

# **COKING/COAL GASIFICATION USING INDIANA COAL FOR THE ENVIRONMENTALLY CLEAN PRODUCTION OF METALLURGICAL COKE, LIQUID TRANSPORTATION FUELS, FERTILIZER, AND ELECTRIC POWER**

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# RECENT COKE PRICE VOLATILITY

- ✖ The market price of coke has varied from **\$130** to **\$800/ton** in the last year.
- ✖ This means that there is a need to be able to mitigate the consequences of this type of price fluctuation.
- ✖ How can we leverage the investment (sunk and opportunity cost) in coke production to produce other value?
  - + Need to be able to optimize value over multiple market segments.

# HISTORY

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- ❖ Before the coke property called CSR (coke strength after reaction with CO<sub>2</sub>) was implemented in the USA during the 1970s, Illinois Basin coal was used extensively at a local steel company in blends as follows.
  - ❖ For wet charged coke batteries, a blend of 60% Illinois coal and 40% Eastern medium volatile coal was used.
  - ❖ For preheat coke batteries, a blend of 70% Illinois coal and 30% Eastern medium volatile coal was used.
- ❖ These blends produced coke with high cold strength properties (stability, hardness, impact resistance, and abrasion resistance). But, the hot strength property, CSR, was poor.
- ❖ For small blast furnaces, poor CSR values did not cause operating issues, but as furnace sizes increased dramatically in the late 1970s, issues started to arise with furnace component and wall integrity.

# HISTORY

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- ❖ To improve CSR, blends were modified
  - ❖ 30% Illinois coal, 30% Eastern high volatile coal, and 40% Eastern medium volatile coal for wet charged batteries
  - ❖ 43% Illinois coal, 25% western Canadian high/medium volatile coal, and 32% Eastern medium volatile coal for preheat charged batteries.
  - ❖ Optionally, for preheat charged batteries a blend of 43% Illinois coal, 25% western Canadian high/medium volatile coal, and 32% western Canadian medium volatile coal
- ❖ With increased emphasis on CSR as an operating parameter, the use of Illinois coal was discontinued for production of coke.

# PUC RESEARCH GOALS

- ❖ Develop new technology that will provide new environmentally friendly methods to create value from coke oven gas and thereby enhance the capabilities and operations of existing and new coke production facilities.
- ❖ Develop multipurpose Heat Recovery coke plant that maximizes the use of non coking coals (up to 40%) from Indiana. This will significantly reduce coal costs.
- ❖ Combine the best of recovery and non recovery coke making technology to maximize the value of coke oven gas (COG).
- ❖ Assure acceptable CSR and other coke characteristics for large Blast Furnaces.
- ❖ Produce new value from methane as heating fuel or reducing agent for direct reduction, production of diesel oil, fertilizer, and hydrogen.
- ❖ Produce electric power from waste heat gas
- ❖ Reduce carbon footprint by converting CO<sub>2</sub> to a marketable chemical product using nano catalysis

