

# Power Plant Emissions to Biofuels

**US DOE/NETL Contract No: DE-FC26-06NT42759**

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*Arizona Public Service*

**NREL-AFOSR Workshop on Algal Oil for Jet Fuel Production**

**February, 19-21, 2008**

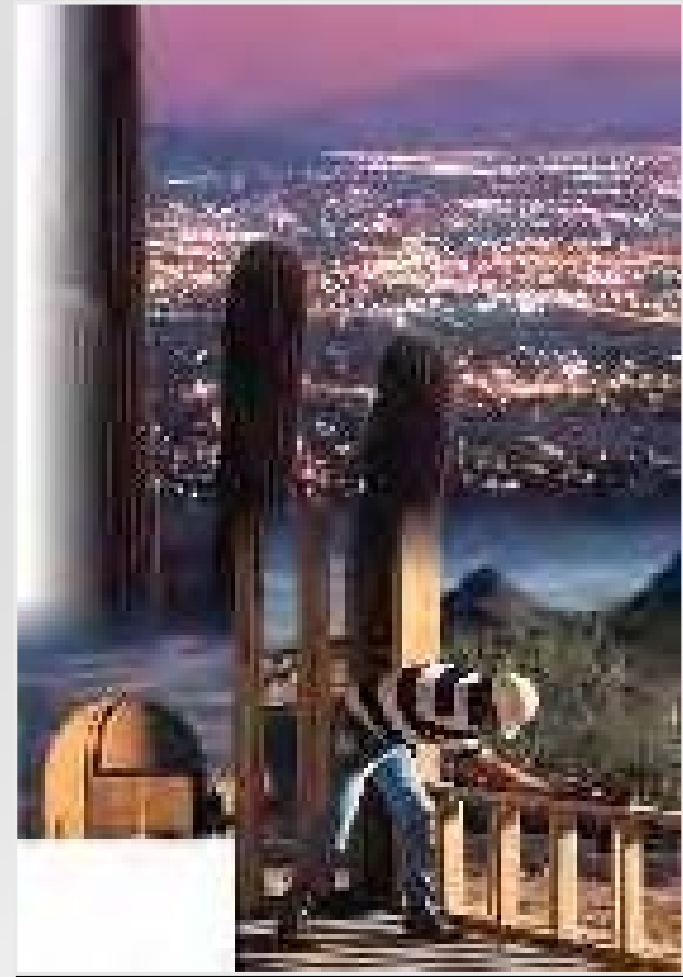


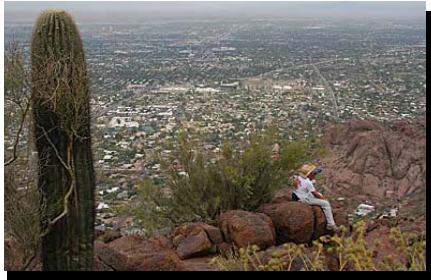


# PINNACLE WEST CAPITAL CORP

- \$ 3.4 Billion Revenue\*
- Retail Energy - APS Energy Services
- Pinnacle West Energy
- Arizona Public Service - APS
- Real Estate - SunCor
- Venture Capital - El Dorado
  
- \$ 11.3 Billion Assets\*
- \$327 Million Income\*

\* Results For Year 2006





# APS

## Serving 11 of Arizona's 15 counties

- *Investor Owned Electric Utility – (PNW)*
- *Regulated by Arizona Corporation Commission*
- *2006 reached 1 million Customers (meters)*
- *50,000 square miles of Service Territory*
- *7,000 MW Owned Generation Capacity*
- *12,500 MW Managed Generation Capacity*
- *2006 Peak 7,649 MW, not exceeded in 2007*
- *2007 record number of days at or above 110 F*
- *Generation Mix: 31.2% Coal, 16.5% Nuclear, 17.3% Gas, 35% Purchased*

# NUCLEAR



**Palo Verde – 4,000 MW**  
*Largest Nuclear Plant in the USA*



# COAL FIRED POWER PLANTS

Plant	Total MW	APS MW
Four Corners	2,040 MW	782 MW
Navajo	2,250 MW	337 MW
Cholla	1,000 MW	715 MW



# What drove the program?

- **APS needs Fuel for electric generation. Natural Gas is Great!**
  - ▮ **SNG from coal can meet the need for stable fuel (CH<sub>4</sub>) supply & price**
  - ▮ **Utilize existing infrastructure & meet 2015 commercial target**
- **APS will have to deal with CO<sub>2</sub> capture.**
  - ▮ **Create a use of CO<sub>2</sub> emissions.**
  - ▮ **The Algae option allows the recycle of carbon**
  - ▮ **Algae may prove good economics**
- **APS has made sustainability part of corporate culture.**

# WHY MICRO-ALGAE?

- High productivity per unit area (g/m<sup>2</sup>-day)
- Harvested daily, reducing inventory and logistics
- Do not need arable land
- Do not need potable water
- Able to de-link food/fuel competition
- Tremendous natural variability; over 50,000 species each with many strains.

