# Hawaii Hydrogen Center for Development and Deployment of Distributed Energy Systems

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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.

## 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

## 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

## 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 $H_2$ production from biomass

- Evaluate $H_2$ yield potential of Pearson Technologies' gasification process
- Develop skid-mounted test system for tar reforming and $H_2$ 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 $H_2$ purification unit operations to allow use with other biomass facilities in Hawaii to evaluate $H_2$ yield potential and assess remaining issues

# Technical Accomplishments/Progress/Results
## Task 1: Hawaii Hydrogen Power Park

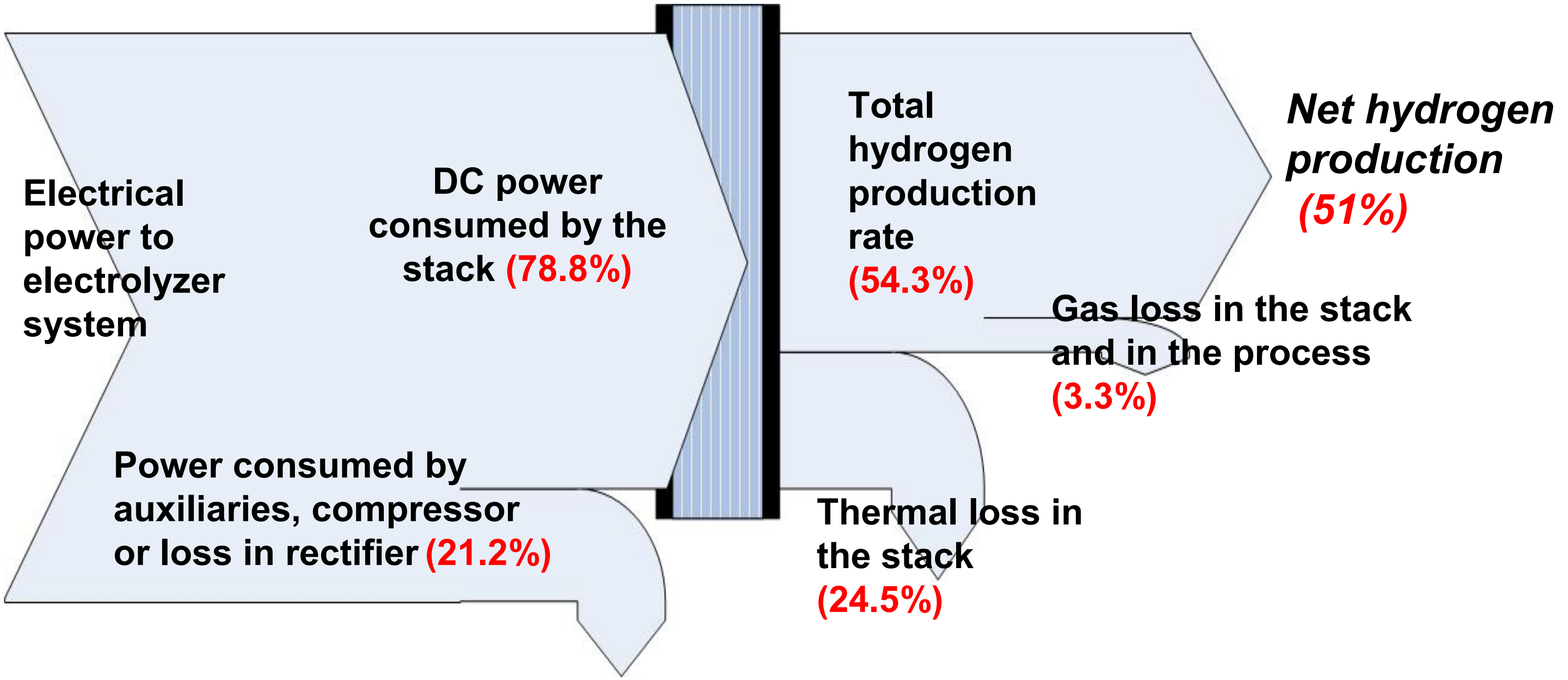
### Component Evaluation
- Electrolyzer characterized at steady state at several power levels
- Fuel cell characterized throughout operating range
- Data collected and analyzed by HNEI and Sandia National Lab (see SNL presentation TV-2)

### 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 $H_2$ Test Bed
- Facility Rental Agreement negotiated with NELHA for use of HGEC