# RESEARCH TEAM

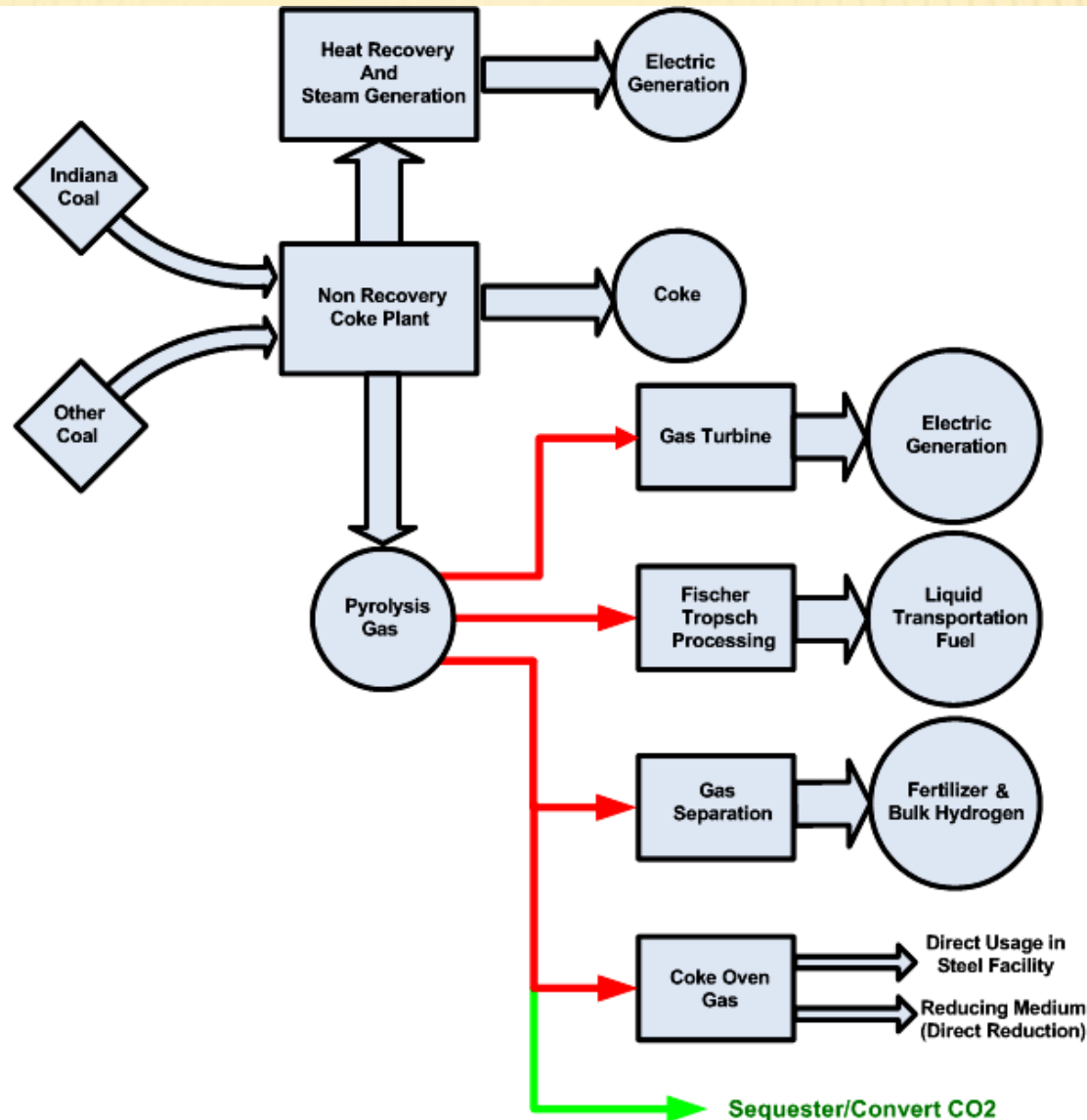
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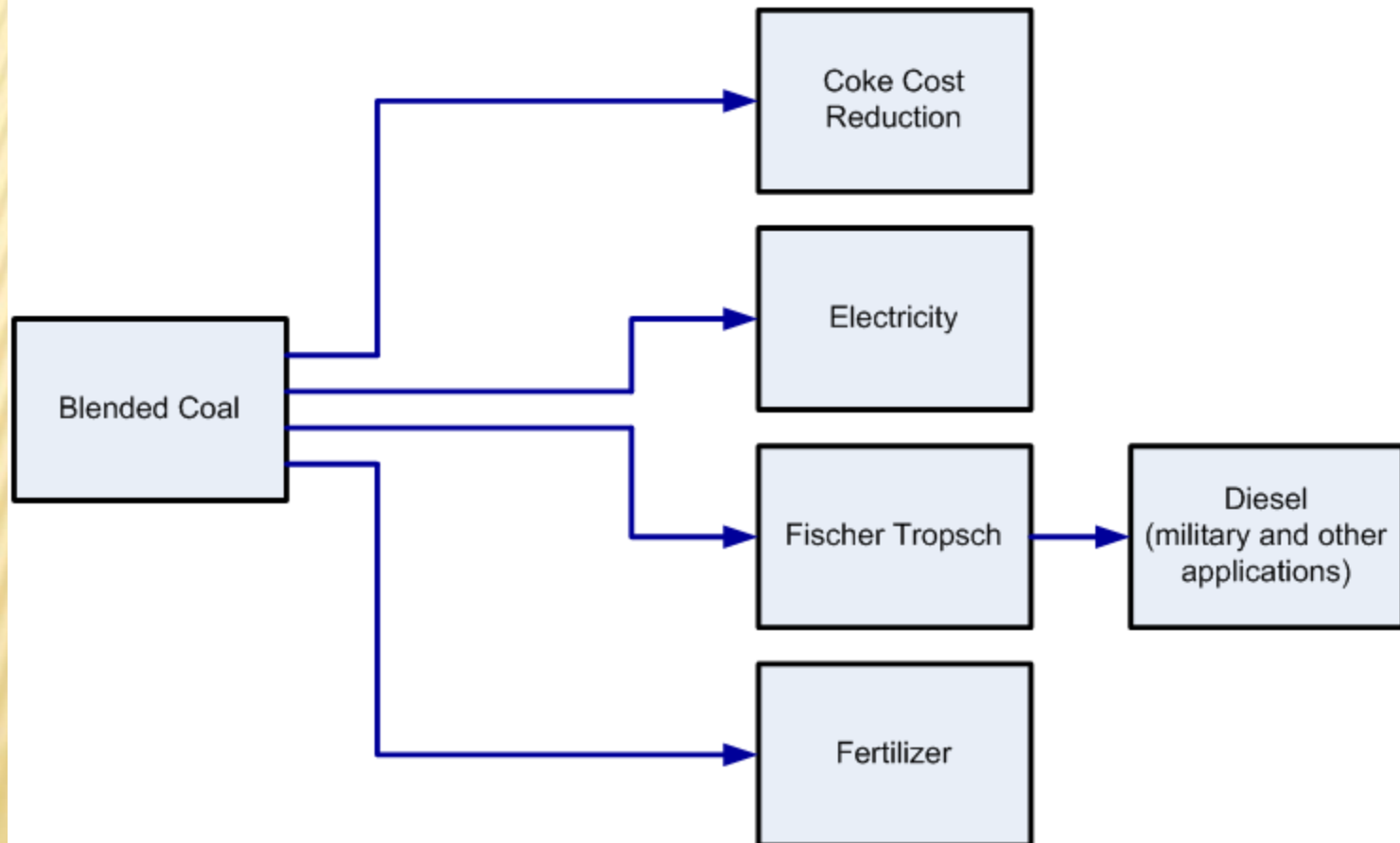
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# MULTIPURPOSE COKE FACILITY IS UNDER DEVELOPMENT THAT WILL PROVIDE CLEAN COAL TECHNOLOGY AND MULTIPLE PRODUCTS



