HYDROGEN FROM BIOMASS FOR URBAN TRANSPORTATION

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DOE Hydrogen Program Review

This presentation does not contain any proprietary or confidential information.

TVP 4

Overview

Timeline

- Project start date: 2003
- Project end date: 2004
- Percent complete: 100%

Barriers

- Feedstock cost and availability
- Efficiency of pyrolysis and reforming technologies
- Durable, efficient and impurity tolerant catalysts
- Hydrogen separation and purification
- Market and delivery

Partners

- National Renewable Energy Lab
- Eprida, Inc.

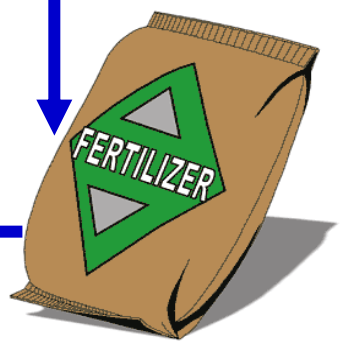
OBJECTIVES

- **Undertake the engineering research and pilot scale process development studies relating to:**
  - Production of hydrogen from biomass (e.g., agricultural residues) for $2.90/kg H_2 by 2010; $2.30 by 2015
  - Separation, safe storage and utilization of the hydrogen
  - Production and identification of uses of the co-products
- **Increase diversity of the Nation's workforce and the broader impact of the project through the education and training of underrepresented minorities.**

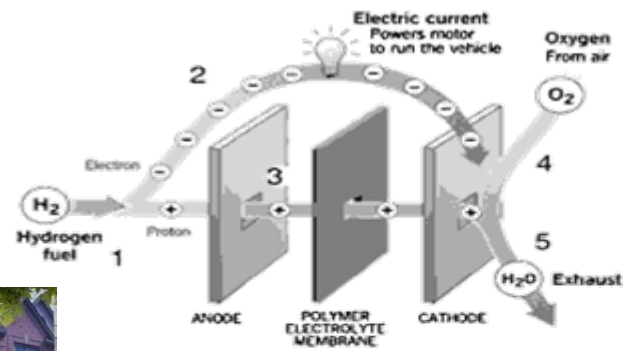
APPROACH

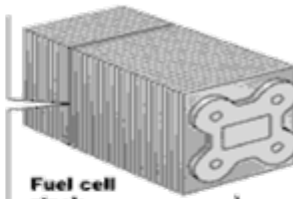
- **Develop process based on biomass pyrolysis and steam reforming of pyrolysis vapors (bio-oils and gases).**
- **Perform catalytic steam reforming in a fluidized-bed (25-250 kg/day H_2 production)**
- **Conduct pyrolysis at: T: 500°C; P: 10 psig; Feed Rate: 50-500 kg/hr pelletized peanut shells.**
- **Study reforming at: T: 850°C; P: 6 psig; $H_2O/C = 5$, Catalyst: nickel-based (300-500 microns)**

The Peanut Shell to Hydrogen Cycle

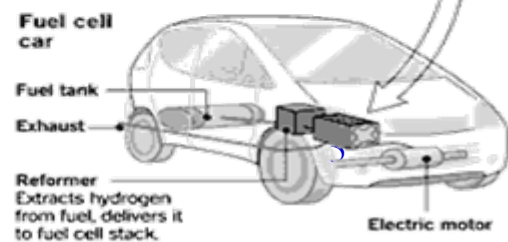


Stationary fuel cell power generation





Fuel cell stack
The reaction in a single fuel cell produces a very low voltage, so many cells are combined into a stack to produce the desired level of electrical power.



