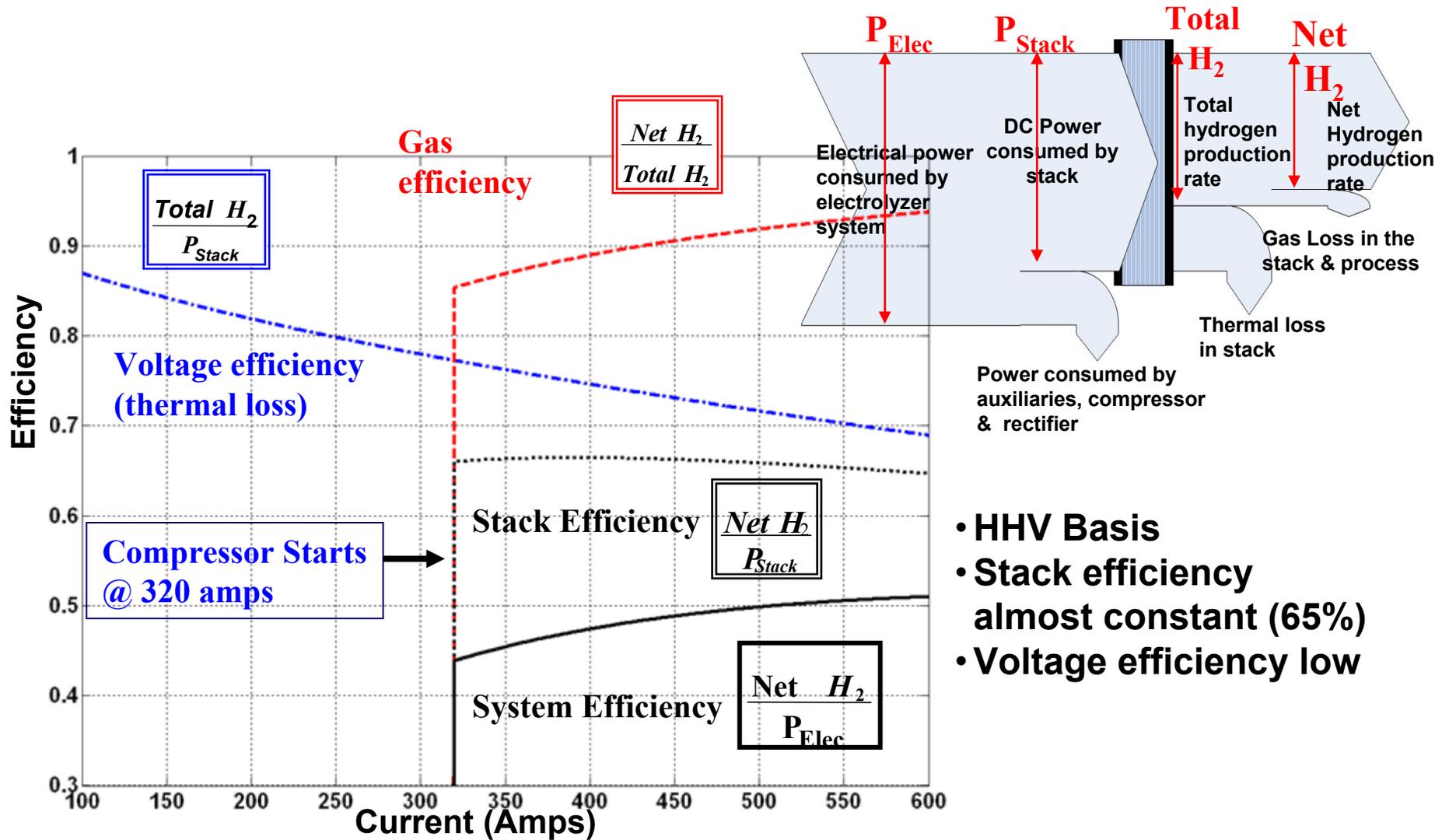


- **Steady State operation**
- **HHV basis**
- **Efficiency and loss percentage compared to input power: P_{elec}**

- **Efficiency increases with input power**
- **No hydrogen production (no compression) up to half power**



