An Integrated Hydrogen Production-CO_2 Capture Process from Fossil Fuel

Zhicheng Wang, Boxiong Liao
Clark Atlanta University
Yaw Yeboah
Pennsylvania State University

UCR/HBCU Contractors Review Conference
June 7-8, 2005

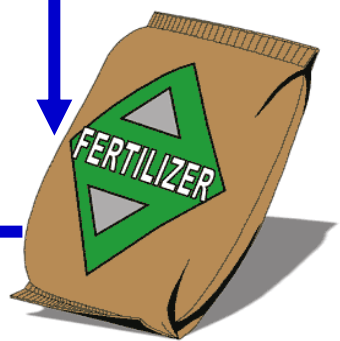
OBJECTIVES

- **Determine the feasibility of using the char from a coal/biomass pyrolysis-reforming process and CO_2 emissions at a smokestack to form a solid NH_4HCO_3-char product that may subsequently be used as a fertilizer.**
- **Increase diversity of the Nation's workforce and the broader impact of the project through the education and training of minorities.**

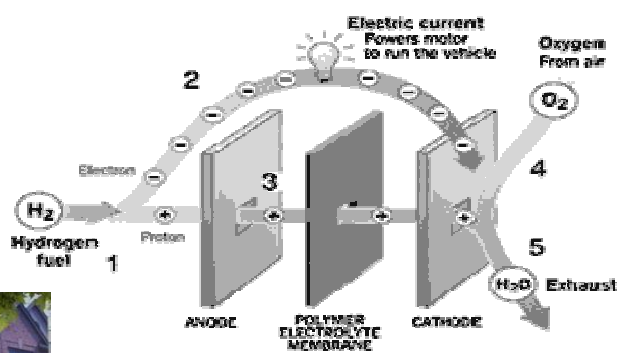
Outline

- Introduction to the integrated hydrogen production-CO_2 capture process.
- Char production, an integrated hydrogen-char production from bio-mass via pyrolysis
- Bench scale study of NH_4HCO_3-char production and fertilizer characteristics
- Future work: pilot scale study sketch of NH_4HCO_3-char production and fertilizer characteristics

The Peanut Shell to Hydrogen Cycle

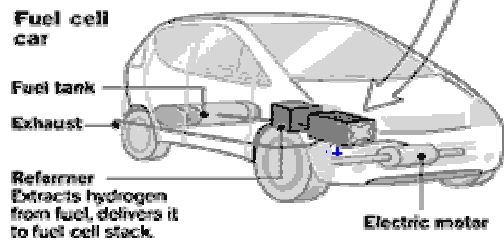


Stationary fuel cell power generation

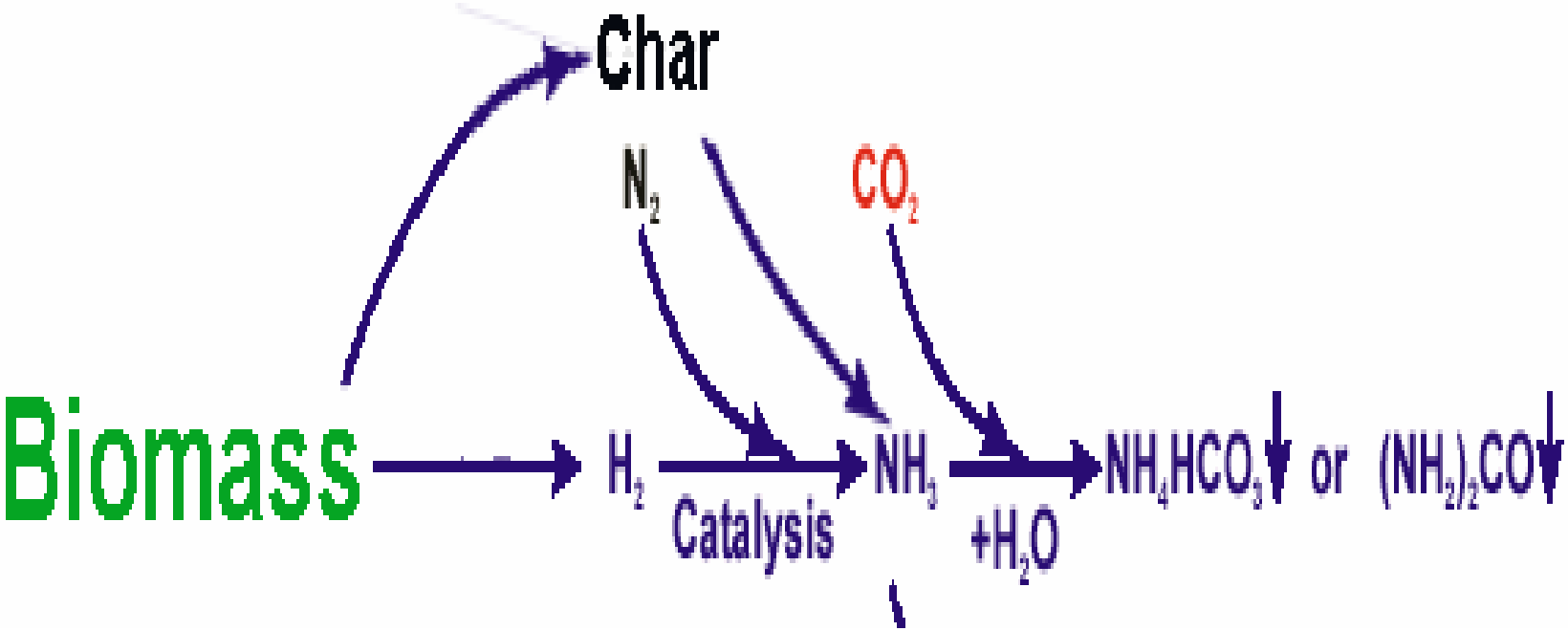


Fuel cell stack

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.



