Development of a Hydrogasification Process for Co-Production of Substitute Natural Gas (SNG), Biofuel and Electricity from Western Coal

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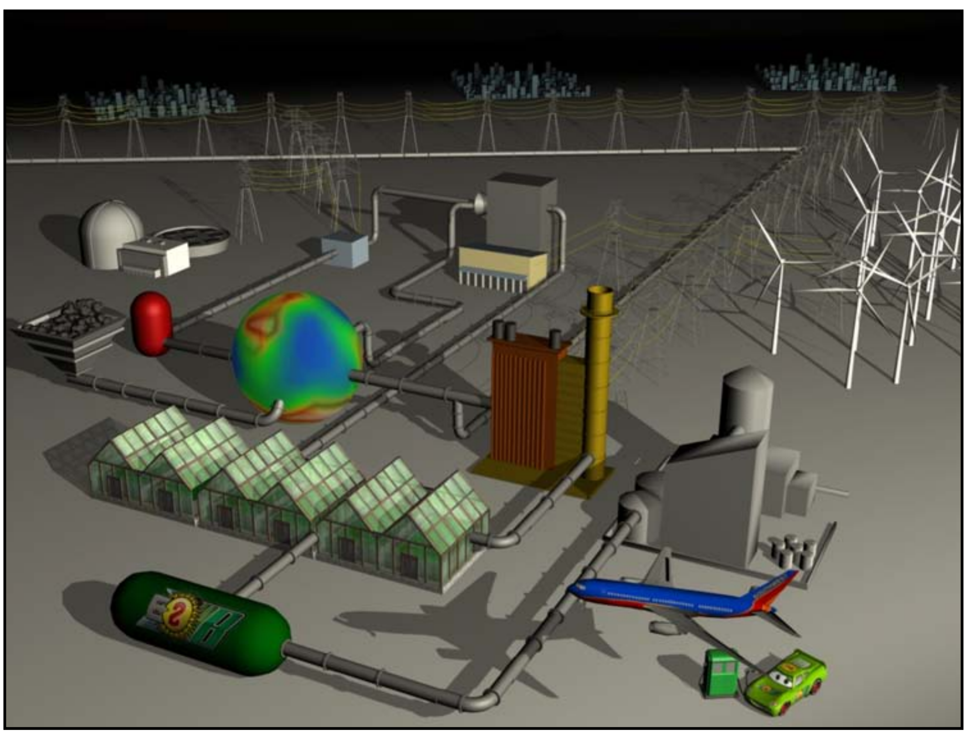
Carbon Summit September 17, 2008
Scottsdale, Arizona



What has changed?

Public Policy

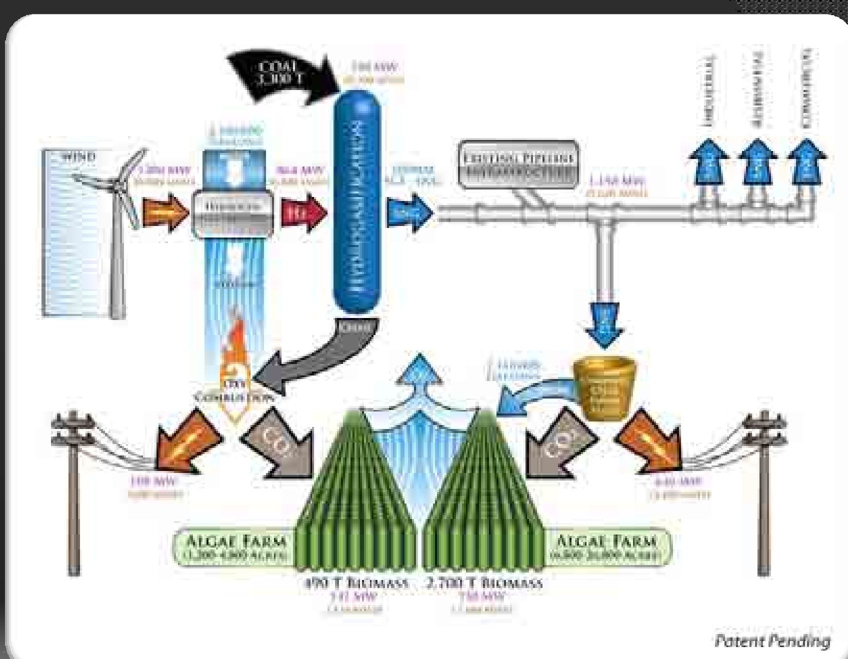
- Renewable Standards Portfolio (RPS)
- Utility Mandates
- CO2 Financial Penalties (high potential)