Characterization of Electrolyzer Stack

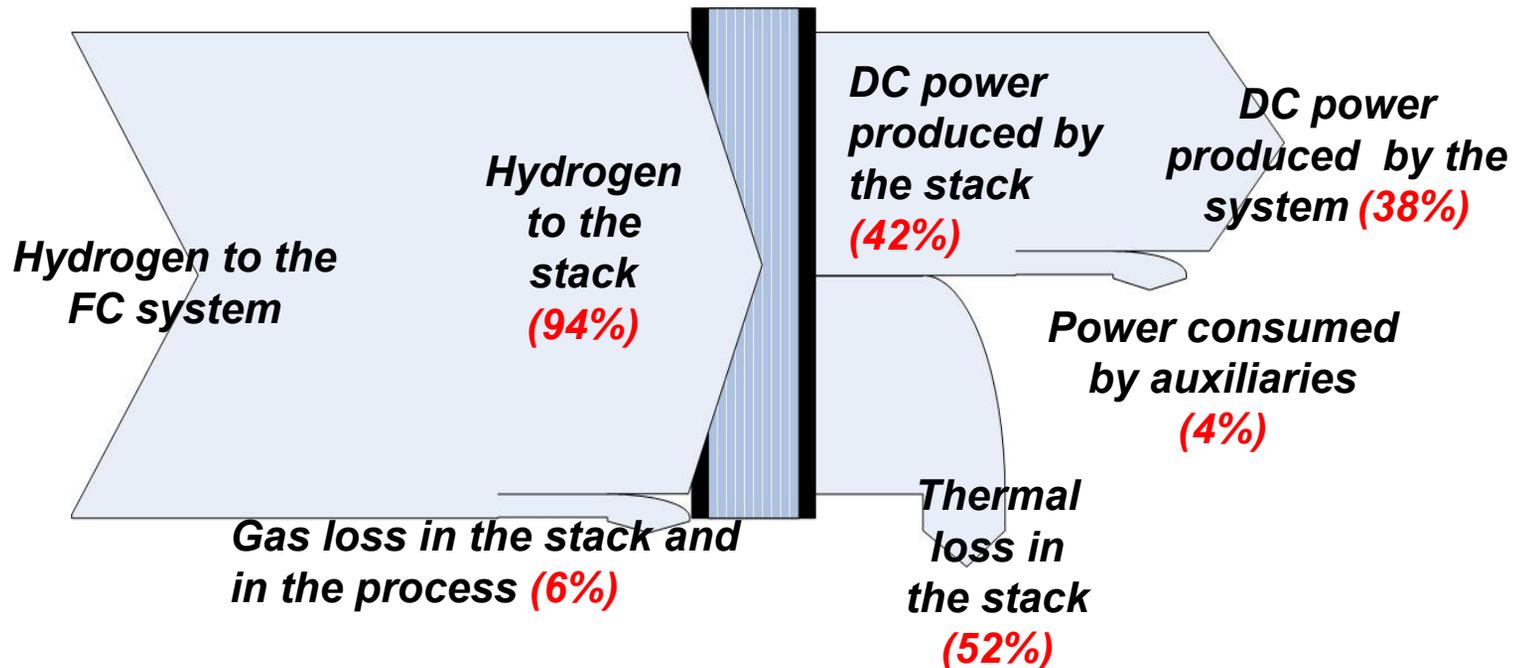


- HHV Basis
- Stack efficiency almost constant (65%)
- Voltage efficiency low



Fuel Cell Energy Balance

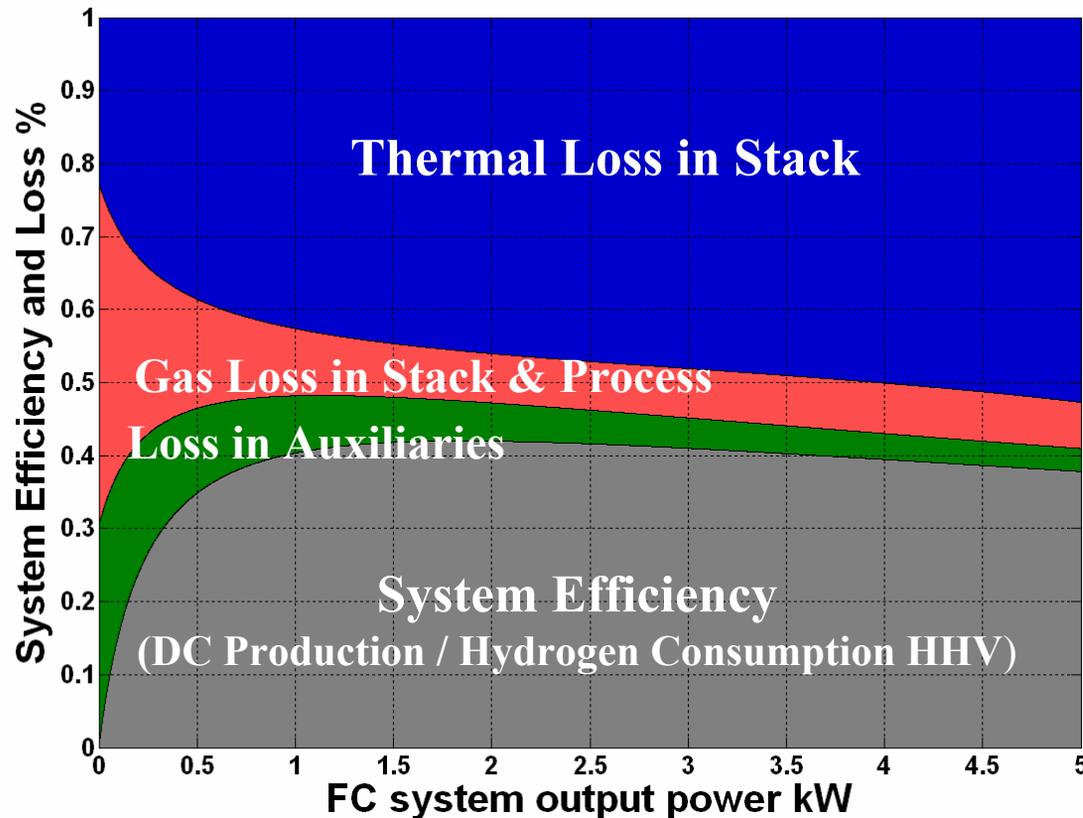
Efficiencies at steady state operation at maximum power ($5 \text{ kW}_{\text{electric}}$)
Plug Power Gencore, PEM technology, Pure hydrogen, 75SLM, 80 psi