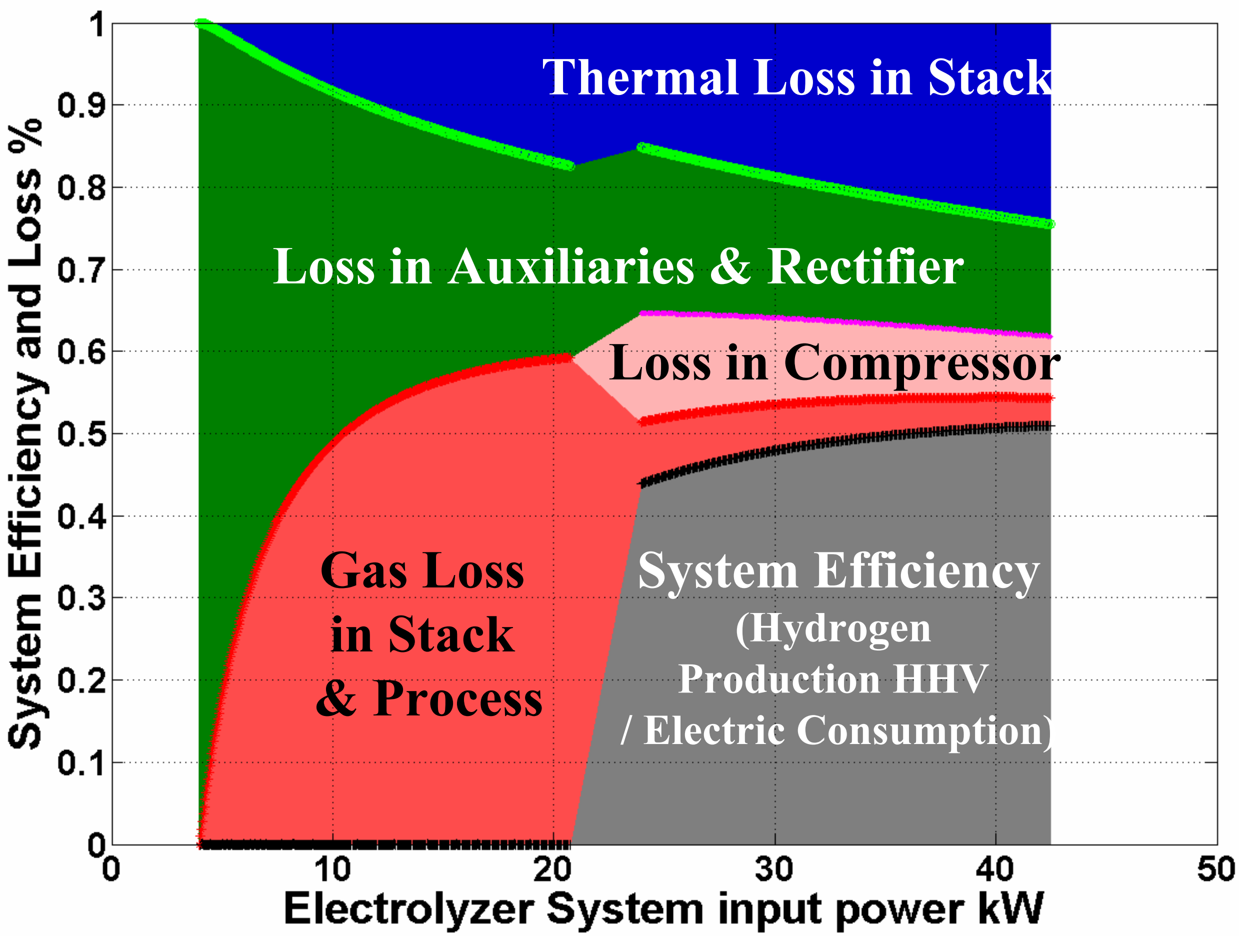
# Electrolyzer Energy Balance

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




- All $H_2$ efficiencies based on higher heating value (HHV)
- Efficiencies and losses relative to input AC power
- Net $H_2$ production - 7kWh/Nm3
- Auxiliary losses include compression to 3000 psi
- Gas loss and auxiliary consumption critical for improved performance

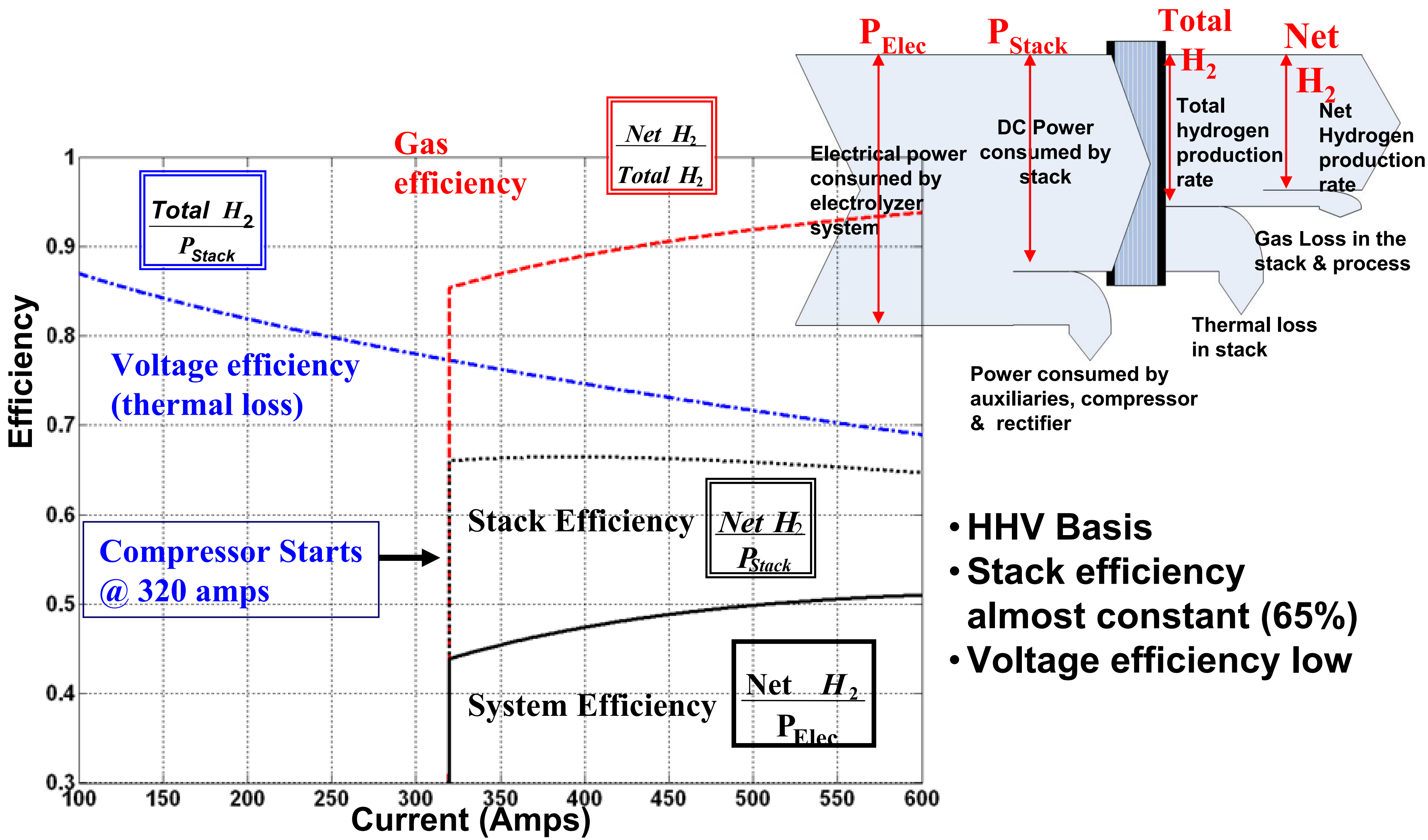
# Electrolyzer Efficiency as Function of Input Power