Biocarbon-Based Fertilizers



Schematic Flow Diagram of the Biomass Pyrolysis-reformer Process

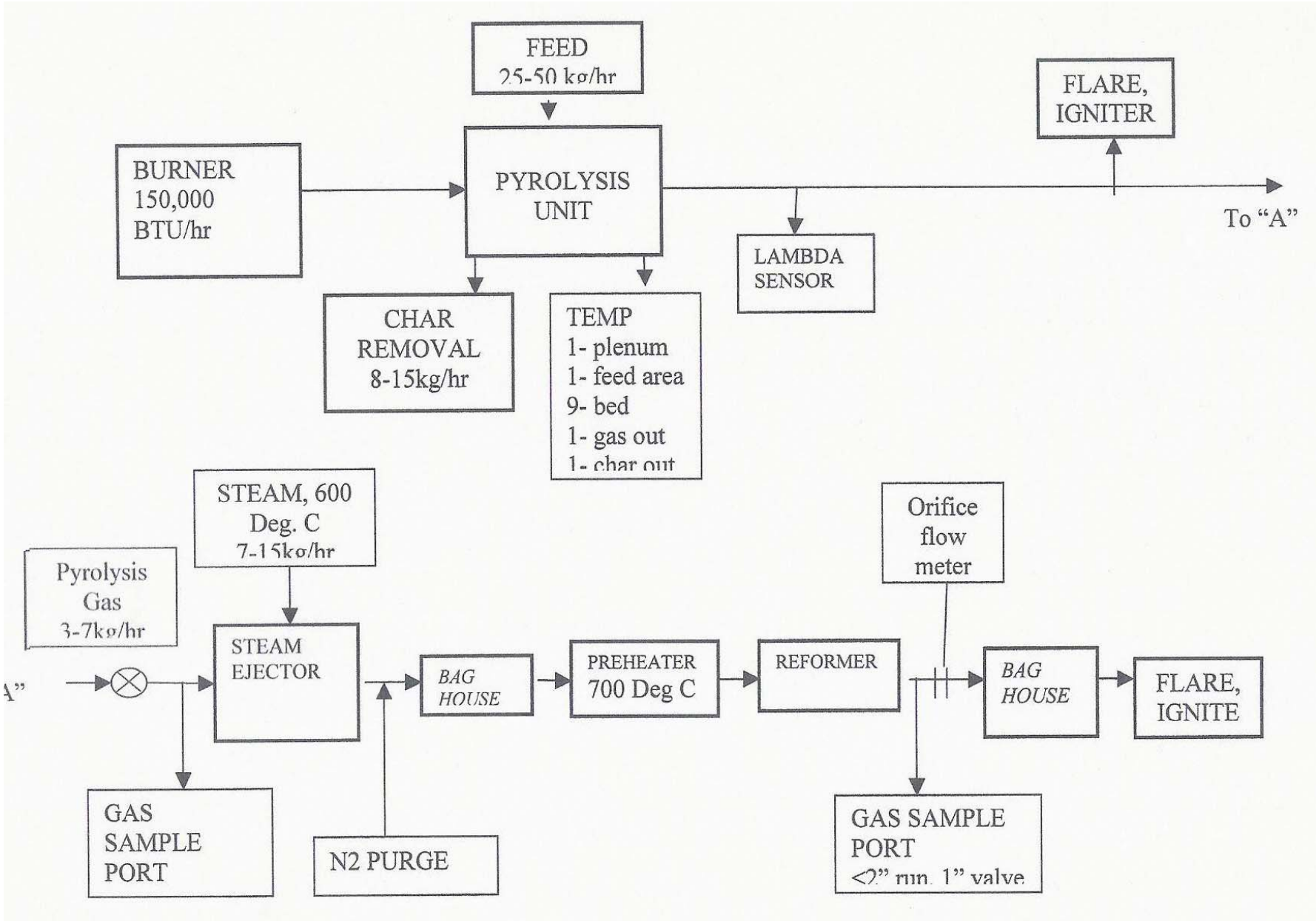
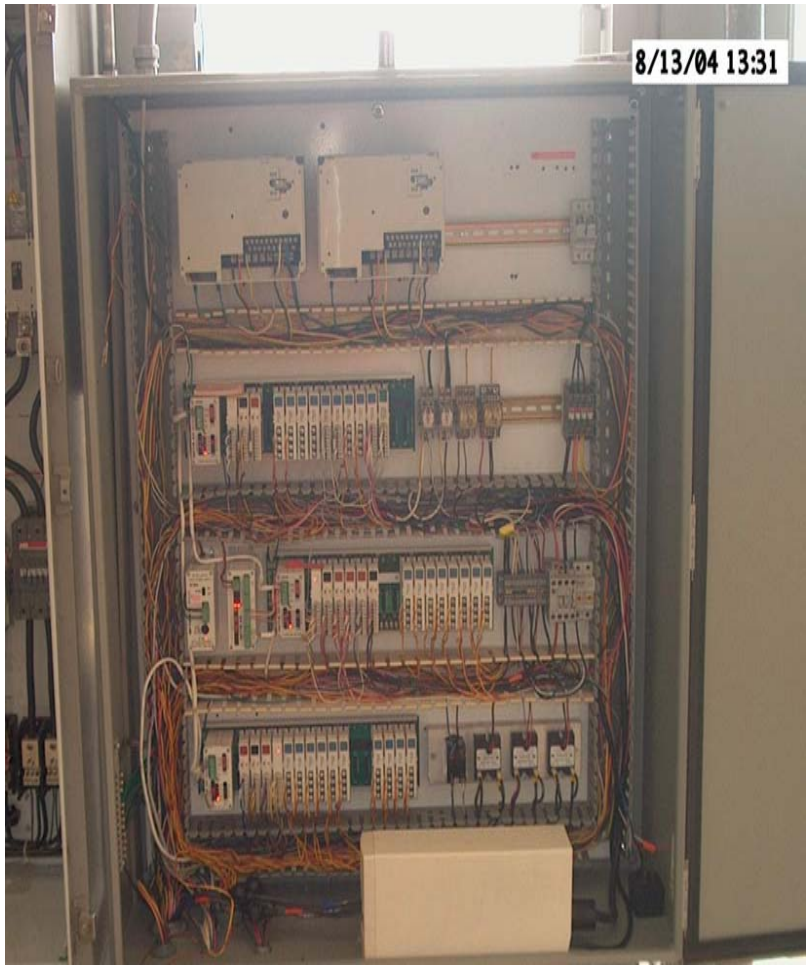