Crop	Annual Oil Yield liter/ha
Corn	120
Soy	440
Safflower	780
Sunflower	950
Castor	1400
Rapeseed	1600
Jatropha	1800
Jobba	1800
Coconut	2700
Palm	6000
Algae	15,000-80,000



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# Biological Capture of Carbon Dioxide Power Plant in power plant flue gas emissions using naturally occurring algae

## *Review of GreenFuel Vertical Thin Film Performance from Summer 2007 Testing*

October 2007





# Background

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- GEN2 installed on MIT power plant roof top
- GreenFuel first installed Advance Module (GEN3) bioreactors in Jul 2005
- Ran for approximately 15 months
- Installed advanced VTF (Vertical Thin Film) technology (GEN5) starting Nov 2006
- Commenced testing April 2007

# 2004: GEN2 1 MIT, Cambridge, MA

## 35MW (oil & gas)

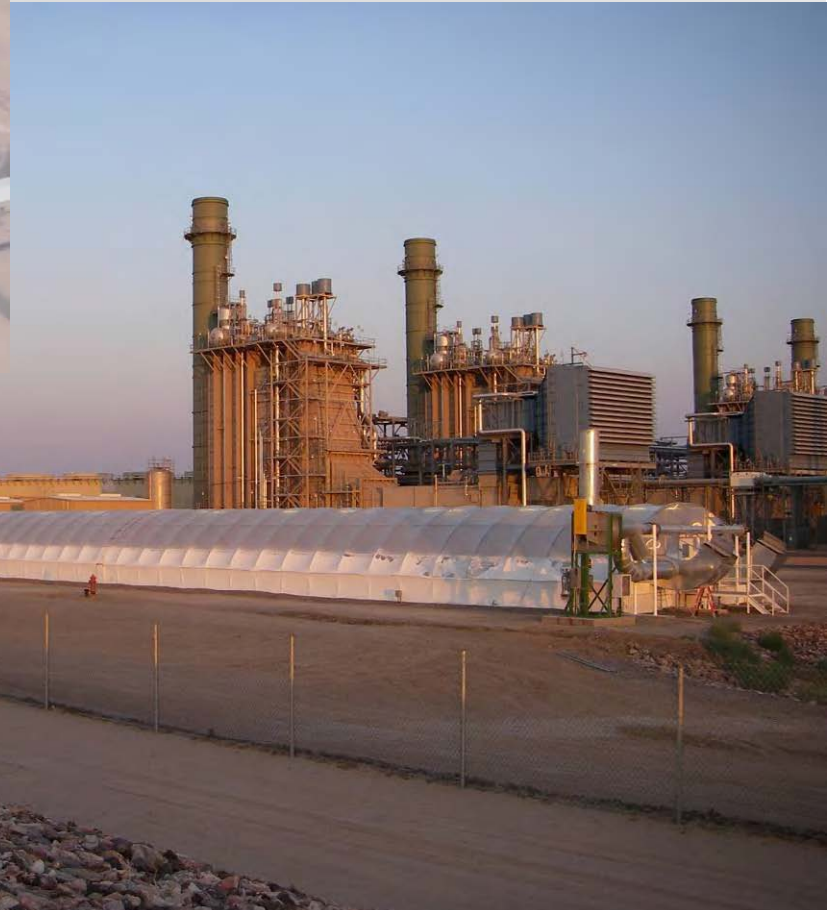


# 2005: GEN3 at APS



# 2006-2007: GEN5

## *APS Red Hawk, 1060 MW NGCC*



# CO2 Capture by Algae





# System

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- **1000 M<sup>2</sup> Closed System**
- **CO<sub>2</sub> input from Red Hawk Power Plant – Direct Flue Gas from Stack, no pre-treatment of flue gas**
- **Identification of some design issues that needed further refinement**