Schematic Flow Diagram of the Biomass Pyrolysis-reformer Process

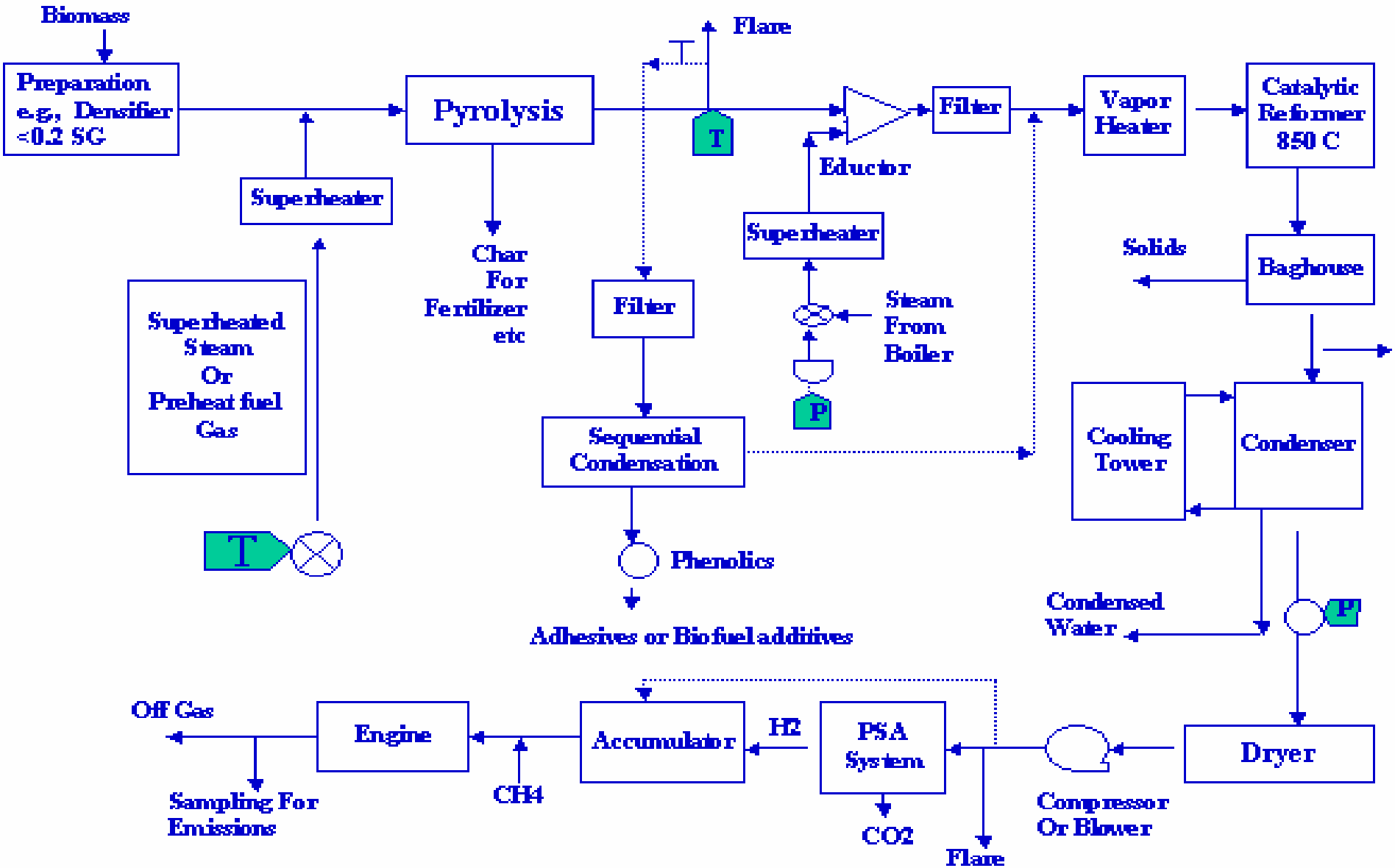
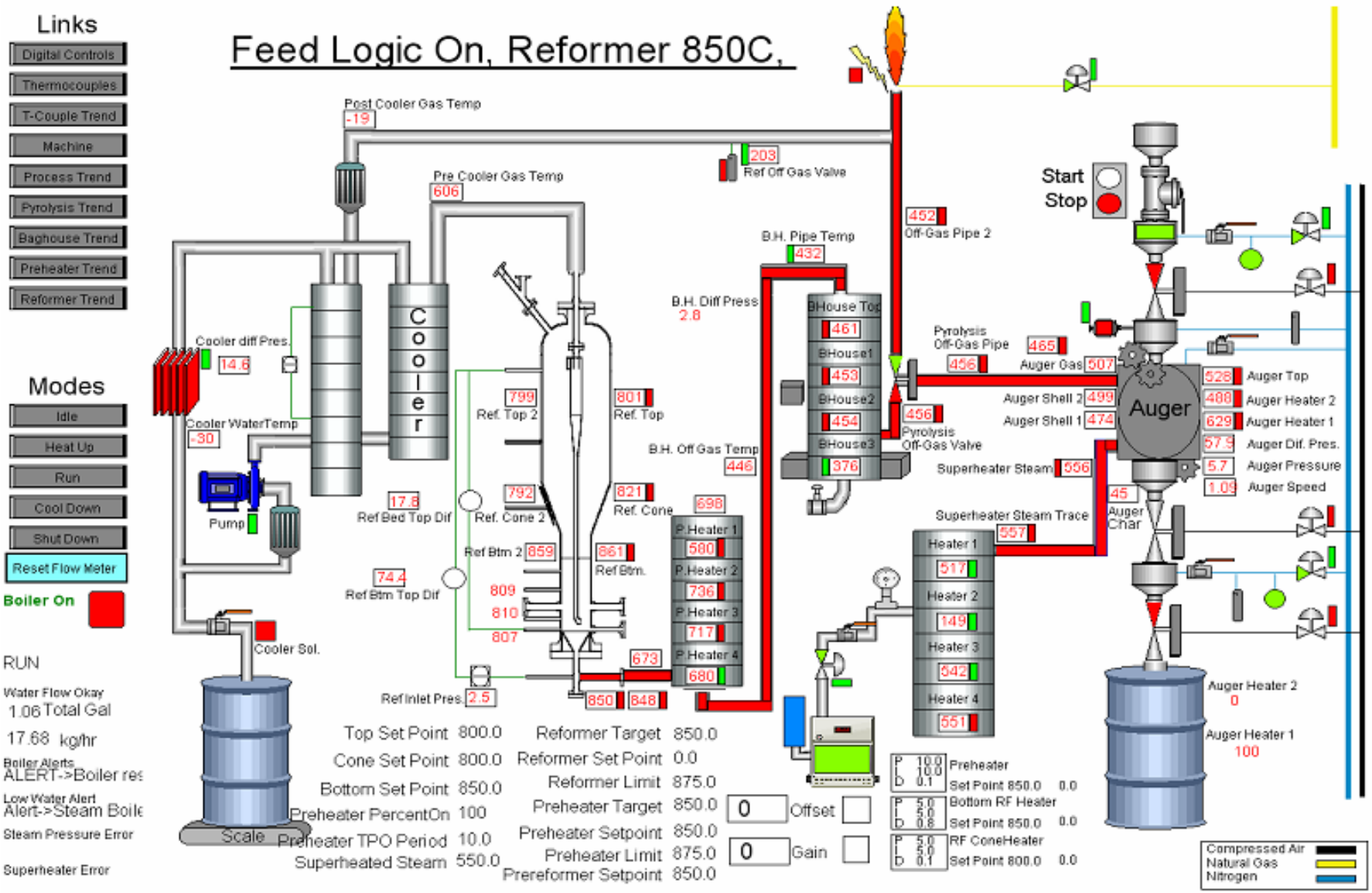