- 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

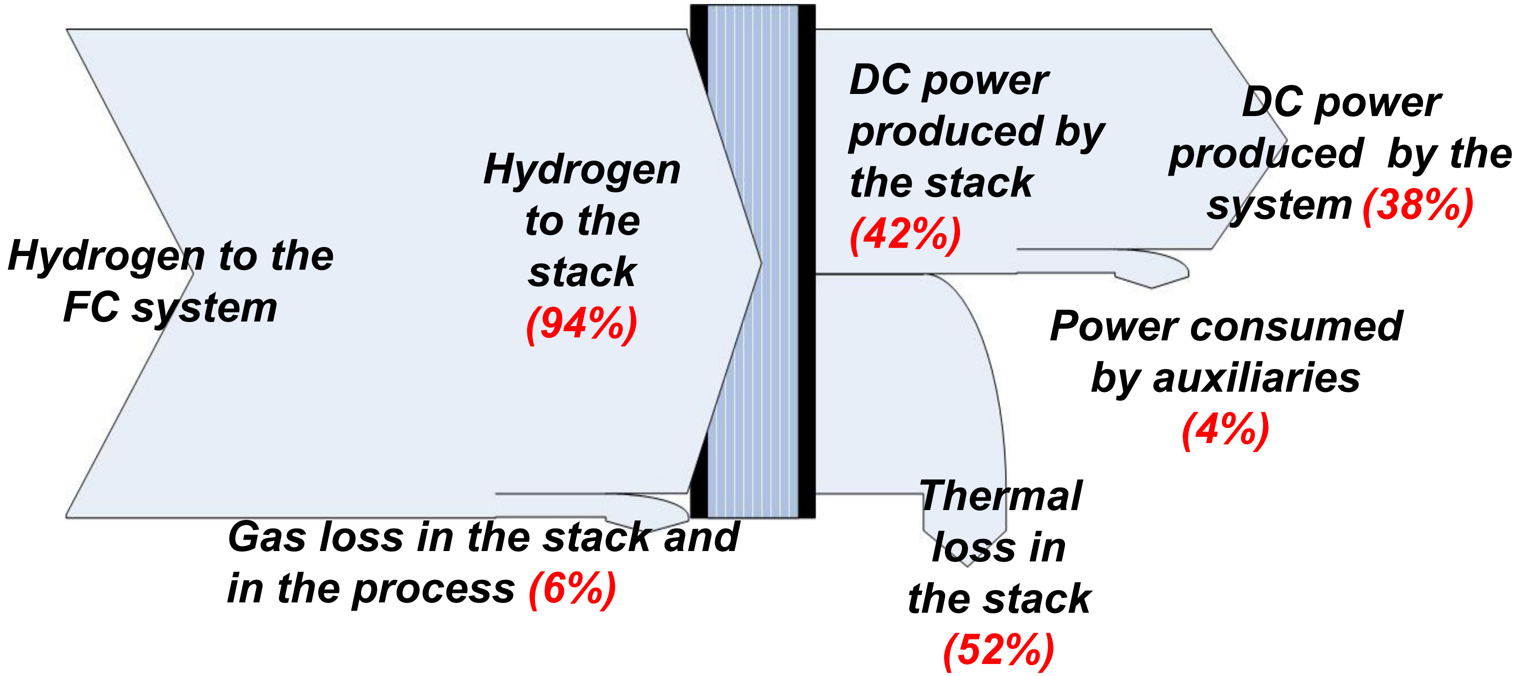
# Characterization of Electrolyzer Stack