Economic Flows

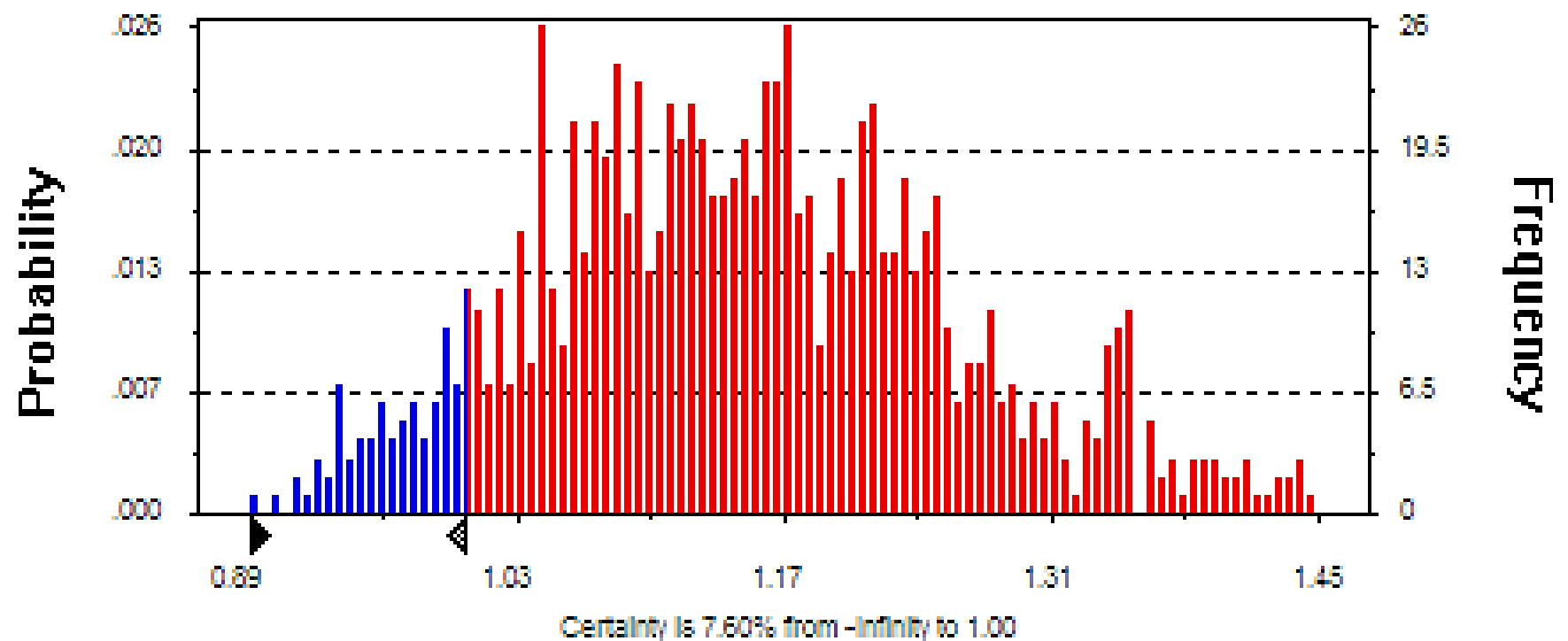


# Forecast: Total Value

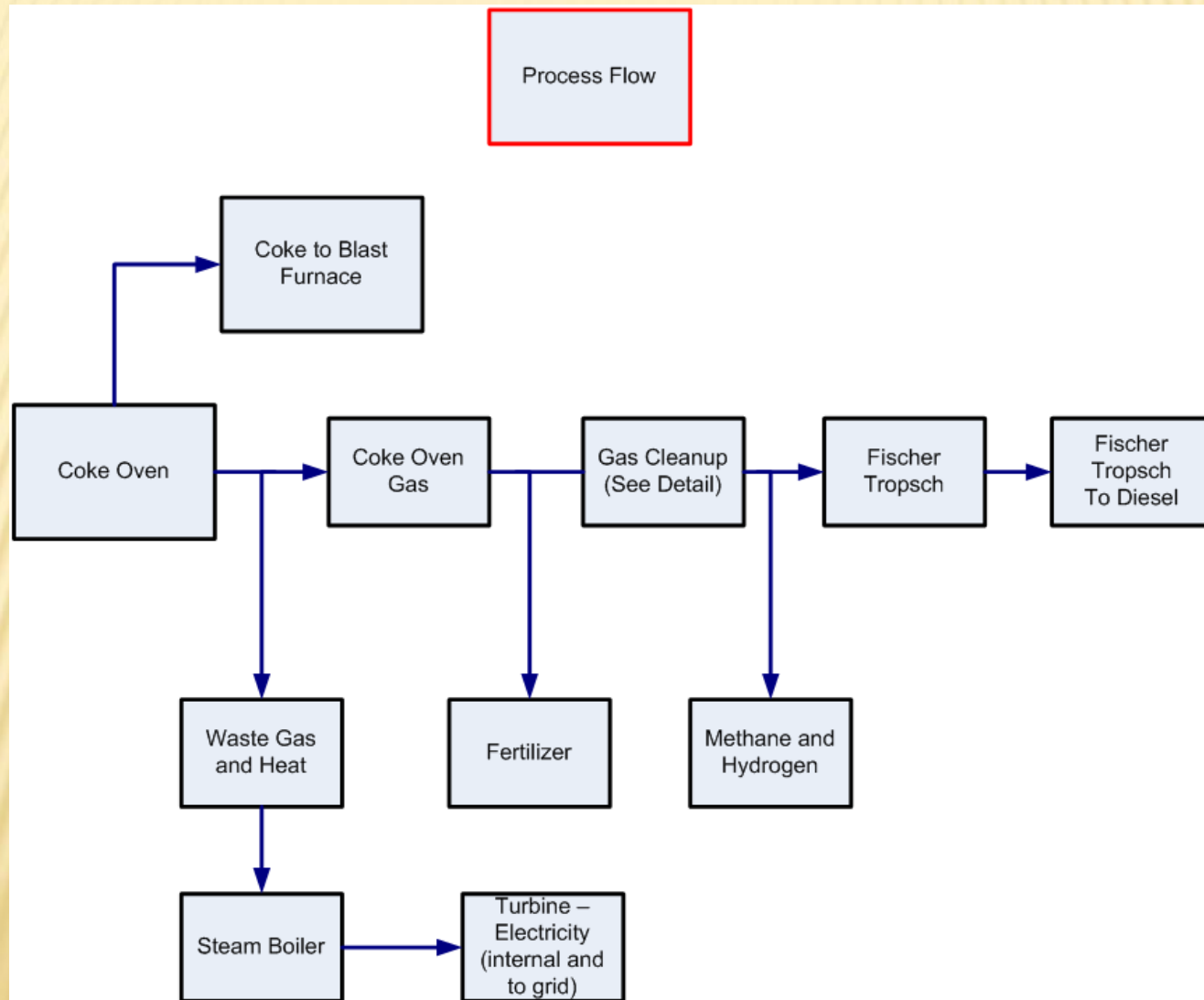
1,000 Trials

Frequency Chart