Photo of Hydrogen Production System

Hydrogen Production Control



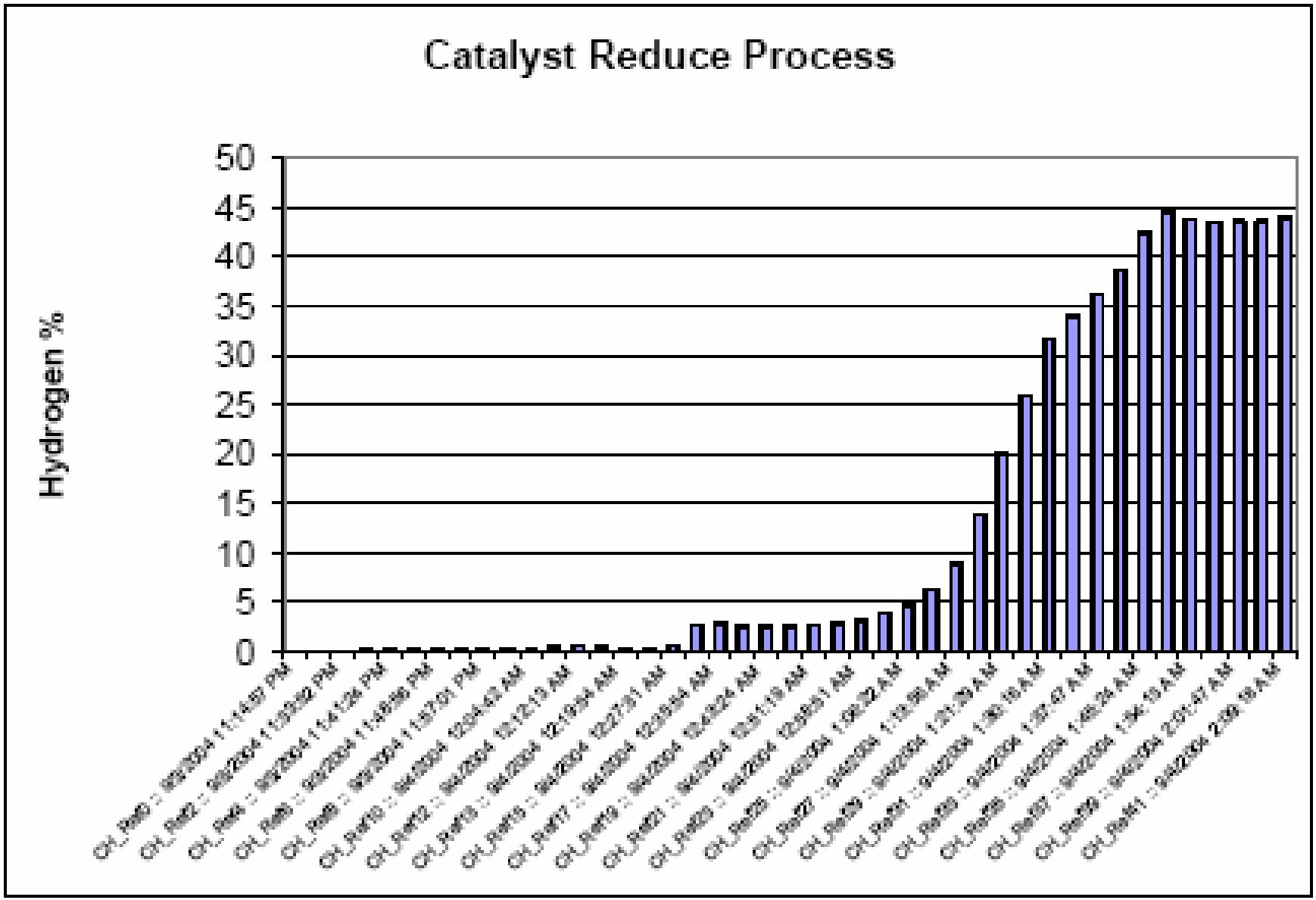