# 4C Coal Plant (2000 MW) looking East



© 2007 Europa Technologies  
Image © 2008 DigitalGlobe  
Image © 2008 TerraMetrics  
Streaming 100%

© 2007 Google™

Pointer 36°41'10.32" N 108°28'19.67" W elev 5370 ft

Eye alt 8317 ft



# 750 MW PC Plant - Algae Farm

## Pulverized Coal Plant

Rating	750	MW
Bituminous Coal (hhv)	12,000	BTU/lb
Fixed Carbon	60%	
Plant Efficiency	33%	
CO2 concentration	15%	
Coal Feed Rate	7,041	Ton/day
CO2 Capture Rate	40%	
Algae Farm	8,322	acres
1 Year	346	days
Total Algae Yield	1,141,987	Tons/yr
Raw Energy Yield	22,771,216,358,9	BTU/yr
Raw Energy Yield	885	MW
Bio-Oil Yield	38,270,952	gallons

- VTF – Vertical Thin Film Configuration
- Operated during daylight hours
- Flue gas fed directly to Farm
- Water Recycled
- Low Pressure System
- Plant low grade heat supplied to Farm
- Flue gas moisture recovered in Farm

Algae Growth Rate	98	g/m2/day
CO2 capture rate	184	g/m2/day
	744,562	g/acre/day
1 year	346	day
CO2 Capture Rate	258	T/acre/year



# Biofuel from Power Plant Emissions

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- *Dried algae from Red Hawk – 10,000 BTU/lb*
- *Biodiesel – first ASTM Biodiesel made Oct 2006.*
- *Ethanol – first ASTM ethanol made October 2006.*
- *Green Diesel – patented by UOP, can be made from algal oil.*
- *Direct vegetable oil engines tested at Yellowstone 2007.*
- *DOD/DOE joint program to create a production process leading to military fuel from algal oil.*
- *APS/NETL Briefed 25 Utilities in February 2007.*

# APS FLEET VEHICLE 07001X

*Fueled with E2B 20 Biodiesel*

*APS Vehicle 1<sup>st</sup> to  
operate on Power  
Plant Emission*



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**Efforts on**

**High Heating Value Bio-Fuel Development**

# Previous Trial (1)

Test	Method	Result	Specification
Calcium/Magnesium combined	EN 14538	< 1 ppm	5 max
Sodium/Potassium combined	EN 14538	< 1 ppm	5 max
Flash Point	D93	385 °F	199 min
Water Content	D2709	< 0.050 %	0.05 max
Sediment Content	D2709	< 0.050 %	0.05 max
Viscosity @ 40°C	D445	4.58 cSt	1.9-6.0
Sulfated Ash	D0874	0.00 % (wt)	0.02 max
Sulfur (x-ray)	D2622	0.023 % (wt)	0.05 max (S500 grade)
Copper Strip Corrosion	D130	1	3 max
<b>Cloud Point</b>	<b>D2500</b>	<b>35.1 °F</b>	
Carbon Residue	D4530	0.027 % (wt)	0.05 max
Cetane Number	D0613	56.7	47 min
Acid Number	D974/D664	0.33 mg KOH/g	0.5 max
Free Glycerin	D6584	0.02%	0.02 max
Total Glycerin	D6584	0.34%	0.24 max
Phosphorus	D4927	< 0.001 % (wt)	0.001 max
Oxidation Stability	EN 14112	313.49 minutes	180 min
Density @ 60 °F	D4052	0.8972 g/cm <sup>3</sup>	
<b>Heat of Combustion</b>	<b>D4809</b>	<b>17,116 BTU/lbs</b>	
		<b>39.81 MJ/kg</b>	

- Bad Freezing Point;