Public Values

- Greening
- Efficiency, recycling, less waste

Sustainability – very long term

- *Food*
- *Water*
- *Energy*



Why go thru all the pain of the process?

2000 pounds of subbituminus coal costing $23

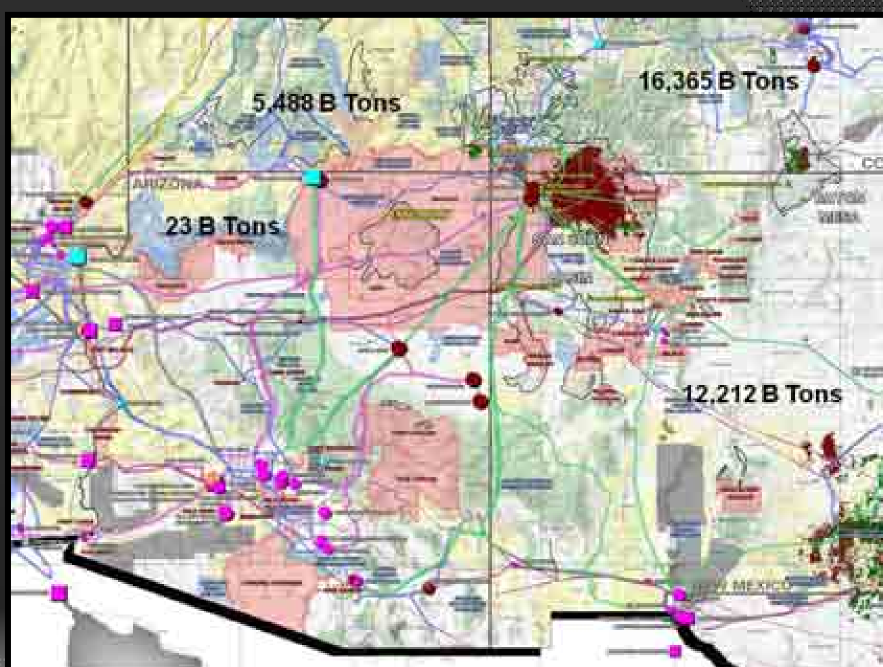
Sub-critical PC Plant running 30% efficient (1.87 MWH/ton)