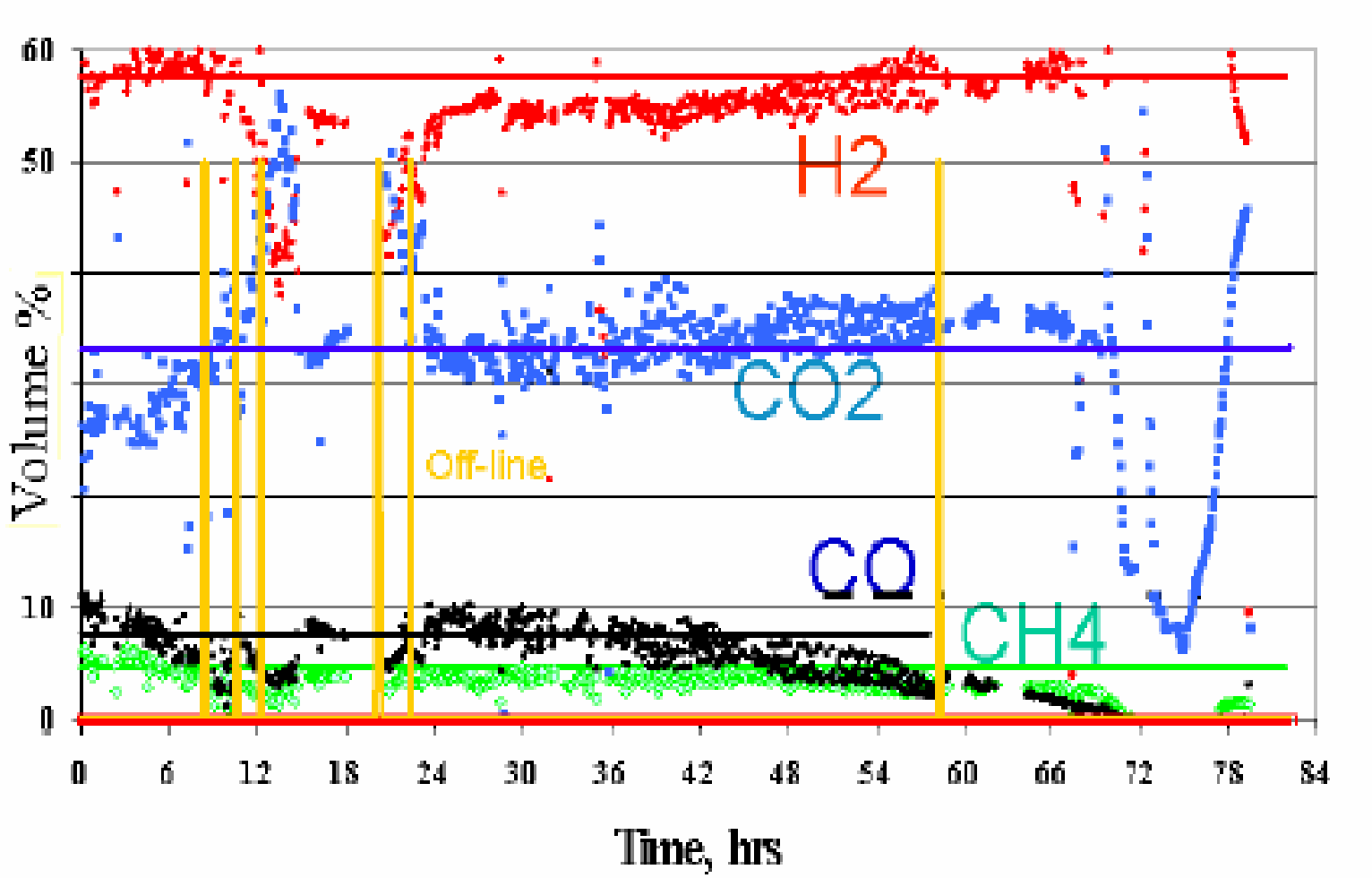
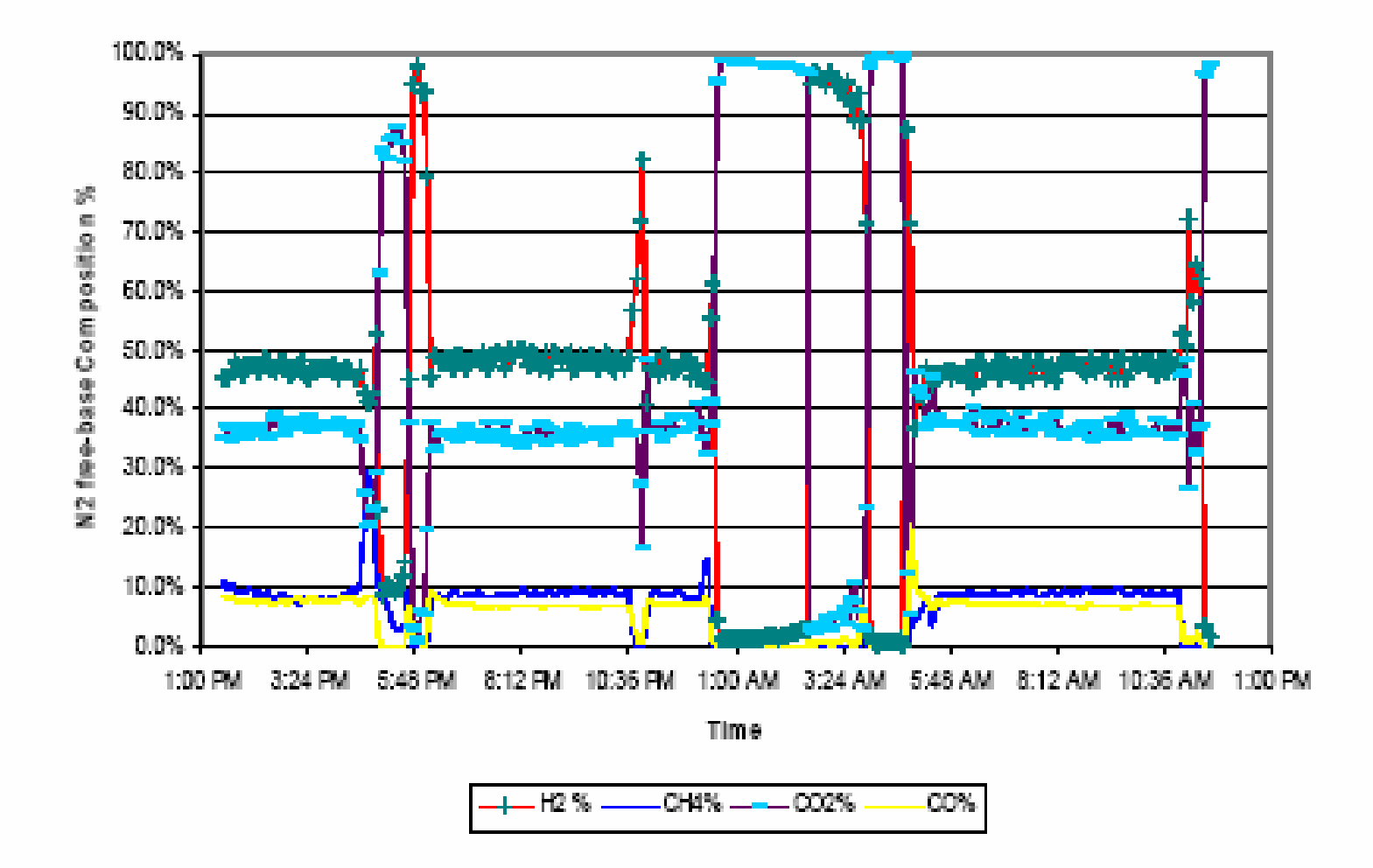