- All H₂ efficiencies based on higher heating value (HHV)
- Efficiencies and losses relative to input hydrogen
- Net power production – 1.35 kWh/Nm³
- Need to improve stack performance to overcome stack losses.



Fuel Cell System Losses as Function of Output Power

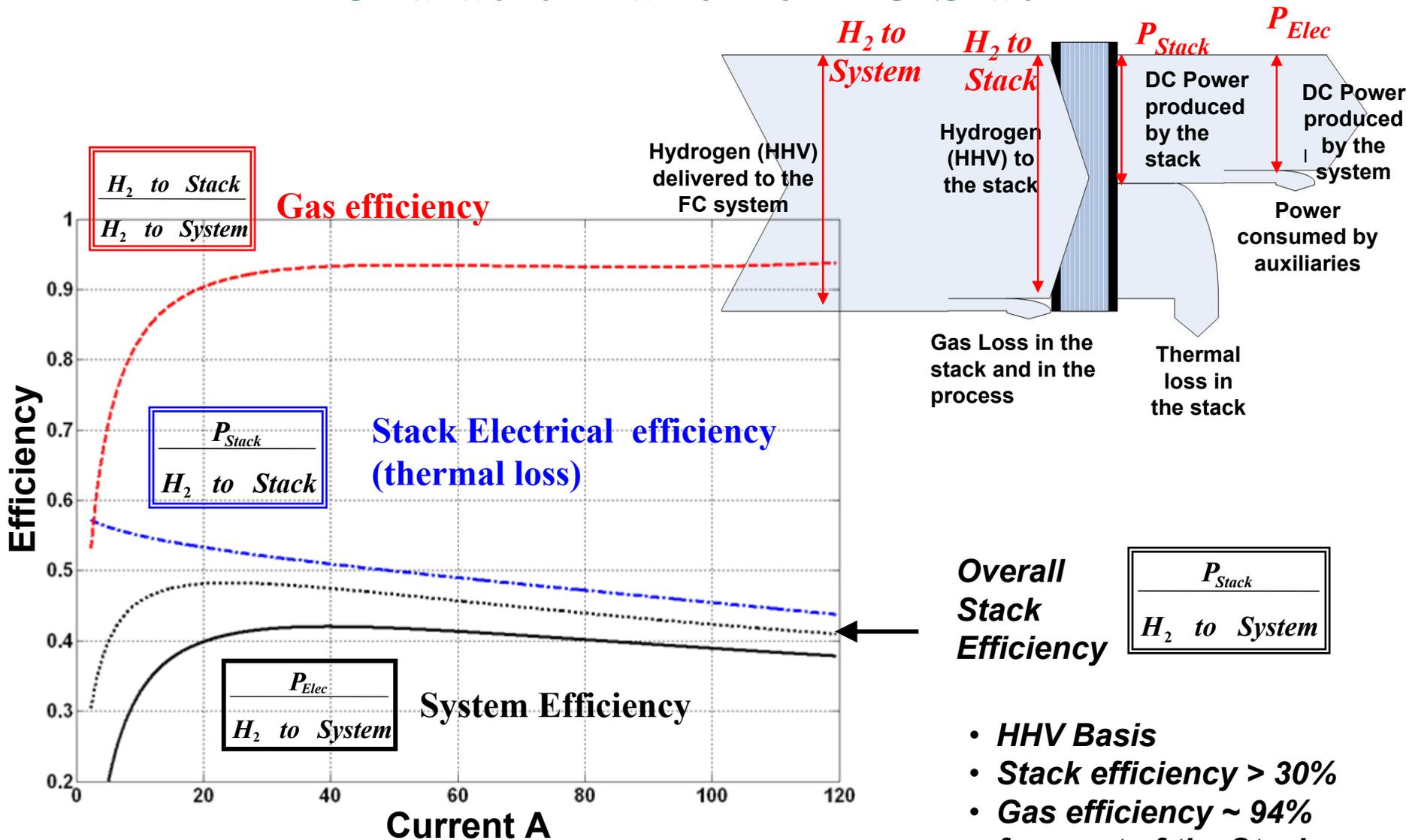


- Steady state operation
- HHV basis
- Efficiency and loss percentage compared to input power: P_{H_2}

- Good performance
- Low system losses (gas & auxiliaries)
- Lowest consumption
1.35kWh/Nm³ around 2kW
- Efficiency (HHV) > 35% from 10% to 100% of the system capacity