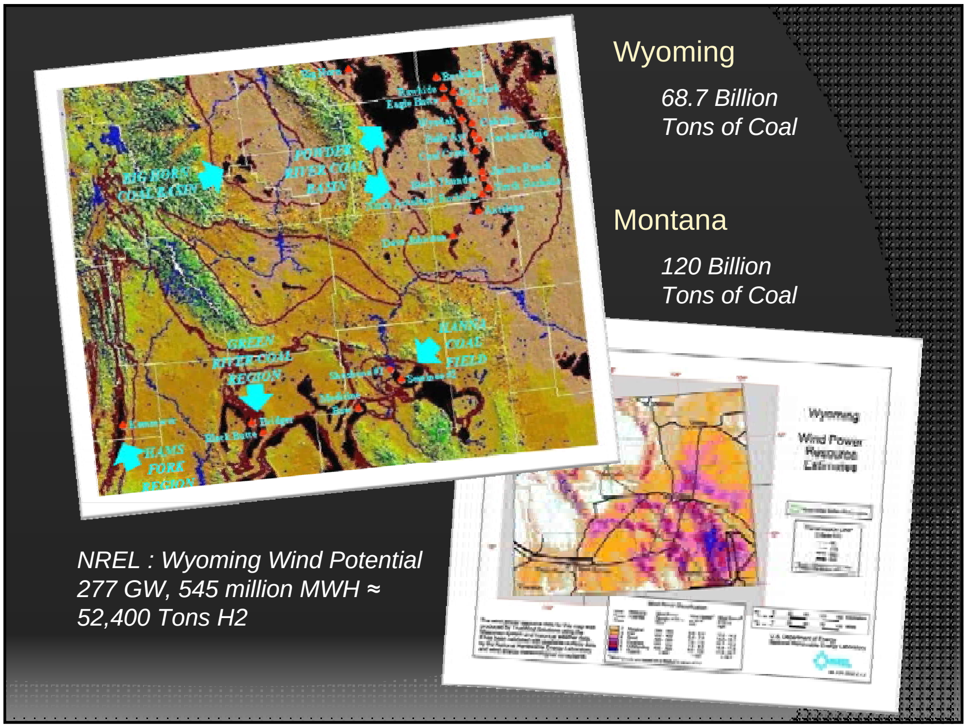
Revenue $28-$94, electric sales (@ $15 – $50/MWH)
*Consumes 2,281 gallons of water**
Penalty for 4,392 pounds of CO2, costing $21.96 - $76.86 ($10 - $35/ton)

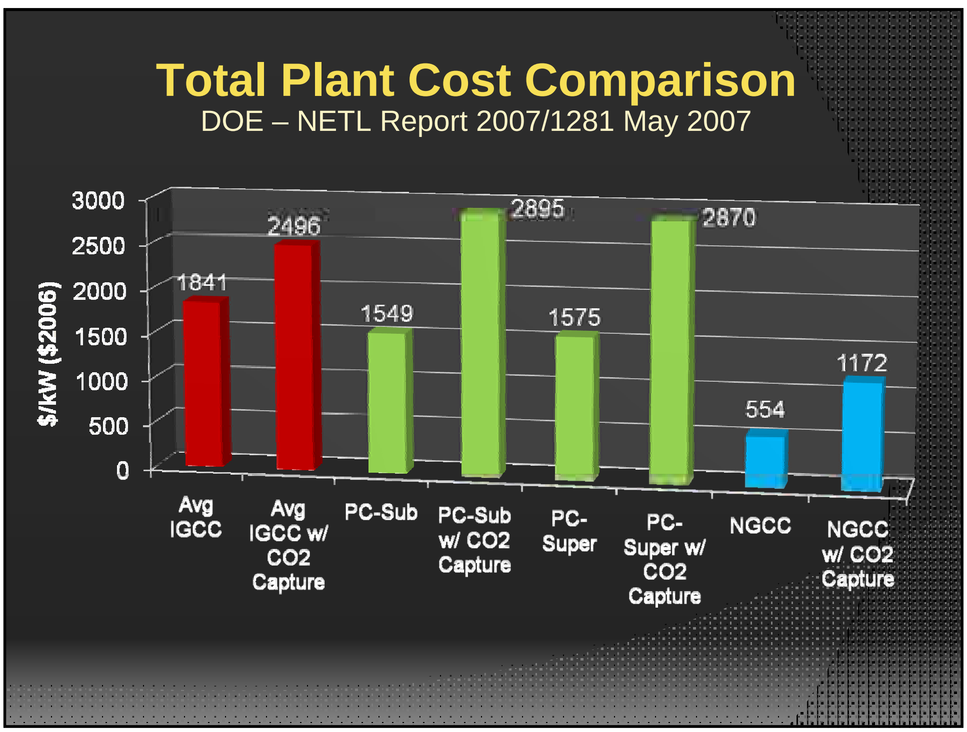
AHP SNG Carbon to Product (Fuel – SNG)

Consumes 640 gallons of water.
Consumes 176 kg of hydrogen.
Revenue $240 - $430 SNG (9 MWH thermal @ $8-$14 MMBTU).
Revenue Electric sales $13-$45 (0.9 MWHrs from oxy-combustion steam-electric at 46% efficiency - $15-$50/MWH).
Oxy-combustion makes 677 pounds of CO2, which can be recycled into 1278 pounds of Biomass (Oxy-combustion from steam electric).
Revenue Biomass $128 - $1086 (@ $0.10/lb to $0.85/lb).