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

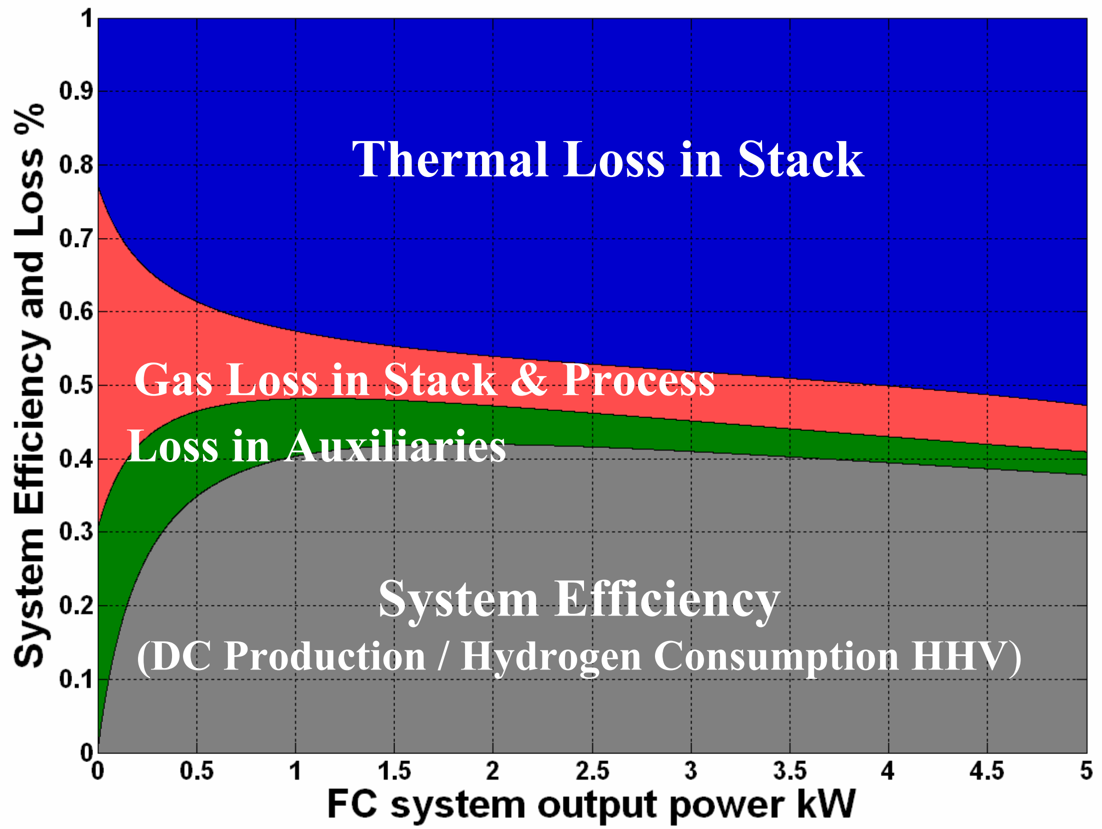
# Fuel Cell Energy Balance

**Efficiencies at steady state operation at maximum power (5 $kW_{electric}$)**
**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 $kWh/Nm^3$
- Need to improve stack performance to overcome stack losses.

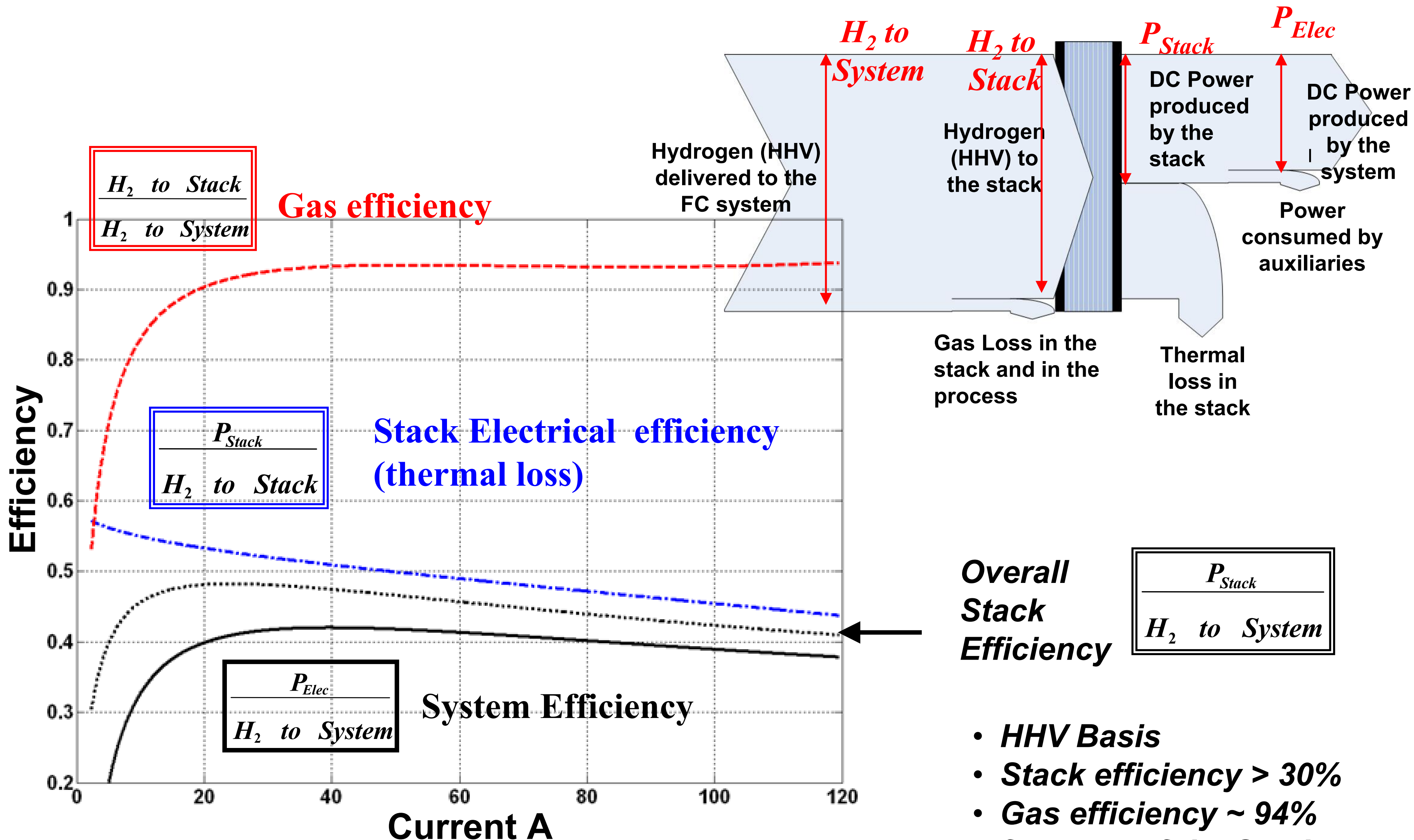
# Fuel Cell System Losses as Function of Output Power