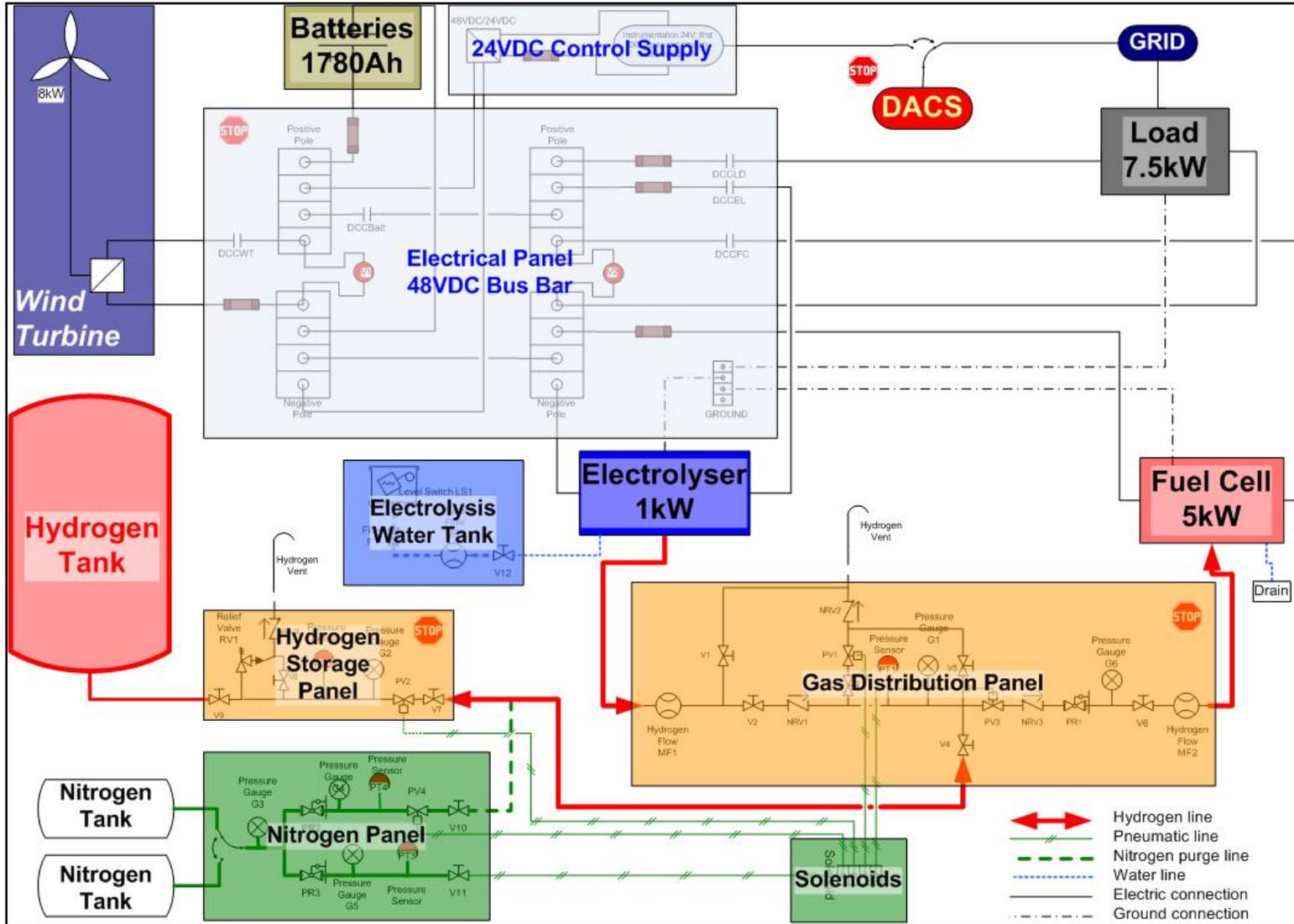
Characterization of FC Stack



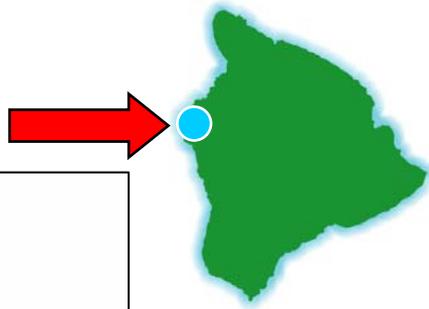
- **HHV Basis**
- **Stack efficiency > 30%**
- **Gas efficiency ~ 94% for most of the Stack current**



Wind-Hydrogen System Design



Hawaii Gateway Energy Center (HGEC)