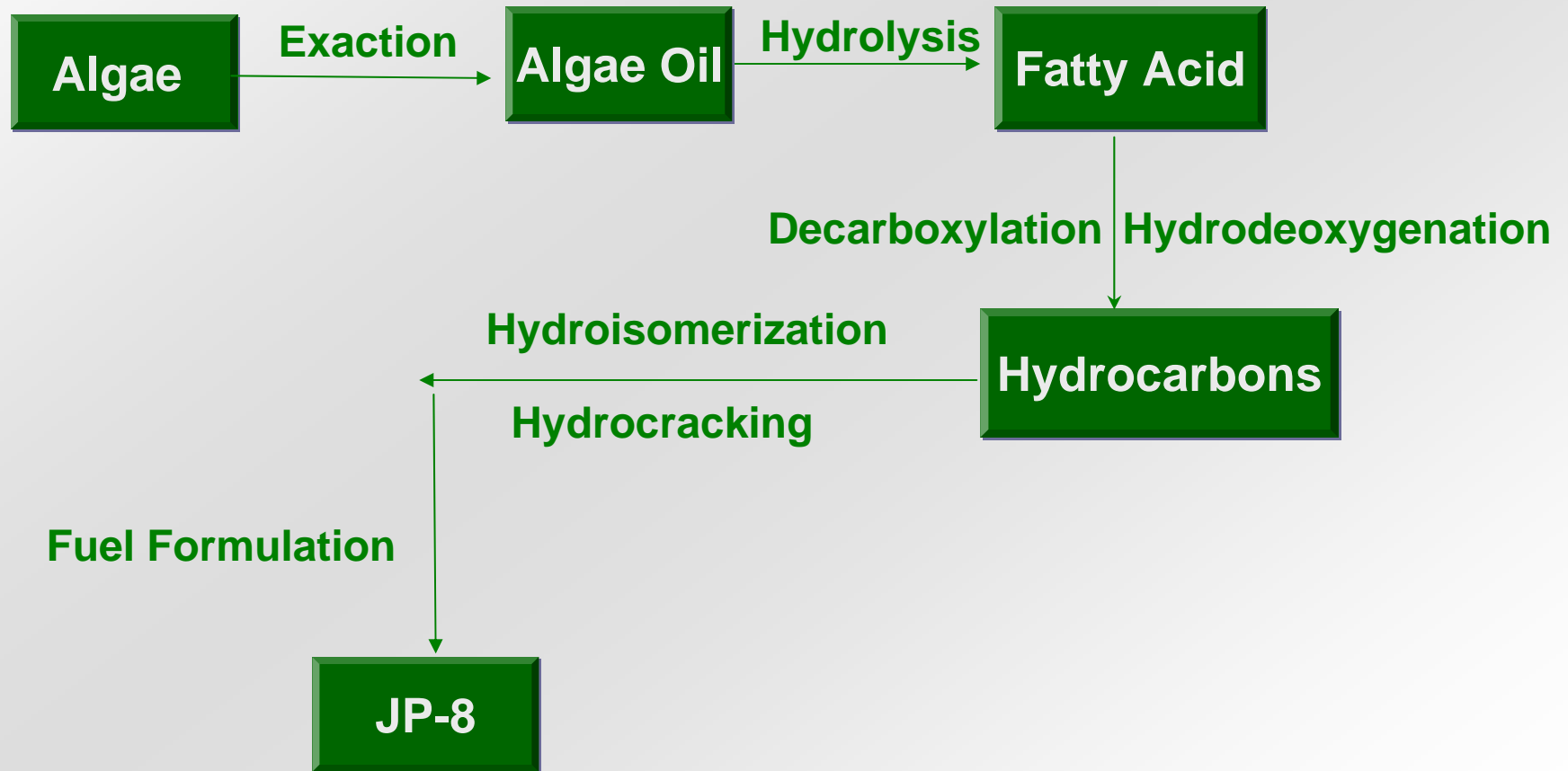
## Previous Trial (2)

Characteristic	ASTM Test Method	Sample Results 3502	Units	JP-8 req
Cetane Index	D 976	22.3		Typical values between 35 and 50
Density @ 15C	D 4052	0.9151	g/L	0.84 max
Distillation	D 86			
Initial Boiling Point		81	deg C	
10% Point		141.5	deg C	205 max
50% Point		239	deg C	
90% Point		284	deg C	
End Point		N/A	deg C	300 max
Residue		0.7	vol. %	1.5 max
Loss		N/A	vol. %	1.5 max
Flash Point	D 93	37.5	deg C	38 Min
<b>Heating Value</b>	<b>D 4809</b>	<b>28.947</b>	<b>MJ/Kg</b>	<b>42.8 Min</b>
<b>Freezing Point</b>	<b>D2386</b>	<b>-65</b>	<b>deg C</b>	<b>-47 Min</b>
Peroxides		15.2	ppm	Typical values - < 8
Sulfur Content	D 4294	0.0375	mass %	0.3 Max
Total Acid Number	D 3242	>34.72	mg KOH/g	0.015 Max
Water by Karl Fisher		15530	ppm	Typical values - 70 to 90 ppm