** DOE – NETL Report August 2005, Power Plant Water usage and loss study*




Wyoming
68.7 Billion Tons of Coal
Montana
120 Billion Tons of Coal
POWDER RIVER COAL BASIN
BIG HORN COAL BASIN
GREEN RIVER COAL REGION
HANNA COAL FIELD
HAMS FORK REGION
Wyoming Wind Power Resource Estimates
NREL : Wyoming Wind Potential
277 GW, 545 million MWH ≈
52,400 Tons H2


Total Plant Cost Comparison
DOE – NETL Report 2007/1281 May 2007
$/kW ($2006)
3000
2500
2000
1500
1000
500
0
1841
2496
1549
2895
1575
2870
554
1172
Avg IGCC
Avg IGCC w/ CO2 Capture
PC-Sub
PC-Sub w/ CO2 Capture
PC-Super
PC-Super w/ CO2 Capture
NGCC
NGCC w/ CO2 Capture

Challenges

- Hydrogasifier
- Coal Feed – Char Removal
- Pathway for large scale hydrogen production with renewable energy acceptance into the process
- Advanced Algae Bioreactor – Cost Effective.
- Algae dewatering
- Algae Farm water recycling

Project Status

- Hydrogasification
  - BSRx (Bench Scale Reactor – Kinetics)
  - Support Process
  - Test Plan
- CO2 Capture
  - Advanced Membrane – MTR
  - Prior Algae Work
  - Future Work
    - IGV – 4000L System
    - Scalable Bioreactor Demonstration
- Aviation Fuel Process from Algal Oil

SNG Process Comparison Between Steam-Oxygen Gasification and Hydrogasification

Overall Stoichiometry of Steam-Oxygen Gasification*

$$CH_{0.8}O_{0.2} + 0.55O_2 + 0.15H_2O \rightarrow 0.28CH_4 + 0.73CO_2$$

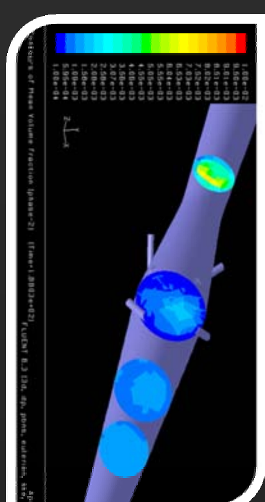
Overall Stoichiometry of Hydrogasification

$$CH_{0.88}O_{0.12} + 1.82H_2 + 0.40O_2 \rightarrow 0.83CH_4 + 0.16CO_2 + 0.59H_2O$$

Overall Stoichiometry of Hydrogasification with Electrolysis

$$CH_{0.88}O_{0.12} + 1.23H_2O \rightarrow 0.83CH_4 + 0.16CO_2 + 0.51O_2$$

*: Steinberg, M., Process for Conversion of Coal to Substitute Natural Gas (SNG). 2005, HCE, LLC: Melville, NY.