- Steady state operation
- HHV basis
- Efficiency and loss percentage compared to input power: $P_{H2}$

- Good performance
- Low system losses (gas & auxiliaries)
- Lowest consumption 1.35kWh/Nm$^3$ 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***

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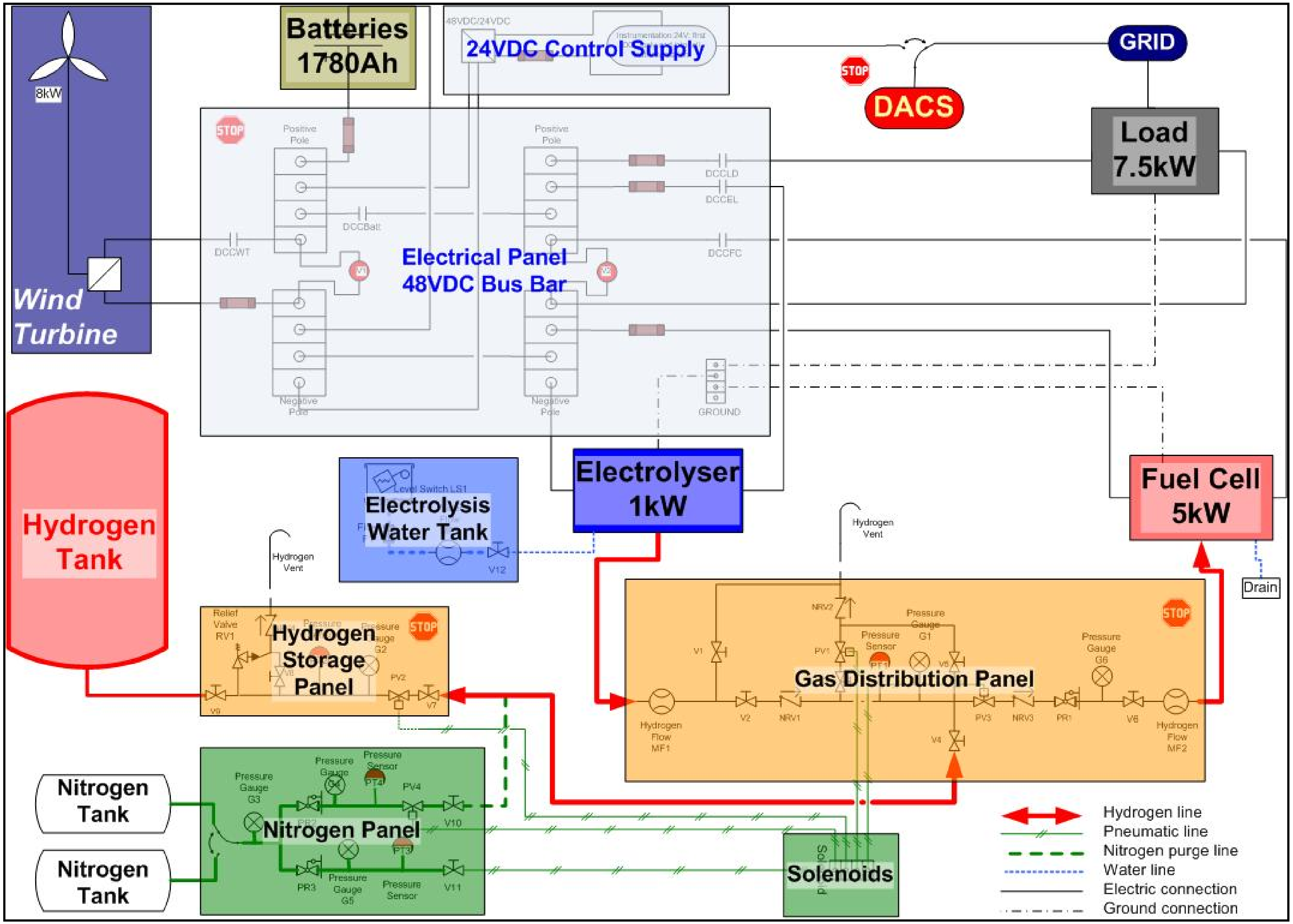
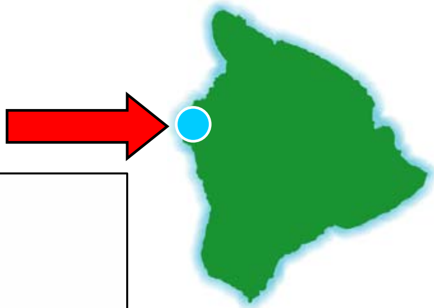
www.hnei.hawaii.edu