- Good Freezing Point; Bad Heating Value



# Proposed Fuel Process – Algae to JP-8



# Decarboxylation

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- **Operation Conditions**

- Batch operation
- High temperature
- Moderate reaction time

- **Catalyst**

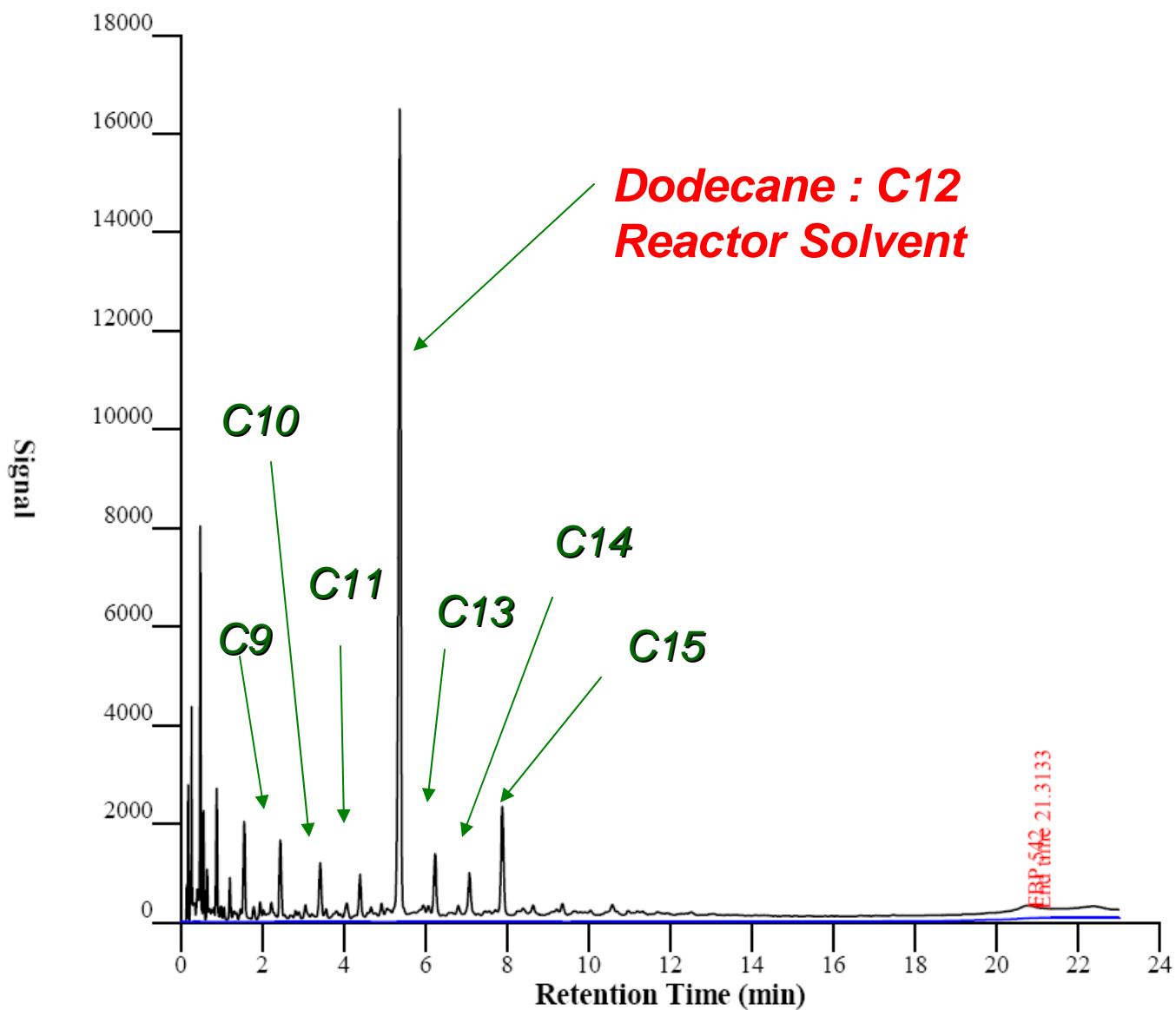
- Metal on activated carbon

- **Main Observation**

- Formation of hydrocarbons (C7-C15)