NETL Computational Modeling

BSRx

Hydrogasification Reactor

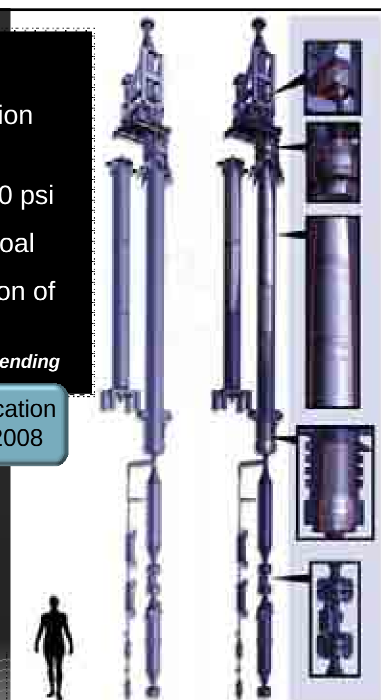
1900 F @ 1000 psi

Hydro-crack Coal

Flash production of methane

Patent Pending

BSRx in fabrication
Delivery Oct 2008



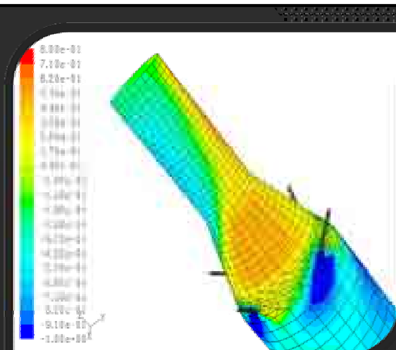
Kinetics Reactor Design

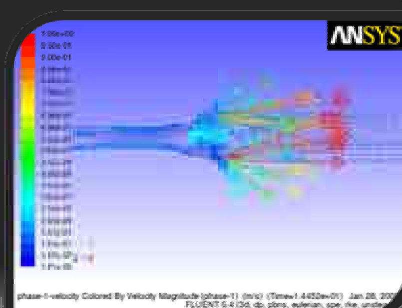
ASME Certified Reactor

- Reactor Design Highlights
  - One step Methane synthesis
  - Double wall design
  - Entrain Flow
  - No refractory
  - Dry coal feed rate 5 -15 lb/hr
  - Pulverized coal feed 200 mesh
  - Residence time up to 40 s
  - Inner Tube Design Pressure 1150 psig
  - Inner Tube Design Temperature 1950°C
  - Design Pressure Differential 50 psid
  - Design temperature for expansion calculation 1750°C
  - Reactor Annular Space 1200 psig
  - Char Pot 1150 psig
  - Bellows 1200 °F

CFD Modeling

- Hydrodynamics Study
  - Reactor Design
  - Hydrogen Nozzle Design
- Reaction Prediction
  - Kinetics Implementation
  - Model Validation
  - Reaction Prediction





Example 1: Nozzle Design

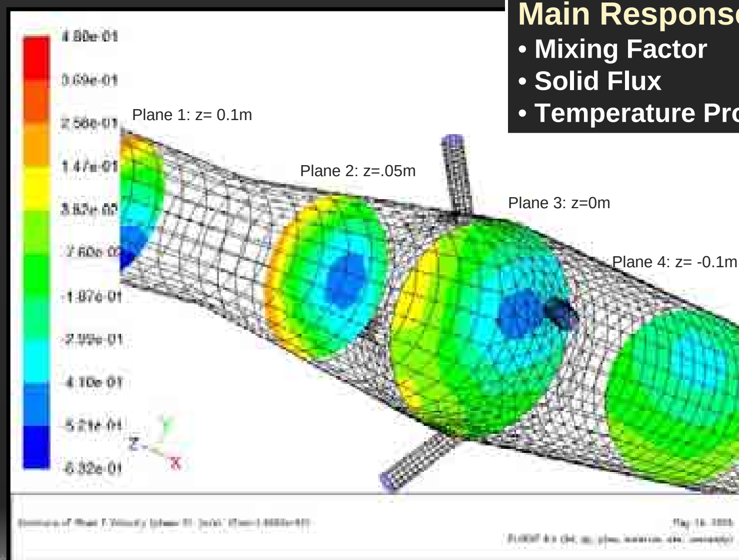
Evaluating Parameters

Hydrogen Injector I.D. (in)	0.064-0.18
Shooting Angle (°)	45-75
Coal Feed Rate (lb/hr)	5-15
H2 Feed Rate (lb/hr)	0.5-5.85
H2 Carrier Gas Rate (lb/hr)	0.05-1.5
Swirling(°)	30-60