Catalyst Reduce Process
Hydrogen %
50
45
40
35
30
25
20
15
10
5
0

Photo of Hydrogen Flame

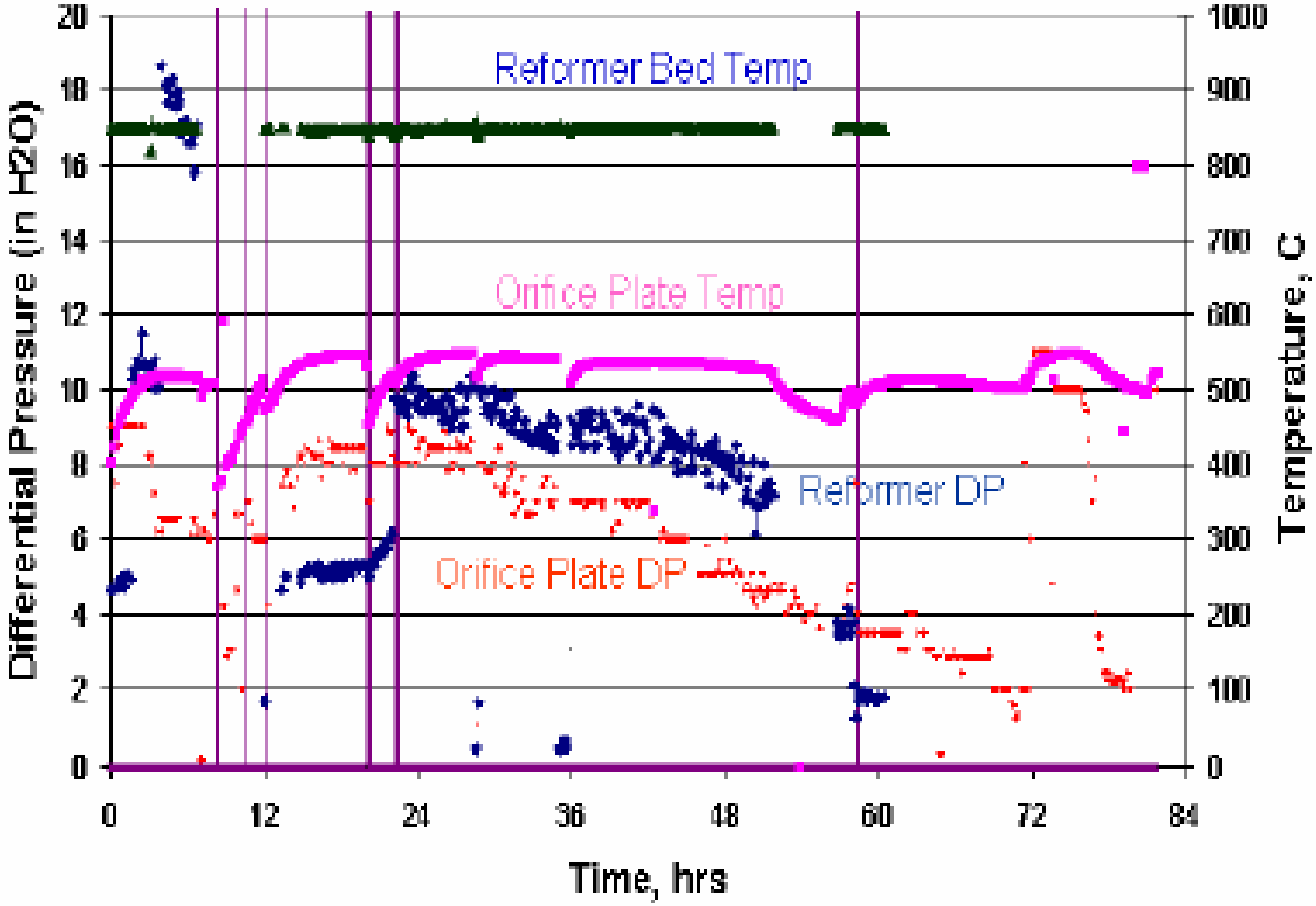
Total Gas Composition VS. Time (N2-free basis)