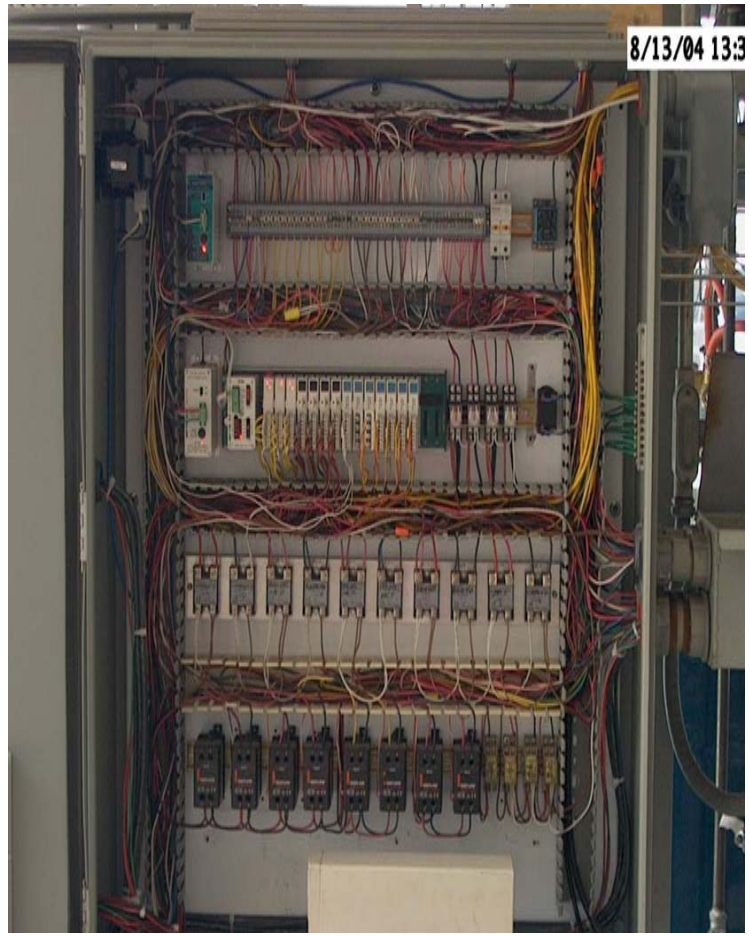
Photo of Hydrogen Production System

Photo of Pyrolysis Unit and feeder

- Feed Biomass
- Pyrolyze biomass
- Output Char

Photo of Automation System





OptoDisplay Runtime - C:\Opto22\Eprida\Display\Eprida1.MMI

File View Alarm Window Help

Eprida Hydrogen Production Unit

Feed Logic On, Reformer 850C,

Links

- Digital Controls
- Thermocouples
- T-Couple Trend
- Machine
- Process Trend
- Pyrolysis Trend
- Baghouse Trend
- Preheater Trend
- Reformer Trend