HNEI Space



Seminar & Office Space



PV Array



Lab Building



Technical Accomplishments/Progress/Results

Task 2: Hydrogen Fuel Quality Assessment

Hawaii Fuel Cell Test Facility



Greenlight Power FCATS G50
Test Stations for Fuel Quality
Assessment

- Five test stands installed and instrumented for fuel quality testing (DOD funded)
- Equipment calibrated to ISO 17025 standards
- GC-based gas analyzer upgraded for improved sensitivity:
 - CO (100 ppb) - Pulse discharge ionization det
 - CO² (1 ppm) - Flame ionization det
 - Hydrocarbons (1 ppm) - Flame ionization det
 - S (50 ppb) - Pulsed flame photometric det
 - NH₃ (100 ppb planned) - Pulse discharge ionization det
- Test protocols developed in collaboration with USFCC, DOE, industry
- Test hardware from GM, Ballard Power Systems and UTC Fuel Cell on site



Technical Accomplishments/Progress/Results

Task 2: Hydrogen Fuel Quality Assessment

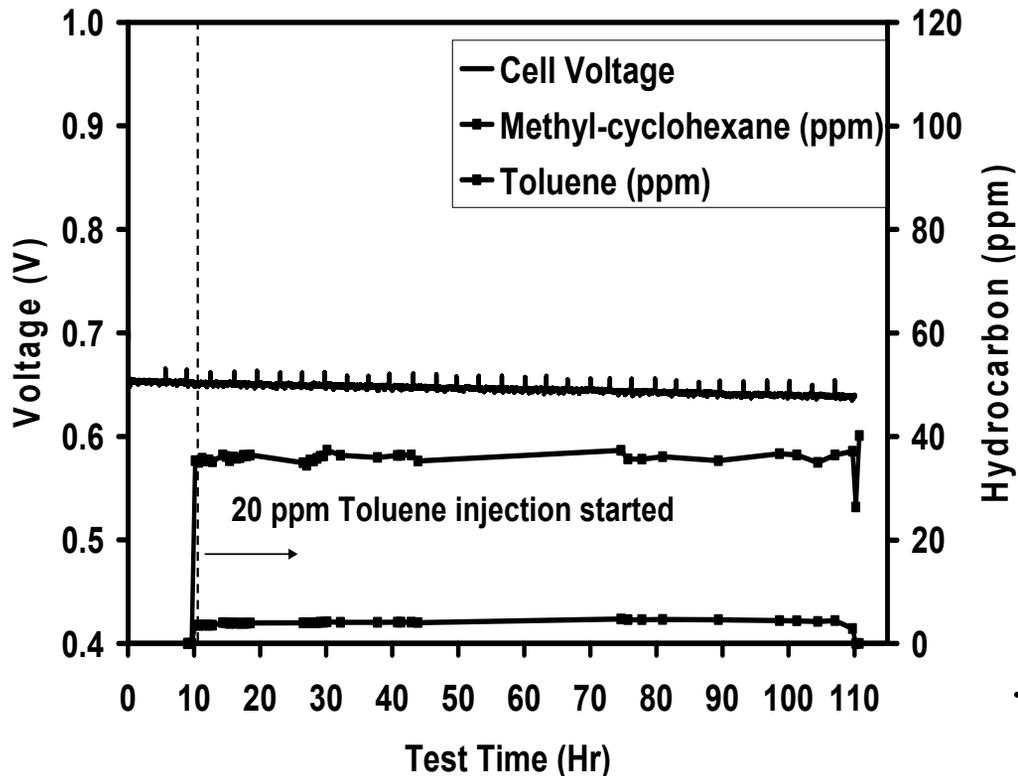
- **Benzene** - No measurable fuel cell degradation with up to 60 ppm over at 80°C and 1 A/cm²
- **Toluene** - No measurable fuel cell degradation with up to 60 ppm at 80°C and up to 40 ppm at 60°C and 1 A/cm² (higher values not tested)
 - Significant toluene hydrogenation observed at both temperatures
- **Carbon Monoxide** – Reversible degradation observed under at all operating conditions

Temperature (°C)	CO Concentration (ppm)	Decay (mV)
80	20	393
80	7	197
80	1	15
70	1	32
60	1	185

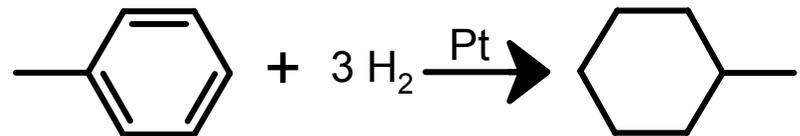


Fuels Purity Sample Data

Effect of 20 ppm Toluene at 1 A/cm²



- Average 100 hrs decay rate of 0.12 mV/hr within baseline
- 4 ~ 5 ppm toluene and 35~36 ppm methyl-cyclohexane in exit
- Toluene hydrogenation occurs, no evidence of carbon deposition on catalyst