# Wind-Hydrogen System Design



# Hawaii Gateway Energy Center (HGEC)




HNEI Space

PV Array

Seminar & Office Space

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

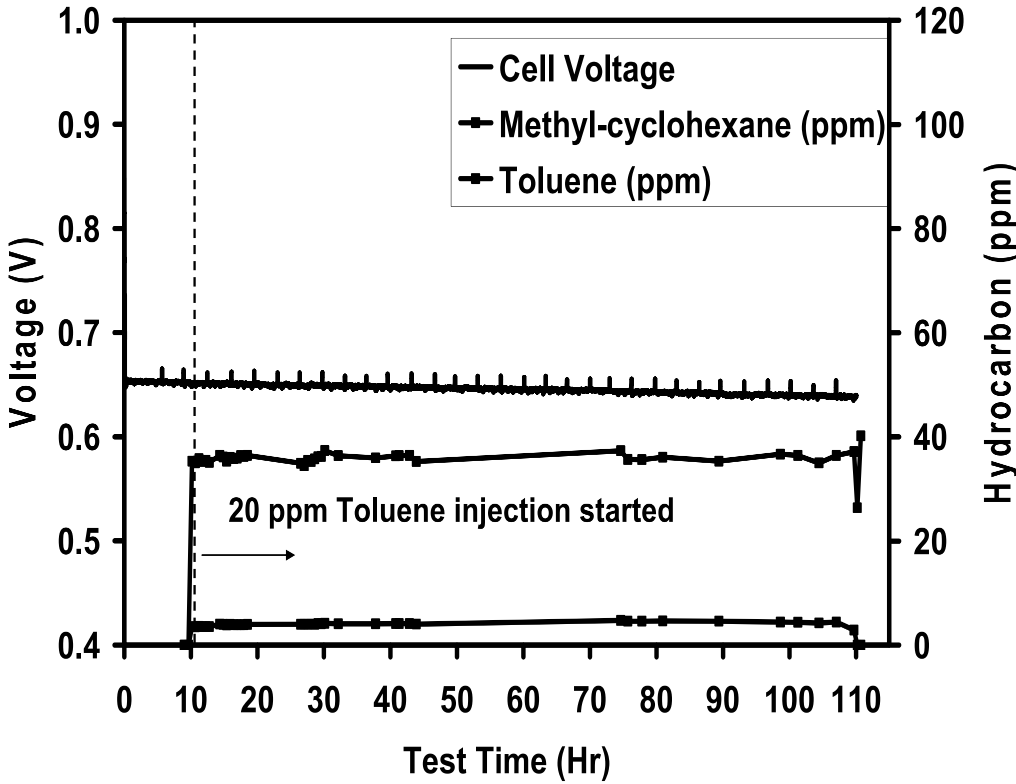
- Five test stands installed and instrumented for fuel quality testing (DOD funded)
- Equipment calibrated to ISO 17025 standards
- GC-based gas analyzer upgraded for improved sensitivity:
  - CO (100 ppb) - Pulse discharge ionization det
  - $CO^2$ (1 ppm) - Flame ionization det
  - Hydrocarbons (1 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

# Task 2: Hydrogen Fuel Quality Assessment

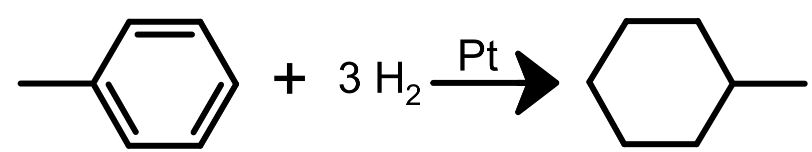
- **Benzene** - No measurable fuel cell degradation with up to 60 ppm over at 80°C and 1 A/cm$^2$
- **Toluene** - No measurable fuel cell degradation with up to 60 ppm at 80°C and up to 40 ppm at 60°C and 1 A/cm$^2$ (higher values not tested)
  - Significant toluene hydrogenation observed at both temperatures
- **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/cm$^2$