Modes

- Idle
- Heat Up
- Run
- Cool Down
- Shut Down
- Reset Flow Meter

Boiler On

RUN

Water Flow Okay

1.06 Total Gal

17.68 kg/hr

Boiler Alerts

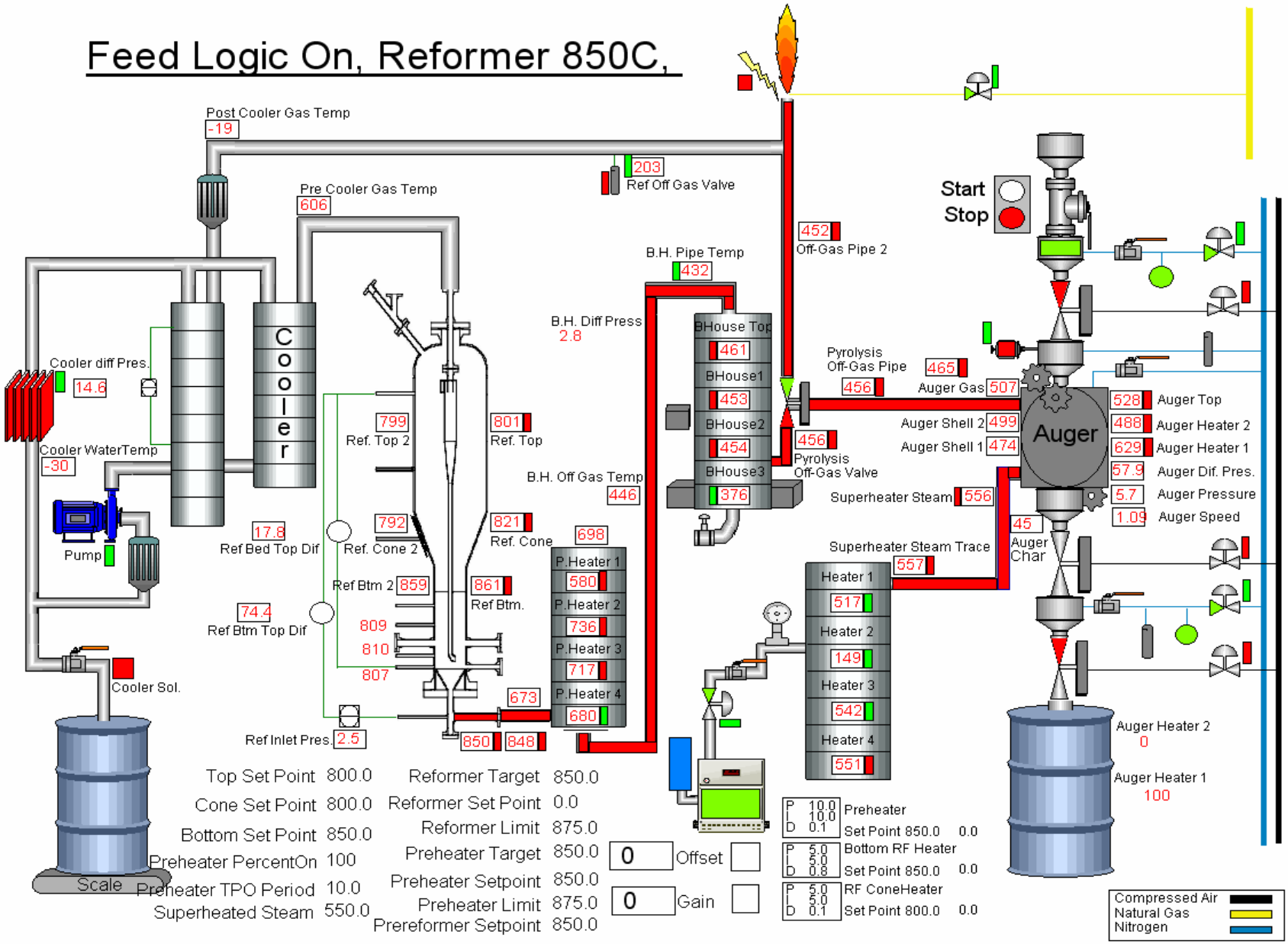
ALERT->Boiler res

Low Water Alert

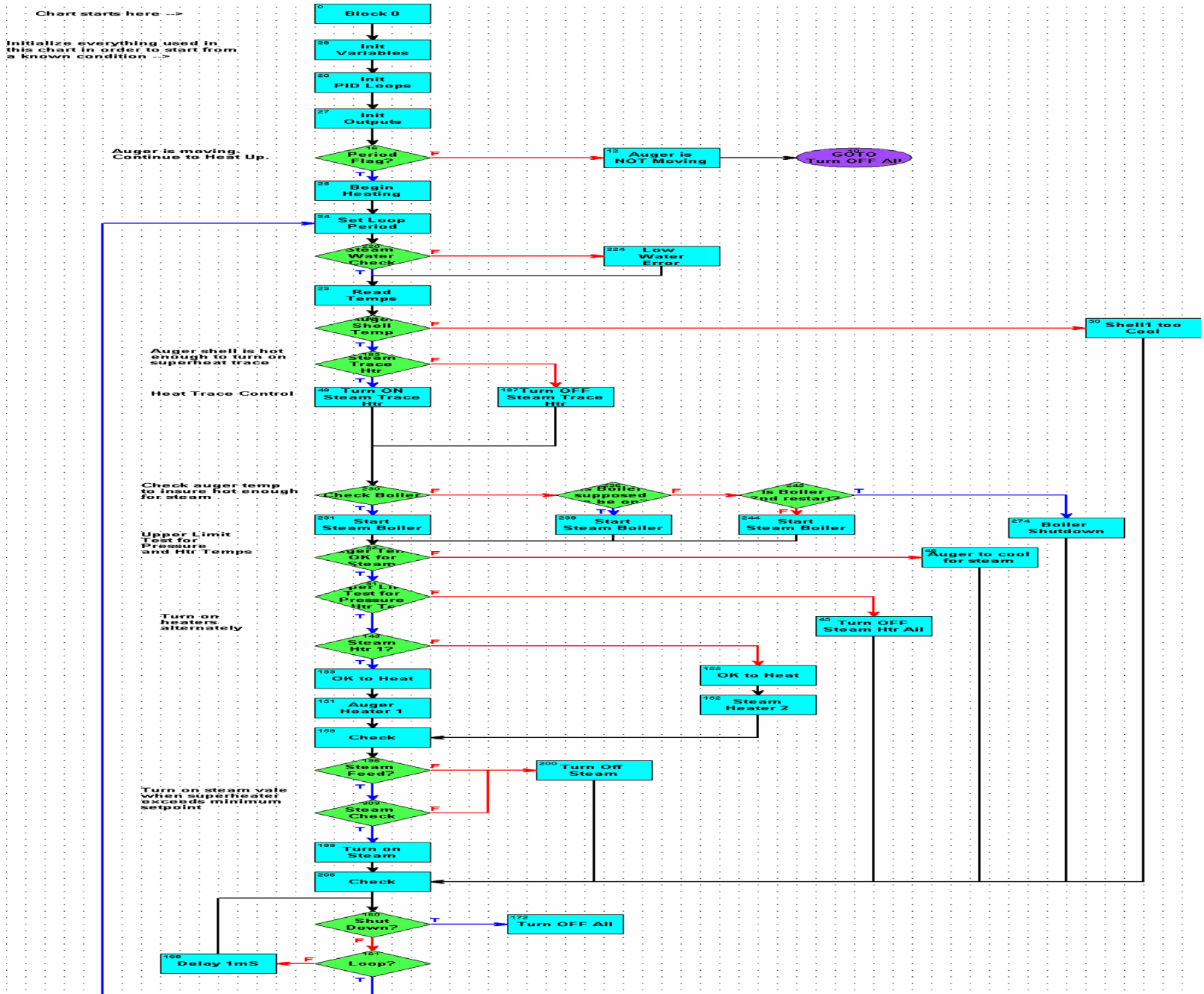
Alert->Steam Boile

Steam Pressure Error

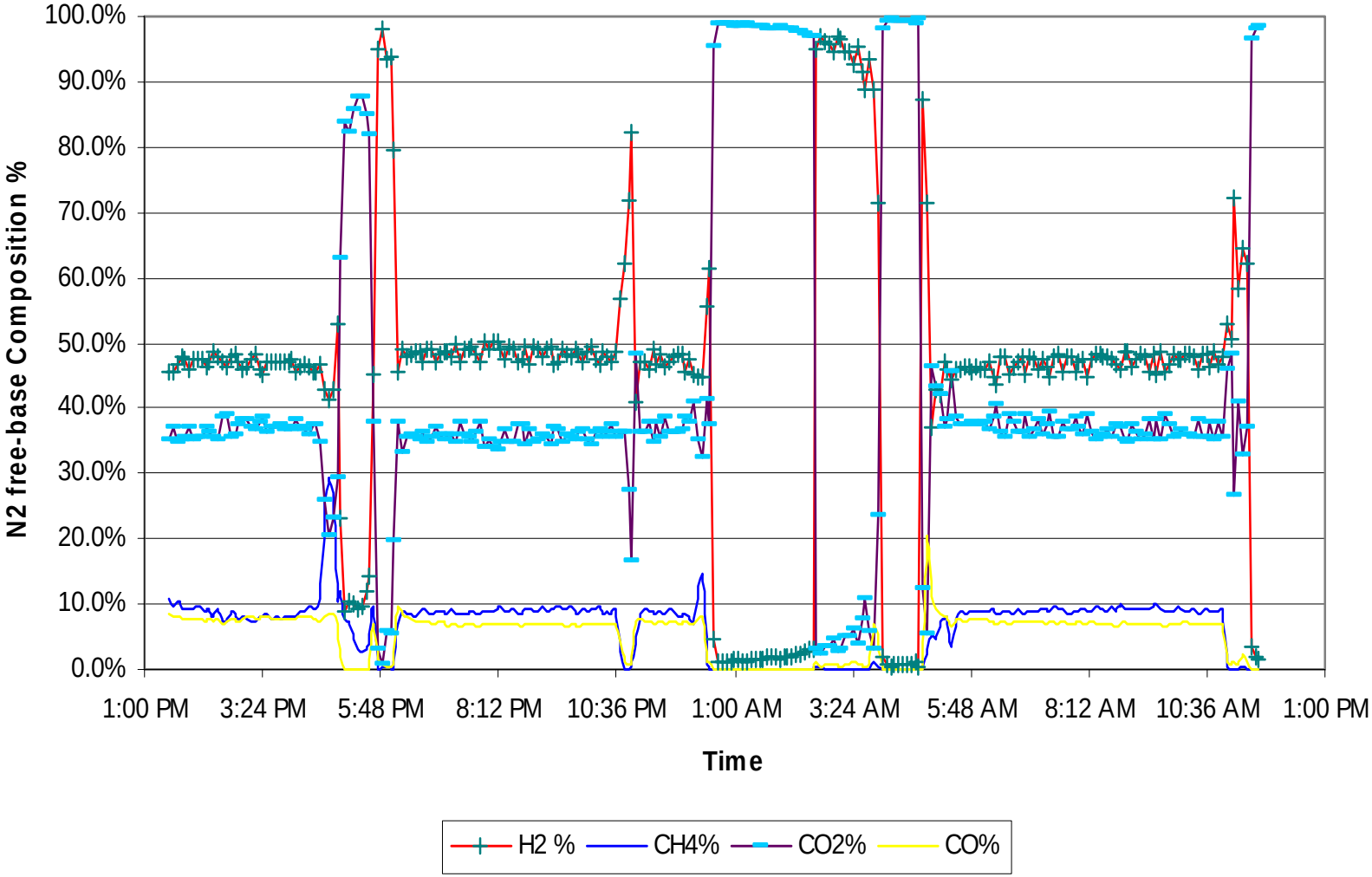
Superheater Error



Hydrogen Production Control (Program-Steam Heat-up)