- Reasonable conversion



# GC/MS Spectrum



# Current Status

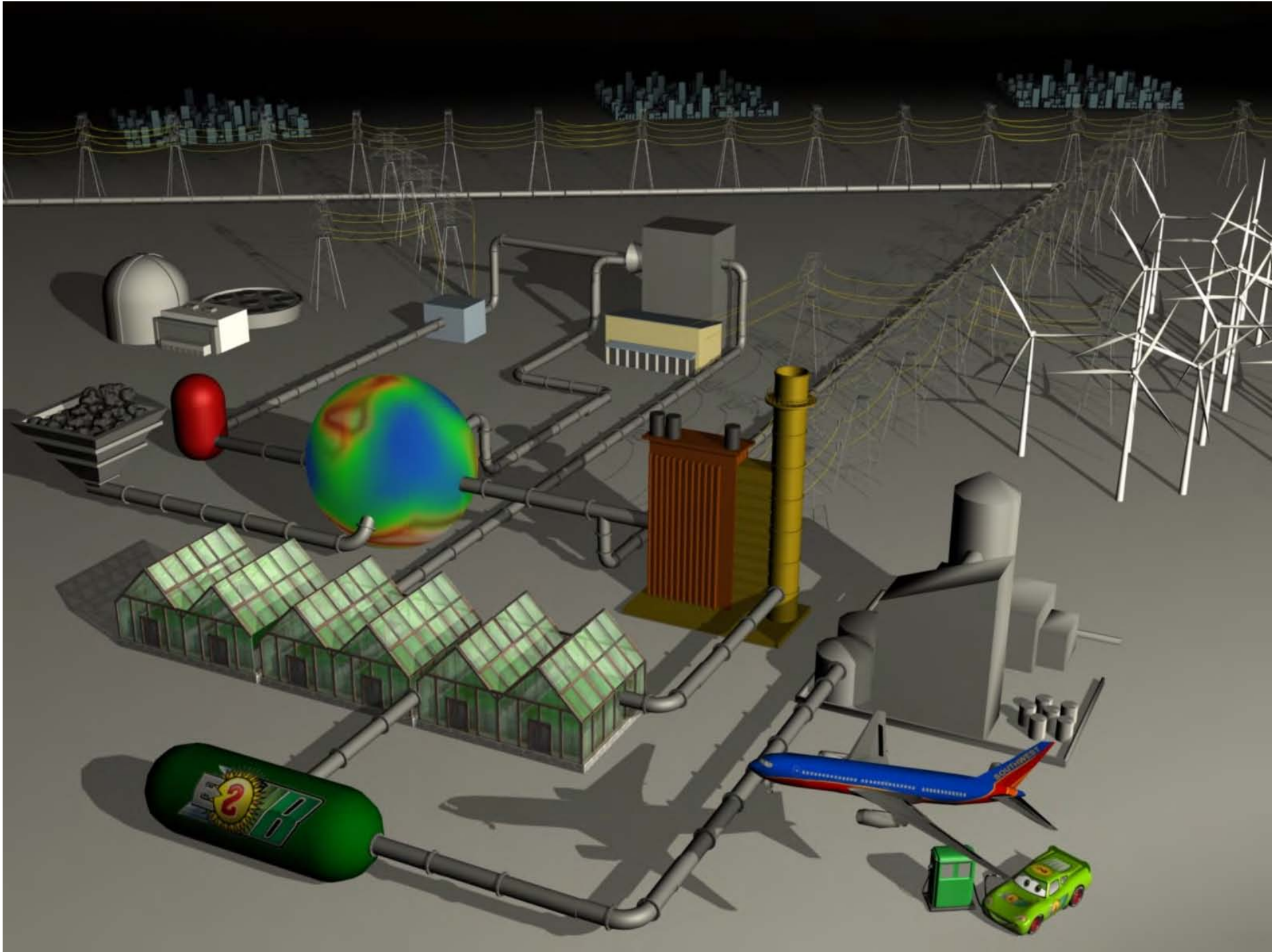
## Laboratory

- ▶ **Construction Complete**
- ▶ **Major Equipments Purchase**
- ▶ **Catalyst Supplier**
- ▶ **Personnel Recruiting**
- ▶ **Networking**



**Agilent 5975C GC/MSD**

**Floor Stand Reactor, 2L, Fixed Head,  
Heavy Duty Drive with 4843 Temperature Controller**



# COAL TO SNG Phase II PROJECT TEAM