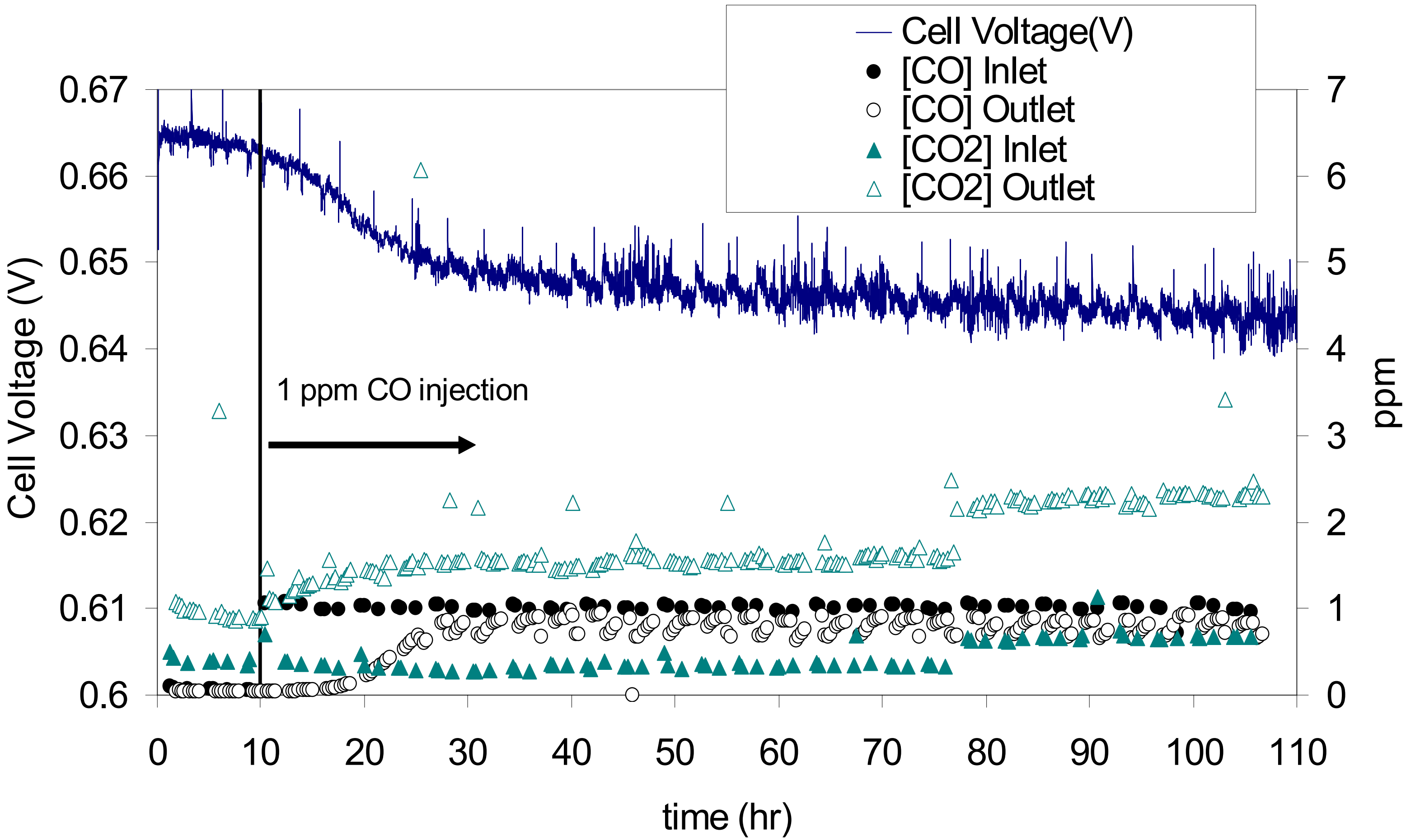



- Average 100 hrs decay rate of 0.12 mV/hr within baseline
- 4 ~ 5 ppm toluene and 35~36 ppm methyl-cyclohexane in exit
- Toluene hydrogenation occurs, no evidence of carbon deposition on catalyst