DOE Design

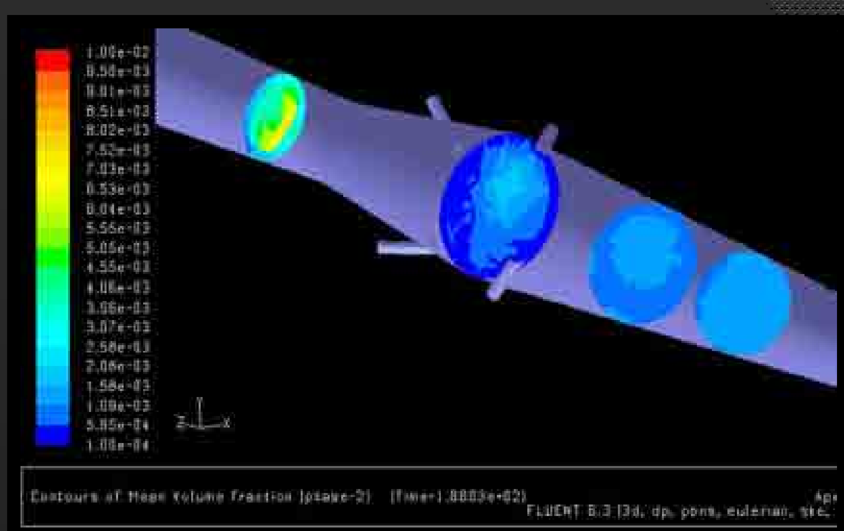
Rows	Injector I.D. (in)	Shooting Angle (°)	Coal Feed Rate (lb/hr)	H2 Feed Rate (lb/hr)	H2 Carrier Gas Rate (lb/hr)	Swirling (°)
1	0.06	75	15.00	5.85	0.15	60
2	0.18	45	6.40	1.92	0.64	60
3	0.06	75	15.00	4.50	1.50	30
4	0.06	45	15.00	2.85	0.15	30
5	0.06	45	15.00	1.50	1.50	60
6	0.18	75	15.00	4.50	1.50	60
7	0.12	60	10.00	3.18	0.78	45
8	0.18	45	5.00	0.62	0.38	30
9	0.18	75	5.00	0.91	0.09	60
10	0.18	45	15.00	2.85	0.15	60
11	0.18	45	15.00	5.14	0.86	30
12	0.18	75	13.61	5.31	0.14	30
13	0.06	45	5.00	1.95	0.05	60
14	0.06	45	6.48	2.00	0.59	30
15	0.06	75	6.37	0.64	0.64	60
16	0.06	75	5.00	0.94	0.06	30
17	0.18	75	15.00	1.50	1.50	30

Response and Location of Planes



Main Responses:
- Mixing Factor
- Solid Flux
- Temperature Profile

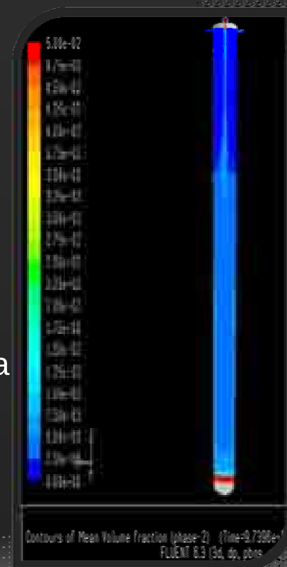
Good Mixing



Example 2: Reaction Simulation

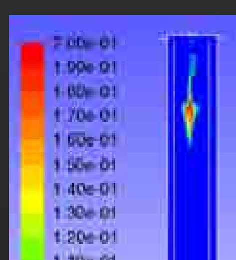
- Investigate effect of:
  - Temperature,
  - H2/Coal Ratio,
  - Coal feed rate,
  - Pressure
- Evaluate production of:
  - CH4, CO, CO2, H2O, BTX, Tar, Cha
- Evaluate H2 conversion