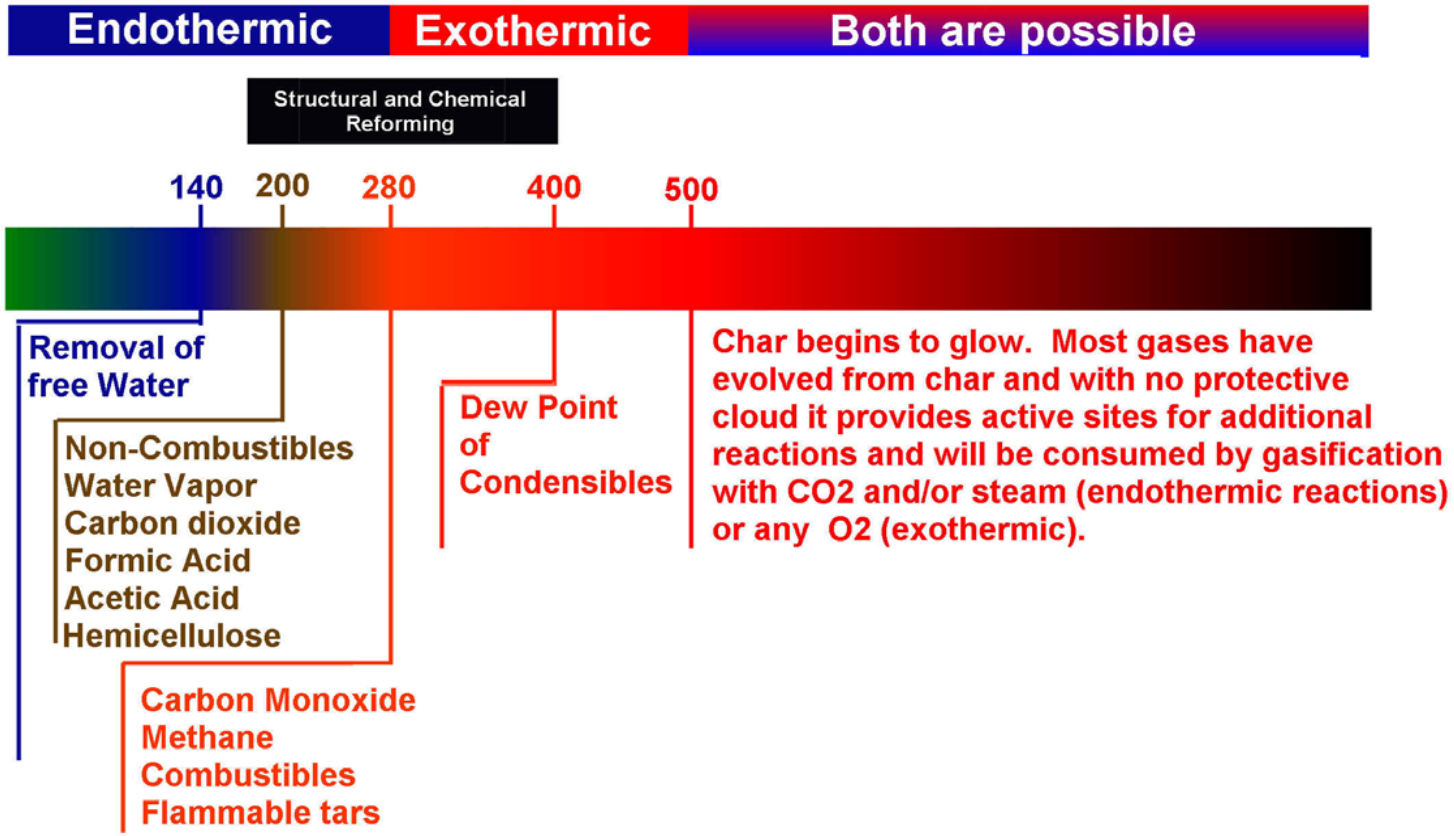


Nitrogen free-Base Gas Composition Vs.Time (24hrs)



Produced Char Sample

Char Formation

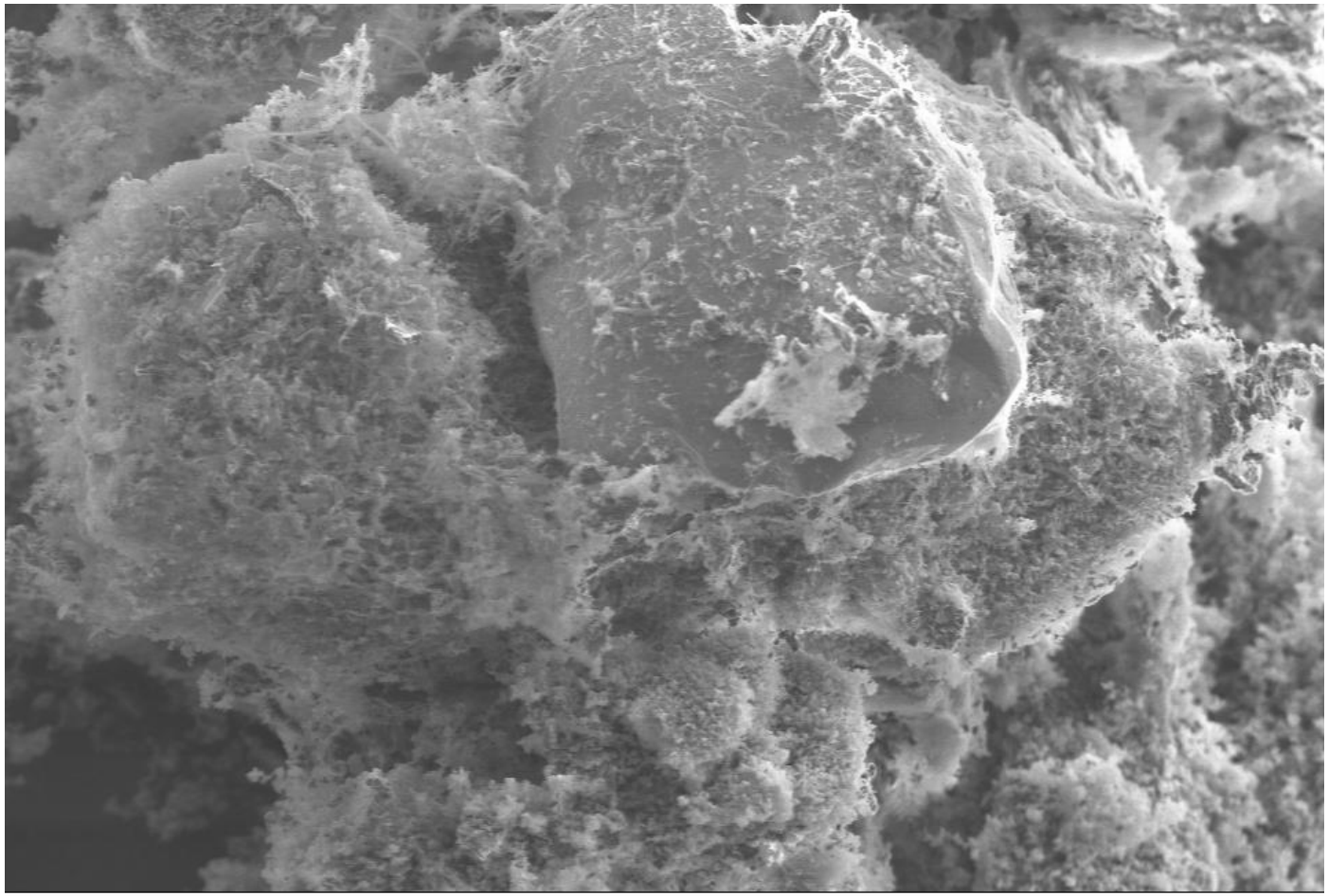


Polycondensates are formed >170C (Runkel and Wilke)