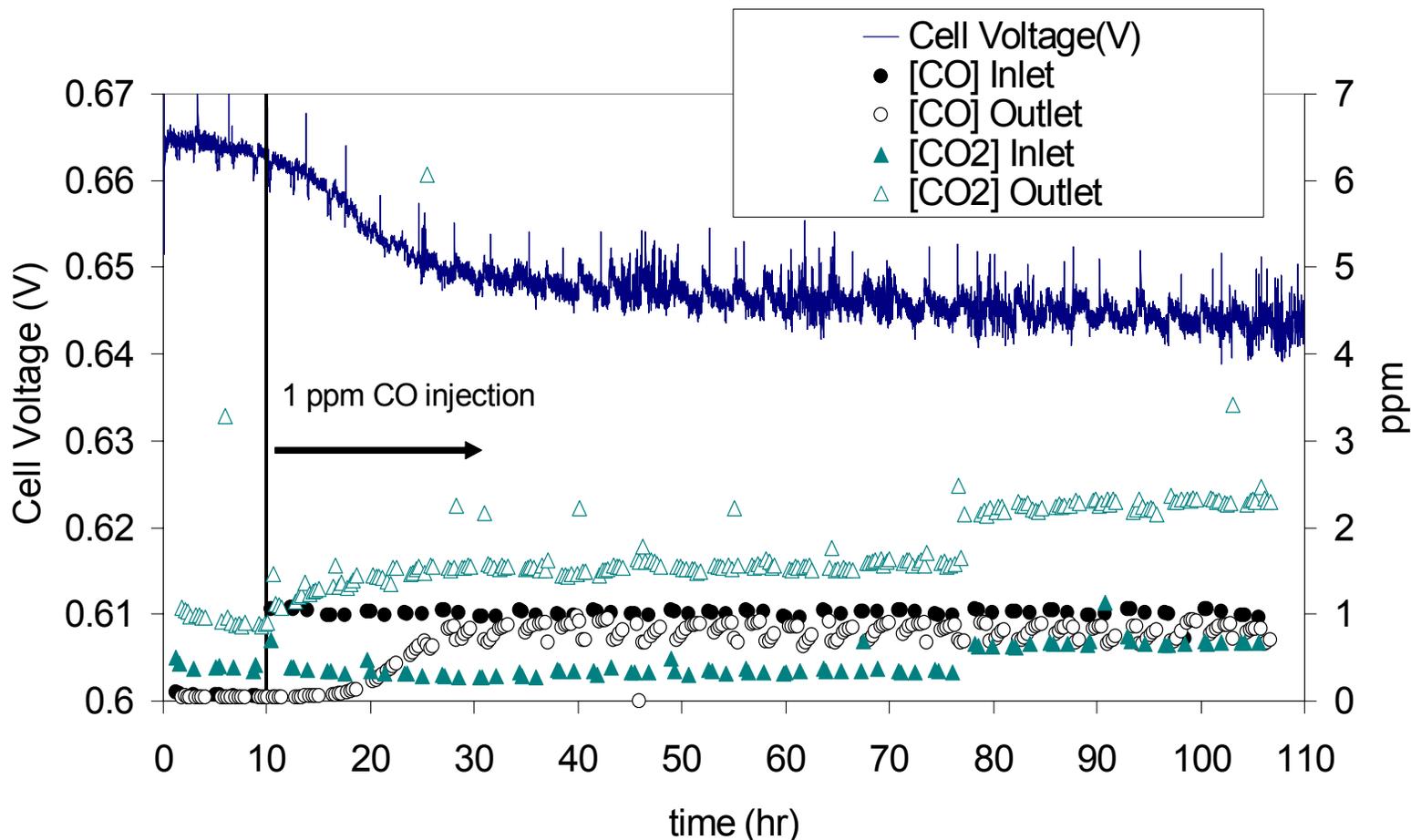


Toluene injected at concentration level 70x max limit proposed in SAE J2719



Fuels Purity Sample Data

Performance loss with 1ppm CO at 80°C

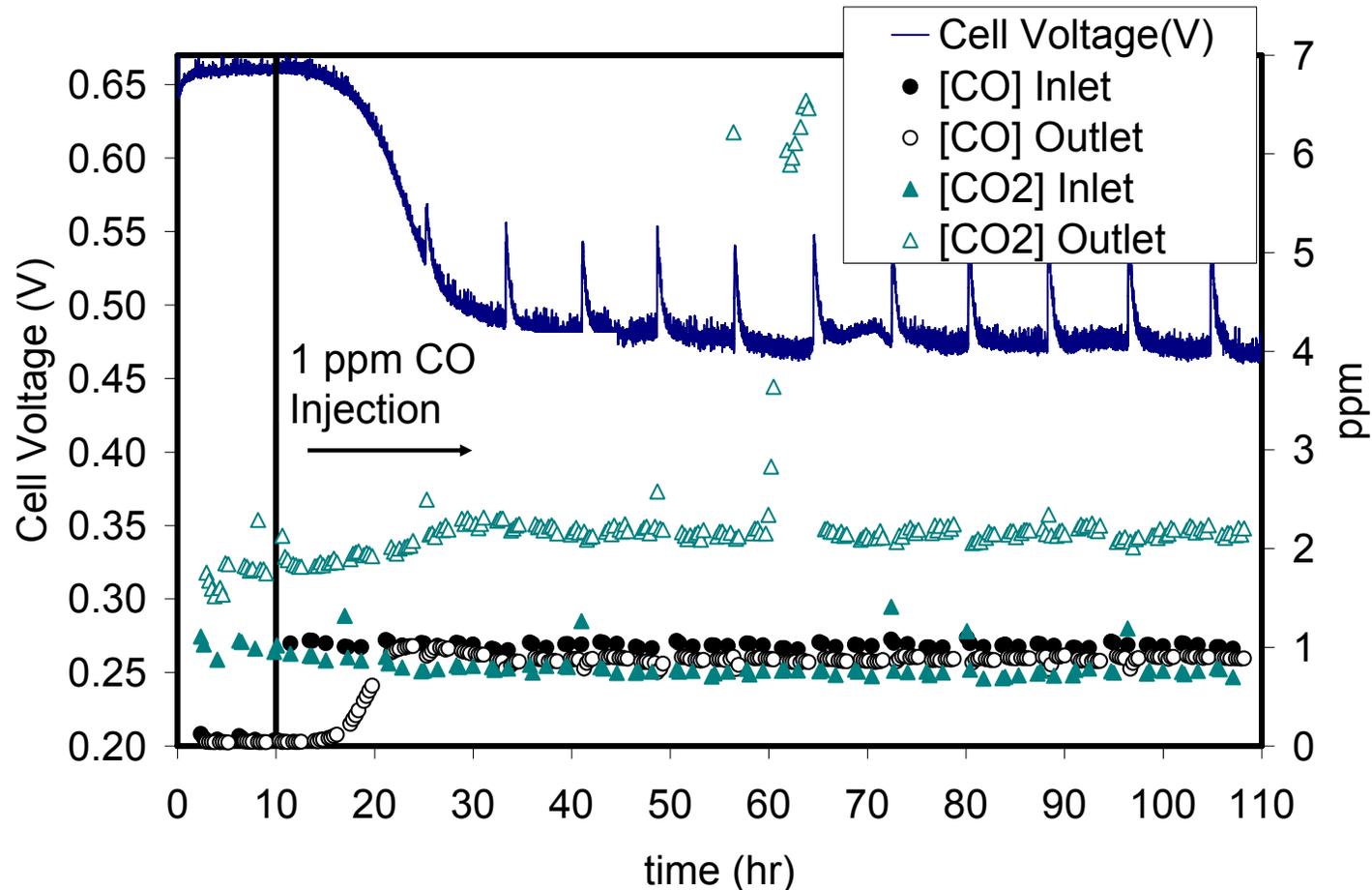


Increase in carbon dioxide after carbon monoxide injection indicates conversion of carbon monoxide to carbon dioxide



Fuels Purity Sample Data

Performance loss with 1 ppm CO at 60°C



Spikes in cell performance attributed to dissolved oxygen in injected humidifier water



Task 3: Renewable Hydrogen Production: Biomass

Parametric tests conducted at Pearson Technologies' 4.5 Mg per day (5 tpd) pilot plant in Mississippi

- Atmospheric pressure, entrained-flow reactor utilizing steam as the oxidizer
- Reactor exit temperature 975°C
- Average inert-free gas composition of 55% H₂, 15% CO, 3% CH₄, 27% CO₂
- Gas yield of 1.8 m³ gas per kg biomass (at STP)
- Yield is 90 kg H₂ per Mg of bagasse, 40% of theoretical yield
- Further yield improvement possible using shift reactor