  With implanted kinetics

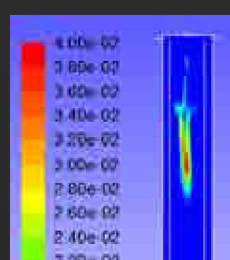


Example 2: Reaction Simulation

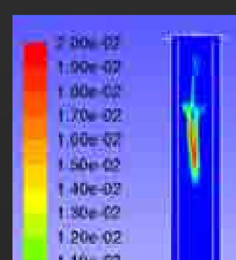
Reaction rate of the devolatilization (kgmol/m3.s)



Coal → CH_4

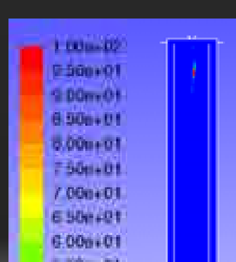


Coal → CO

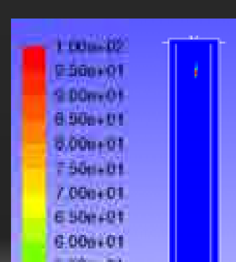


Coal → CO_2

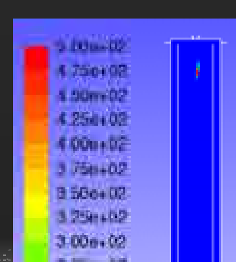
t=3.1 s



Coal → BTX



Coal → OIL



Coal → Rapid Carbon

Kinetics Reactor Testing Process

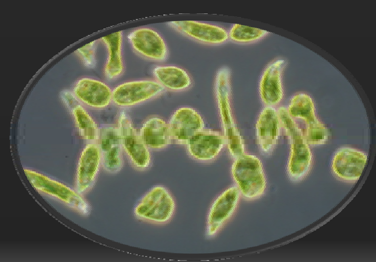
- Phase II – Process Highlights
  - Hydrogen in-house supply
  - High pressure dry coal feeding
  - Reactor external heating
  - Duel char pot design
  - Duel liquid condenser design
  - On line gas analysis
  - Off line liquid and char analysis

Coal Feeder

- Coal Feeder Test Procedures have been developed.
- Testing will occur prior to mounting to reactor.

Why use algae to capture CO2?

- High growth rates (gram/M2-day)
- Continuous operation
- Does not require arable land
- Does not compete with food crops
- Large variety

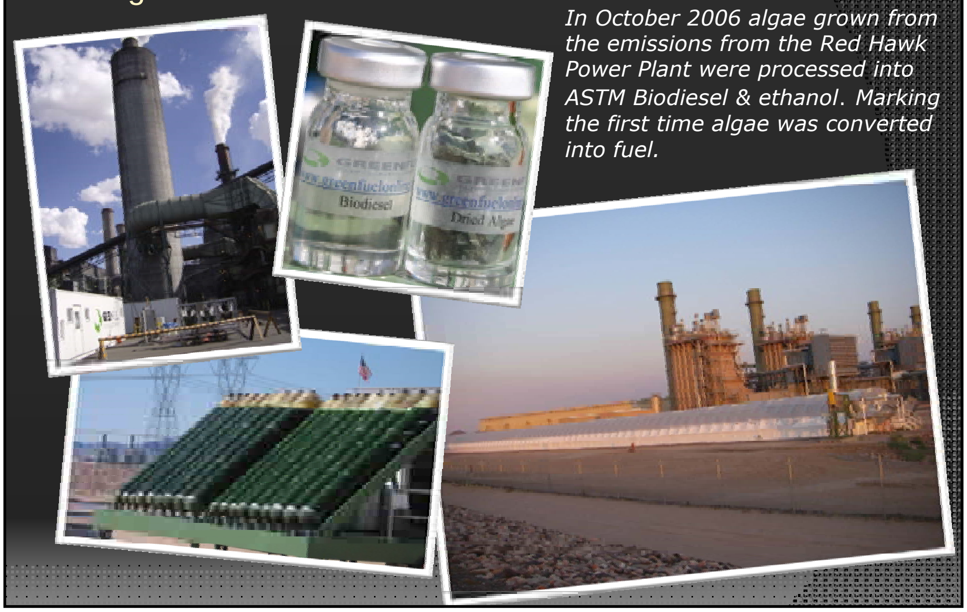


Crop	*Oil gal/Acre*
Algae	1600 - 8550
Corn	13
Soy	47
Safflower	83
Sunflower	102
Castor	150
Rapeseed	171
Jatropha	192
Jojoba	192
Coconut	290
Palm	640

APS & GreenFuel efforts 2005 thru 2007

Algae to Biodiesel

In October 2006 algae grown from the emissions from the Red Hawk Power Plant were processed into ASTM Biodiesel & ethanol. Marking the first time algae was converted into fuel.