Nitrogen free-Base Gas Composition Vs.Time (24hrs)



Temperature and differential pressure of the catalytic reformer



Typical Analysis of Peanut Shell Feedstock

- **Component** **%**
  - Lignin ---------- **34.8**
  - Glucan ---------- **21.1**
  - Extractives ---------- **14.2**
  - Protein ---------- **11.1**
  - Xylan ---------- **7.9**
  - Ash ---------- **3.4**
  - Arabinan ---------- **0.7**
  - Galactan ---------- **0.2**
  - Mannan ---------- **0.1**
  - Others (e.g., free carbohydrates) ---------- **6.5**

TYPICAL PRODUCT COMPOSITION/ YIELDS

Pyrolyzer (Yields)		Reformer (Gas product composition, on dry N_2-free basis)	
Char	**32%**	**Hydrogen**	**49%**
Water	**32%**	**Carbon Dioxide**	**36%**
Bio-Oils	**31%**	**Carbon Monoxide**	**9%**
Gases	**5%**	**Methane**	**8%**

Pyrolysis Bio-Oil Product

- **Empirical Formula: $CH_{1.9}O_{0.7}$**
- **Water: 15 – 25%**
- **Organics: 75 – 85%**
  - Aldehydes, alcohols and acids from carbohydrate fraction
  - Phenolics from lignin fraction
- **Representative Compounds**

Water	Ethanol	Methanol
Cyclohexanol	Formic Acid	Acetic Acid
Glucose	Phenol	O-cresol
2-Butanone	Dodecanoic acid	Tannin

CONCLUSIONS

- The pilot scale plant has increased the hydrogen production rate by orders of magnitude comprising to the bench scale
- Using peanut shells as feedstock, the overall yield from this process is up to 7 wt% hydrogen and 32 wt% charcoal/activated carbon
- The preliminary techno-economic analysis indicates that the integrated process has the potential of producing hydrogen at the cost of about US$6.5/GJ

ACCOMPLISHMENTS

- **Completed design, construction and testing of reformer (Phase 1)**
- **Completed integration of reformer with pyrolyzer (Phase 2)**
- **Completed 100 hours of successful operation of pilot unit (Phase 2)**
- **Completed modifications for 1,000 hours operation**
- **Completed 24 hours catalyst and process testing**
- **Identified potential co-products options**
- **Developed partnership and collaboration with potential companies/organizations**
- **Educated and trained several underrepresented minorities on project**

ACKNOWLEDGEMENTS

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- **Support of the Partner Institutions**
  - Clark Atlanta University
  - Eprida Scientific Carbons Inc.
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  - Georgia Institute of Technology
  - Oak Ridge National Lab, Oak Ridge, TN
  - National Renewable Energy Laboratory, CO
  - University of Georgia, Athens