Copyright 2002 Eprida - Reproduction for non-commercial use granted

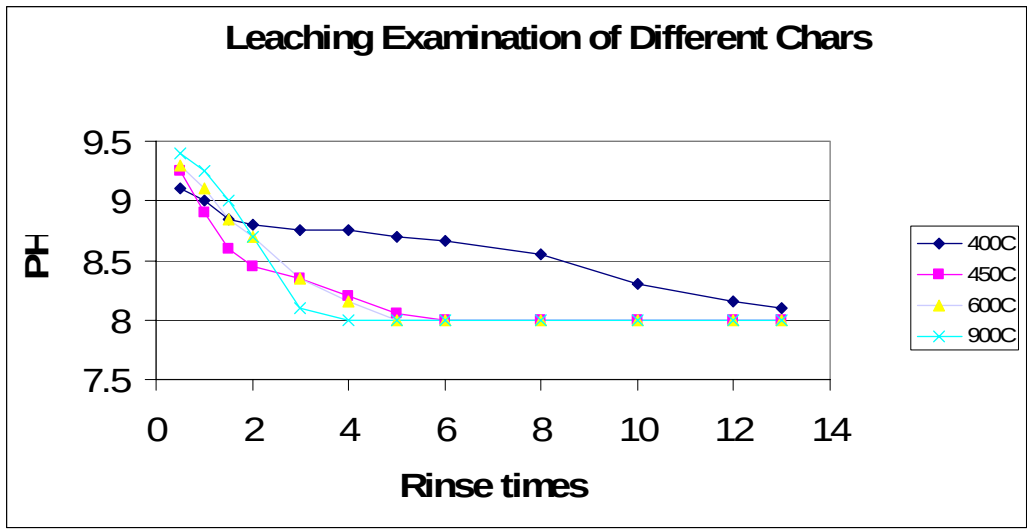
Formation of Ammonium Bicarbonate

(Inside the 15min Char Interior)



Mag = 422 X 20µm EHT = 5.00 kV WD = 18 mm Signal A = SE2 Photo No. = 8426 Date :14 Nov 2002 Time :23:04:32

Leaching Examination of Different Chars



- Test condition, 100ml Rinse, char sample 20.0g
- The 400C char showed the potential of long term slow release of nutrients, hinting good candidate for further testing.

Chemistry Calculation

H_2O (18) + NH_3 (17) + CO_2 (44) → NH_4HCO_3(79)↓

- At 1 atm, 25C, Air: ρ=1.2928 g/l, NH_3: ρ=0.7714 g/l, CO_2: ρ=1.9768 g/l

Bench scale test:

- Reactor volume: ~0.4 liter
- Char: 30.00g
- H_2O: 10.00g
- NH_3: 9.44g
- CO_2: 24.44g
- NH_4HCO_3: 43.89g

Pilot scale test:

- Reactor volume: ~74 liter
- Char: 1000g/hr
- H_2O: 294.70g/hr
- NH_3: 298.4g/hr
- CO_2: 720.5g/hr
- NH_4HCO_3: 1293.6g/hr