2008 – 2010 Coal to SNG Project – CO2 Recycling- Goals

1. CO2 Capture Alternative
2. JP8 from CO2 emissions
3. Large Scale

Project Team has extensive experience in closed & open algae systems

Advanced CO2 Separation Membrane

- Evaluation of the MTR Membrane
- 100 scfm slip stream will be supplied to membrane system.
- Goal: 36% CO2 concentration in product stream.

IGV – 4000L

- The 4000 liter IGV algae system will be installed and integrated with operations at the Red Hawk Plant. All equipment and systems are on site.
- **90% CO2 consumption.**

Scalable Bioreactors and supporting Systems will be demonstrated using a slip stream from a power plant stack in 2009.

Bag Farm

Built to provide algae paste for lab work.

Sample from first Algae Harvest

Algae Lipid Analysis from APS Program

Producing Fuels from Algae:

- Dewatering
- Oil Extraction
- Identification of Catalysts

To: APS
ANALYTICAL REPORT

Sample Description: Algae oil (crude) Aug 20/08

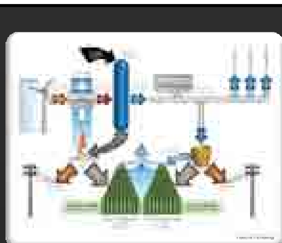
PO#:

Analysis Results:

Analyte	Result	Units
Elemental Analysis		
Phosphorus	12100	ppm
Fatty Acid Profile - Area %		
C6 Caproic	0.11	%
C10 Capric	0.03	%
C14 Myristic	0.88	%
C15 Pentadecanoic	0.04	%
C16 Palmitic	12.88	%
C16:1 Hexadecenoic	1.82	%
C17 Margaric	1.58	%
C18 Stearic	0.30	%
C18:1n9 Oleic	2.42	%
C18:1 Octadecenoic	0.61	%
C18:2 Linoleic	39.09	%
C18:3n3 alpha-Linolenic	3.14	%
C20 Arachidic	0.18	%
C20:1 Eicosenoic	0.19	%
C20:2n6 Eicosadienoic	0.23	%
C20:4n3 Eicosatetraenoic	0.03	%
C22 Behenic	0.08	%
C24 Lignoceric	0.15	%
Others	36.23	%
Total Saturates	16.23	%
Total Monounsaturates	5.04	%
Total Polyunsaturates	42.49	%
Total Omega 3	3.17	%
Total Omega 6	39.32	%
Total Omega 9	2.61	%

Biofuel from Power Plant Emissions

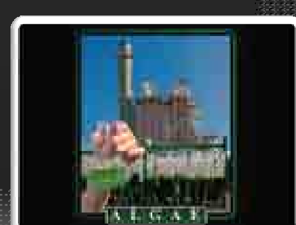
- Dried algae from Red Hawk, APS – 10,000 BTU/lb
- Biodiesel – first ASTM Biodiesel made Oct 2006.
- Ethanol – first ASTM ethanol made October 2006.
- Green Diesel / Renewable Diesel can be made from bio-oil.
- Direct vegetable oil engines tested at Yellowstone 2007.
- DOD/DOE effort to create a production process leading to JP8 from algal oil.



New Fuel Production Methods……. Existing Infrastructures

Energy & Farming

By integrating renewable energy with coal, an energy storage strategy emerges which uses carbon to store hydrogen in fuels that will be sustainable and in harmony with life.




Integration
FOOD
WATER
Energy