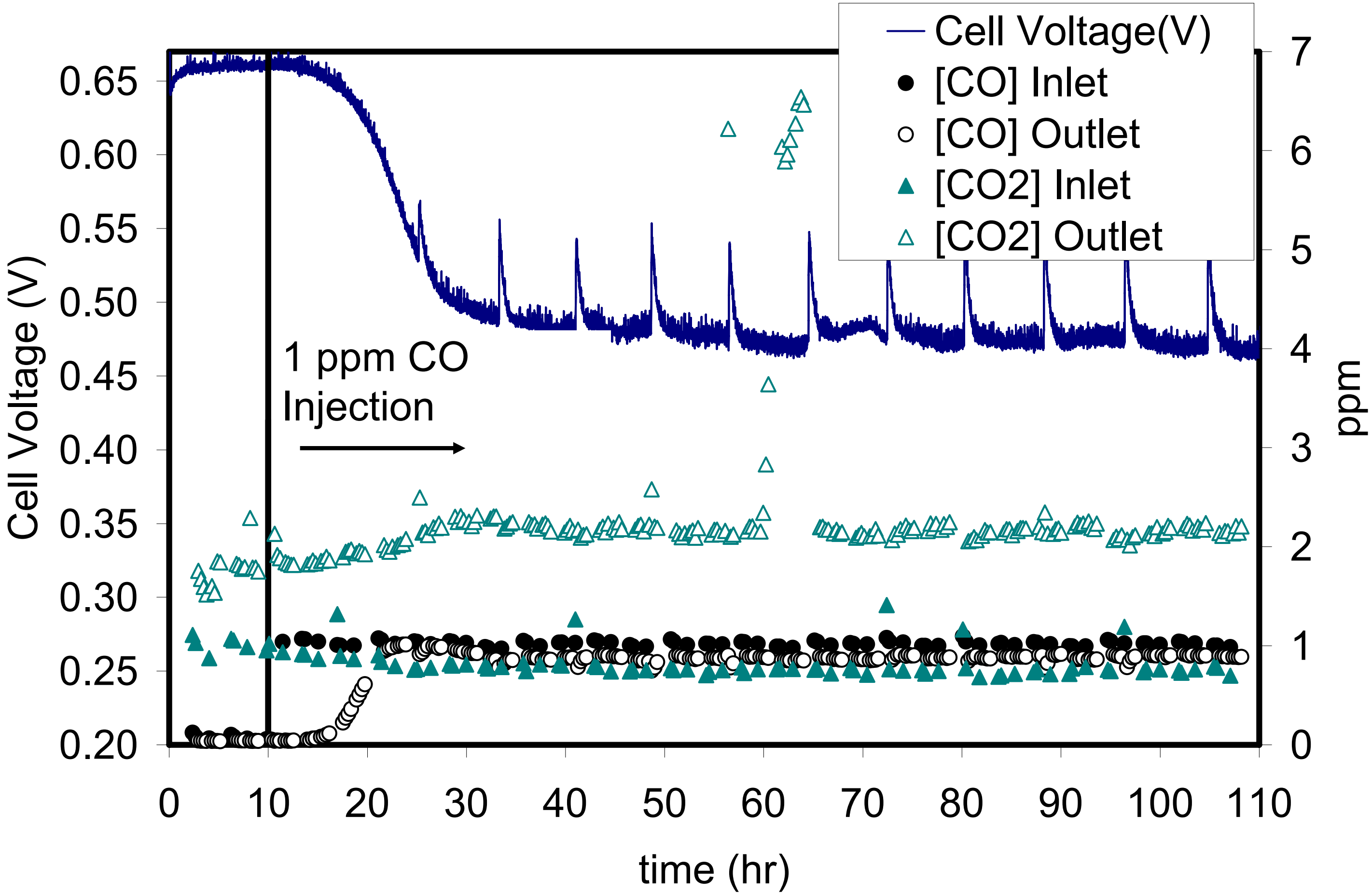

Toluene injected at concentration level 70x max limit proposed in SAE J2719

# 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 1ppm CO at 60°C




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

# Task 3: Renewable Hydrogen Production: Biomass

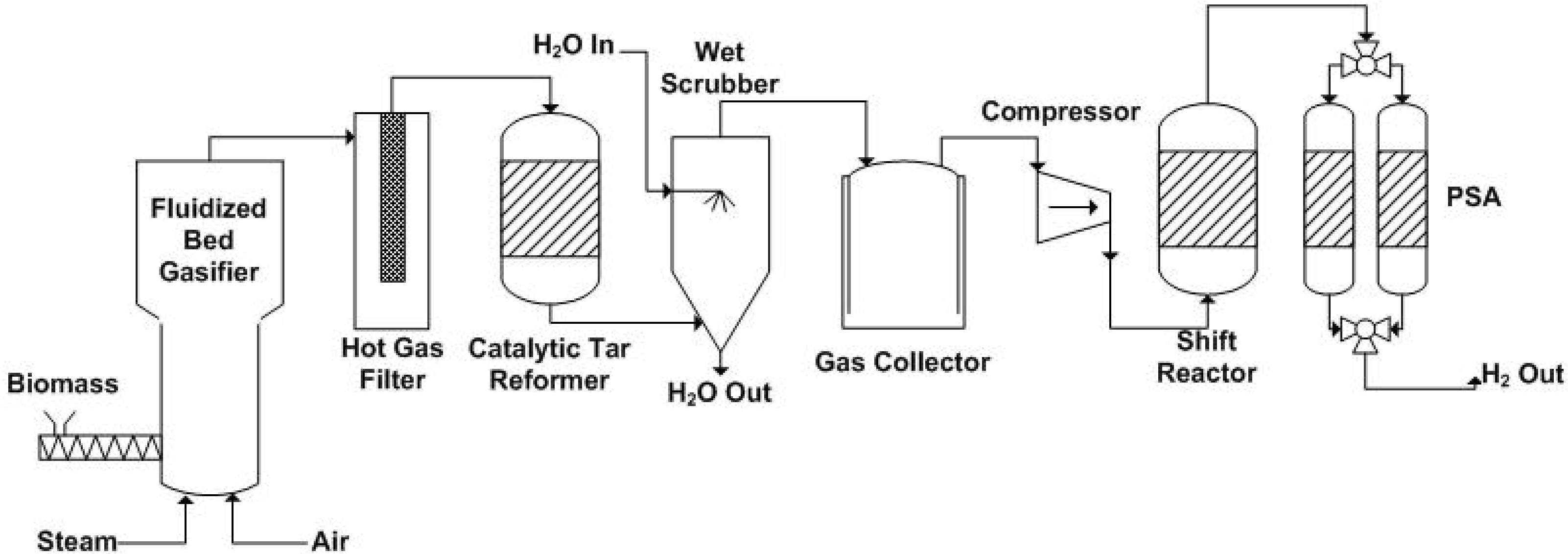
**Parametric tests conducted at Pearson Technologies' 4.5 Mg per day (5 tpd) pilot plant in Mississippi**

- Atmospheric pressure, entrained-flow reactor utilizing steam as the oxidizer
- Reactor exit temperature 975°C
- Average inert-free gas composition of 55% $H_2$, 15% CO, 3% $CH_4$, 27% $CO_2$
- Gas yield of 1.8 $m^3$ gas per kg biomass (at STP)
- Yield is 90 kg $H_2$ per Mg of bagasse, 40% of theoretical yield
- Further yield improvement possible using shift reactor

# 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.