Schematic of Bench Scale Test

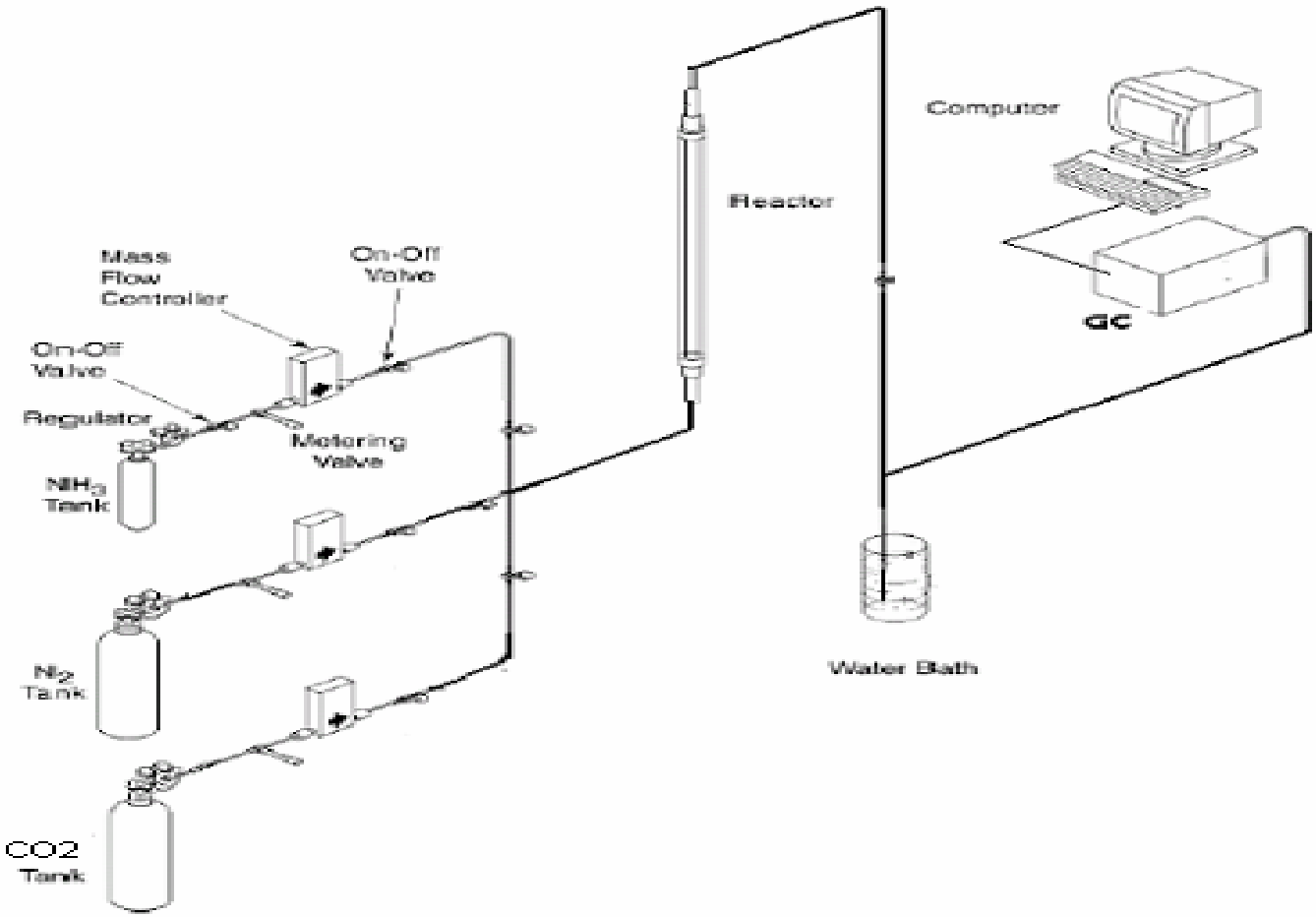


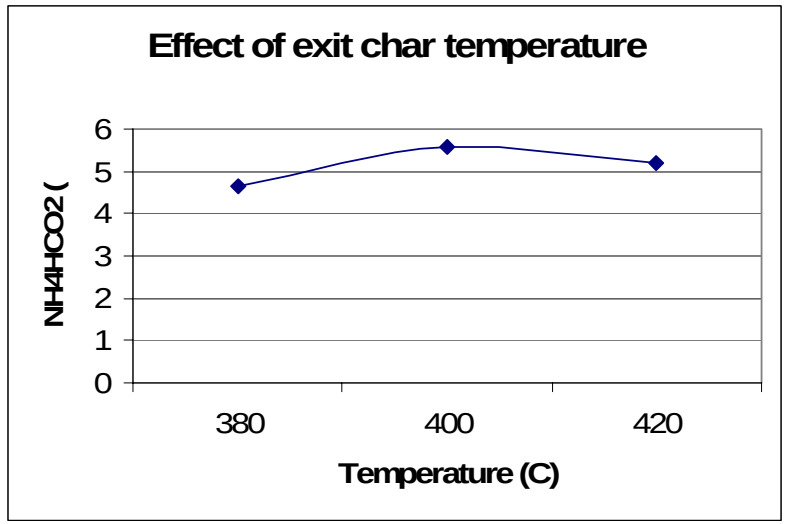
Photo of Bench Scale Test

Procedure of Bench Scale Test

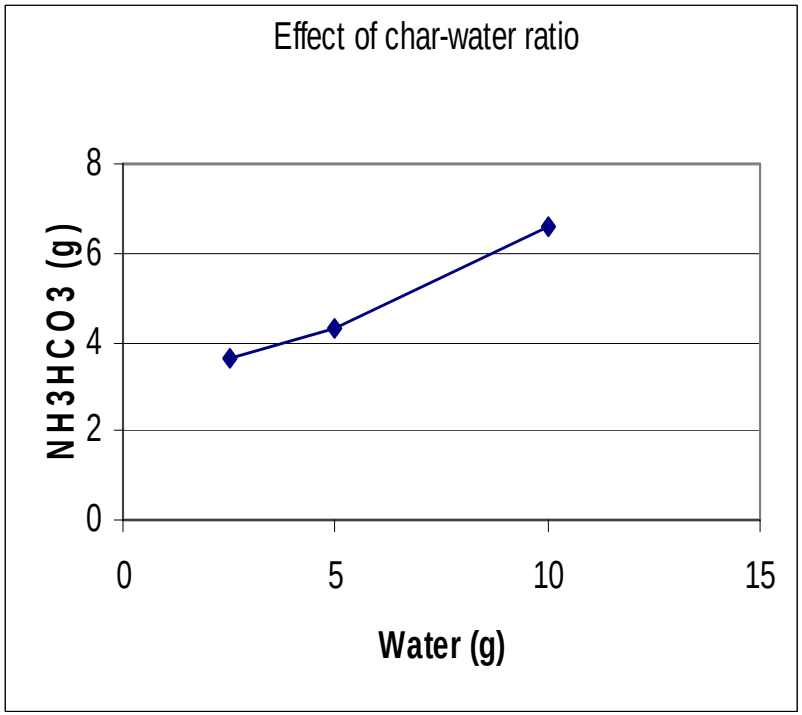
	Fertiler Test Procedure			
Tester		Date/Time		
Task #	Task	Setpoint	Reading	Notes
1	Record environmental temperature			
2	Record tested Char type			
3	Weight Reactor (g)		301.6	
4	Mix water with char (char/water)	11g/11g		
5	Fill wet char (g)	20		
6	Weight reactor + wet char (g)		321.6	
7	Check test setup fixture, install reactor	see drawing		
8	Open N2 to clean pipeline (cfm/min)	1 cfm/1 min		
9	Introduce NH3 to soak char (ccm/min), stir Char.			
10	Stop NH3			
11	Open N2 to clean pipeline (cfm/min)	1 cfm/1 min		
12	Introduce CO2 to make fertilizer (ccm/min), stir char			
13	Stop CO2			
14	Weight Reactor+Fertilizer (g)			
15	Store fertilizer and mark it			
16	Clean reactor etc.			

Effect of Exit Char Temperature on Fertilizer Absorption

- The chars with exit temperature at 380C, 400C and 420C have similar absorbability.
- 400C char has a little better performance.