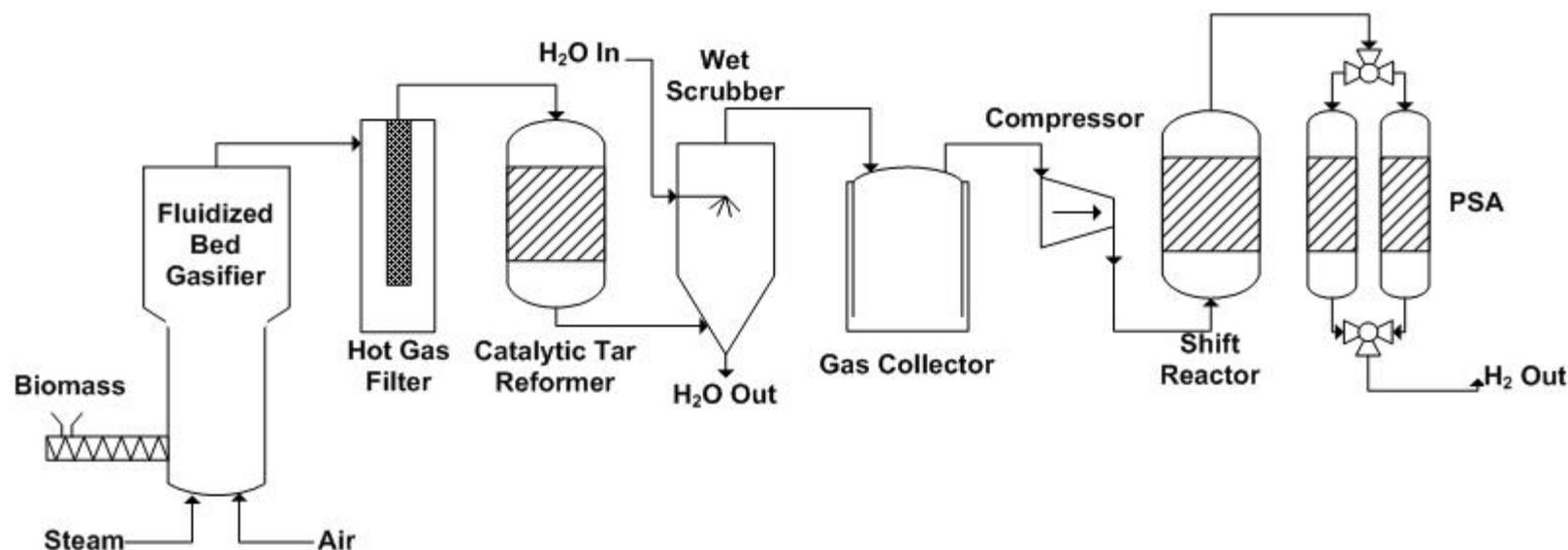


Technical Accomplishments/Progress/Results

Task 3: Renewable Hydrogen Production: Biomass

Development and evaluation of producer gas purification train

- Initial testing of high temperature filters impregnated with catalyst to combine filtration and catalytic tar removal unit operation underway
- Fabrication of remaining test bed components ongoing



Future Plans

Task 1: Hawaii Hydrogen Power Park

- Complete testing of integrated wind-hydrogen-FC system at Kahua Ranch on Big Island
- Complete analysis (with SNL) of integrated wind-hydrogen system
- Initiate test bed infrastructure at Hawaii Gateway Energy Center

Task 2: Hydrogen Fuel Quality Assessment

- Complete short and long term characterization of CO and hydrocarbon contaminant effects

Task 3: Renewable Hydrogen Production: Biomass

- Complete longer-term testing at Pearson Technologies' plant
- Complete skid-mounted, producer-gas clean-up unit and test at the HNEI gasifier facility
- Transport clean-up unit to Kauai for evaluation of 45 Mg per day gasifier under development at the Gay & Robinson Sugar factory
- Characterize fate of trace contaminants in gasifier process



Response to FY 2005 review

Overall project a composite of 4 relatively separate subprojects

- Yes, that was structure of program proposed and accepted by DOE
- Sub-projects are responsive to and meet DOE Multi year plan objectives
- Address Hawaii's renewables-to-hydrogen objectives

Do not have a lot of fuel cell construction technology experience

- HNEI staff trained by OEM's in assembly of cells for fuel quality testing

Suggest deletion of biomass effort

- Biomass has the potential to be the most economic source of hydrogen source in Hawaii

Include cost analysis approach

- Power Park - Teamed with SNL to conduct economic and engineering modeling and analysis



Publications and Presentations

Fuel Purity Assessment

“Effect of Trace Contaminants on PEM Fuel Cell Performance,” T. Thampan, R. Rocheleau, K. Bethune, D. Wheeler, Fall Meeting of the Materials Research Society, Boston, MA, November-December 2005.

“Effect of Trace Contaminants on PEM Fuel Cell Performance,” T. Thampan, R. Rocheleau, K. Bethune, D. Wheeler, 2005 Fuel Cell Seminar Palm Springs, CA, November 2005.

Renewable Hydrogen Production – Photoelectrochemical

“Four-Terminal Solar Cell Based on High-Efficiency Cu(In,Ga)Se₂ Device on Metal Foil,” B. Marsen, A. Madan, S. Dorn, S. Marsillac, F. Matsunaga, R. Rocheleau, and E. Miller, 206th ECS Meeting, Honolulu, HI, 2004.

“Effect of Selenium Effusion Rate on CIGS Thin Films Deposited at Low Substrate Temperature,” B. Marsen, S. Marsillac, S. Dorn, R. Rocheleau, 31st IEEE PVSC, Orlando, FL, 2005.

“Cu(In,Ga)Se₂-based Solar Cells on Flexible Insulating Substrates,” B. Marsen, S. Dorn, R. Rocheleau, E. Miller, S. Morrison, R. Martin, S. Marsillac, Proceedings of the 3rd International Energy Conversion Engineering Conference, 2005.

“Effect of Selenium Effusion Rate on CIGS Thin Films Deposited at Low Substrate Temperature,” B. Marsen, S. Marsillac, S. Dorn, R. Rocheleau, Proceedings of the 31st Photovoltaics Specialist Conference, 386-389, 2005.

Biohydrogen Analysis

“Two-phase Anaerobic Digestion for Production of Hydrogen-Methane Mixtures,” Michael Cooney - submitted to the ***Journal of Bioresources Technology***.

“On-line Measurement of Gas Production Rates,” Michael Cooney - submitted to ***Biotechnology Progress*** as a R&D note.

Patrick Takahashi was presented the Spark Matsunaga Memorial Hydrogen Award at the National Hydrogen Association Annual Conference in Long Beach, California.