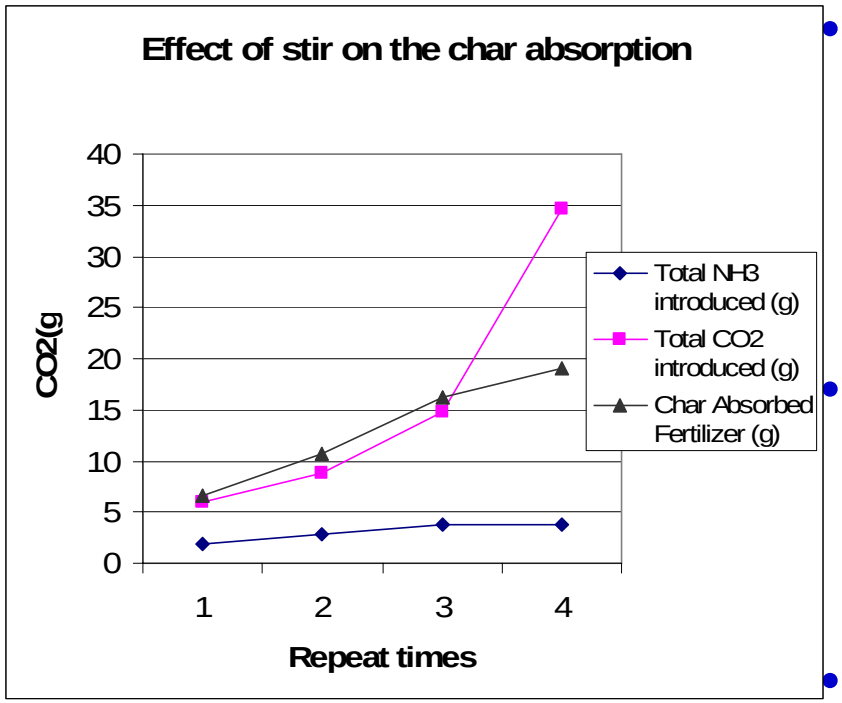


Effect of Char-water Ratio Char Absorption



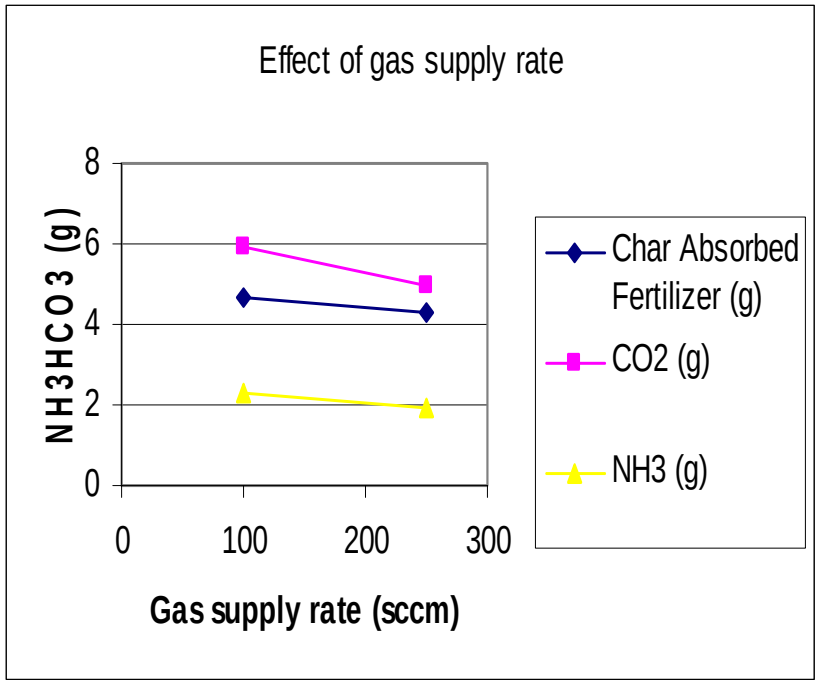
- Char with More water can produce more fertilizer.
- Not all water reacted with NH3 and CO2 and formed NH4HCO3. Some may absorbed by dry char.
- Mixing char and water with weight ratio of 2:1 to 1:1is recommended.

Effect of Stir on Char Absorption



- Repeatedly and alternately introducing NH3 and CO2 can significantly influence the production of the fertilizer.
- Stir the char inside the reactor can significantly help the absorption of fertilizer.
- Supplying NH3 and CO2 with mole ratio of 1:1.5 is recommended.

Effect of Gas Supply Rate

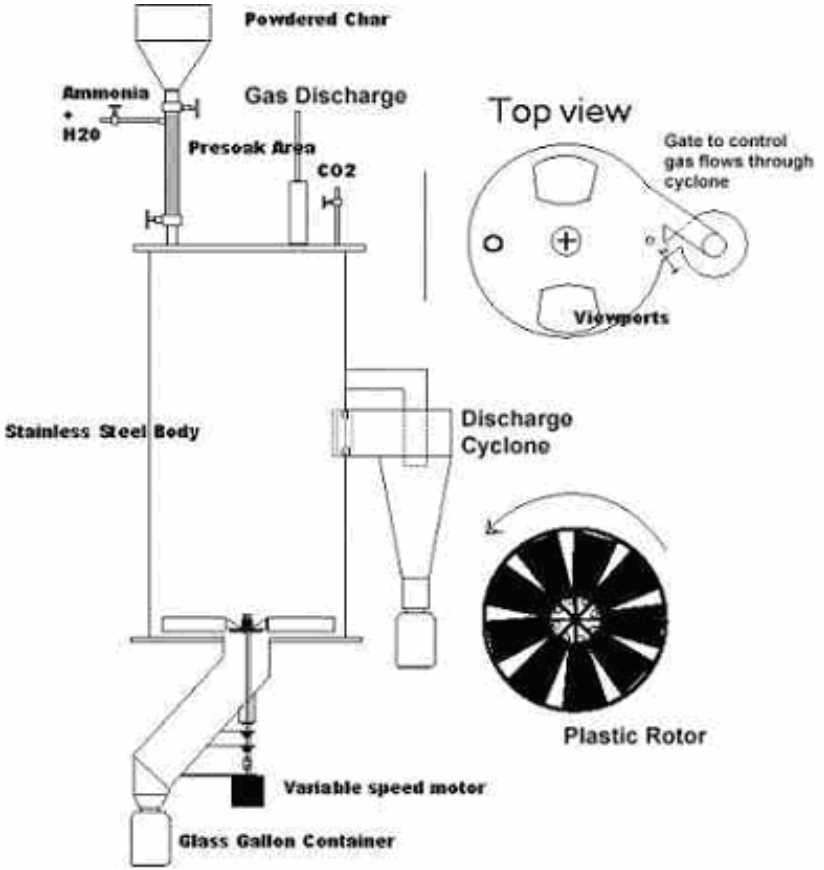


- Gas supply rates introduced into inside the reactor have no significant influence on the char absorption.
- The volume of the bench scale reactor is 400C. The recommended flow rate for this reactor is 200sccm for CO2.

Discussion of Bench Test Results

- The char with exit temperature 400C is recommended for bench scale test.
- Mixing char, water and ammonia with weight ratio of 2:1:1 is recommended.
- The mole ratio of 1:1:1.5 are recommended for H2O:NH3:CO2.
- 200 SCCM (reactor volume:400 cc) flow rate may proper for bench scale reactor.
- Stir the char inside the reactor can significantly help the absorption of fertilizer.

Schematic of Pilot Test Reactor



Suggestions for Pilot Scale Test

- Mix ammonia and water with ratio 1:1.
- Feed char with rate of 1000g/hr.
- Supply ammonia water blending with rate of 600g/hr.
- Introduce Carbon Dioxide with rate of 550g/hr. (4.6 l/min)
- Stir are necessary inside of the reactor.
- 2.3kg fertilizer (10% Nitrogen rate) per hour would be produced for above input.

FUTURE WORK

- NH_4HCO_3-char (Fertilizer) production
- Fertilizer characteristic evaluation
- Develop process models for scale up and process optimization.
- Perform detailed techno-economic analysis based on pilot results.

ACKNOWLEDGEMENTS

- Support of Department of Energy under Grant # DE-FG26-03NT41714.
- Support of the Partner Institutions
  - Clark Atlanta University
  - Eprida Scientific Carbons Inc.
  - Oak Ridge National Lab, Oak Ridge, TN
  - National Renewable Energy Laboratory