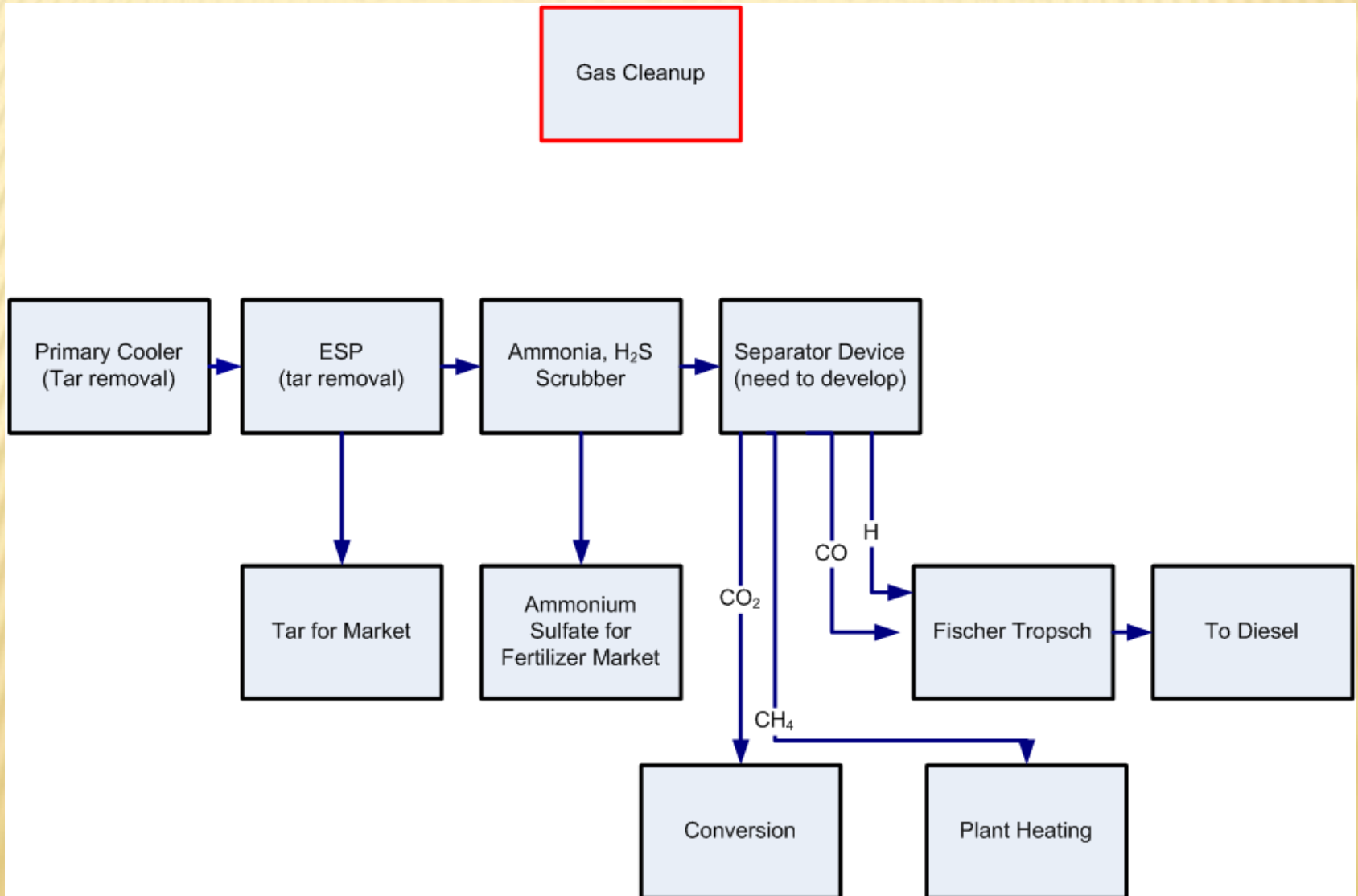
983 Displayed



# PROCESS CHART

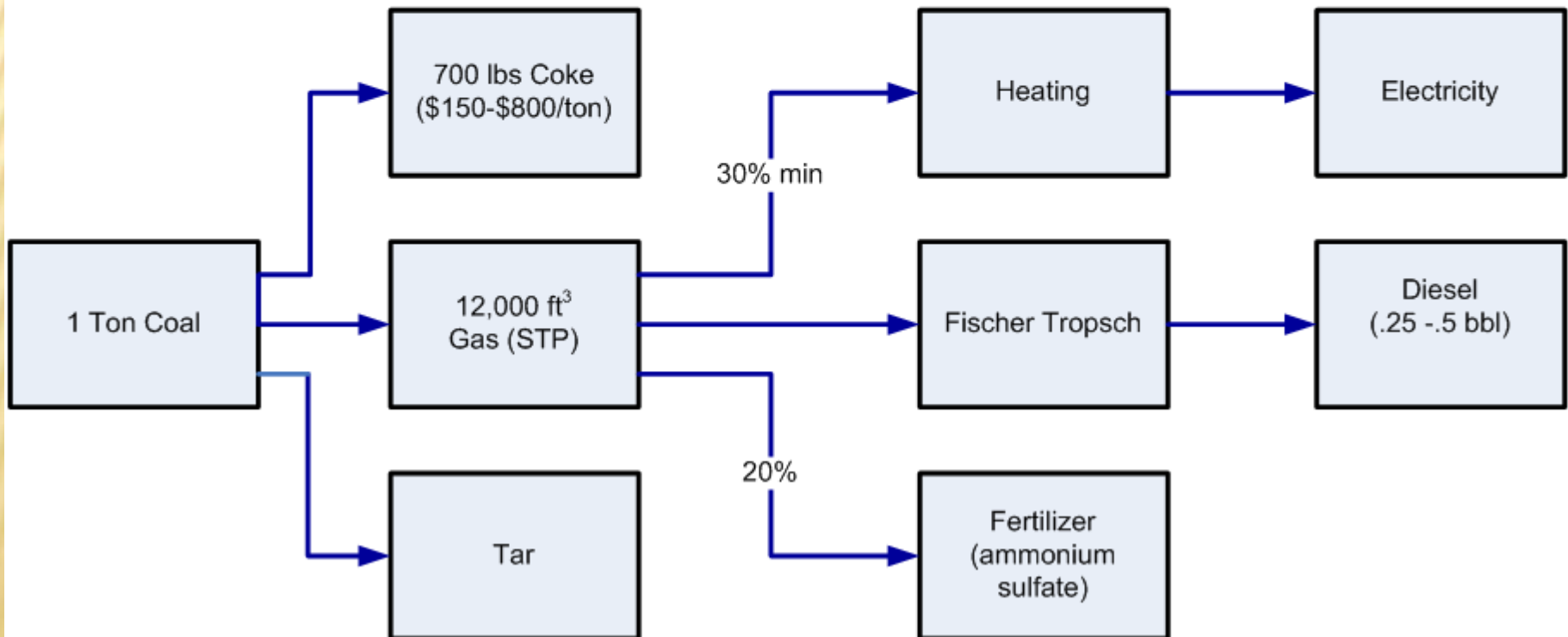


# GAS CLEANUP DETAIL



# ECONOMIC VALUES

Economic Values





Coke Production Level

Liquid Fuel Production Level

Electric Production Level

Liquid Fuel Production Level

Coke Production Level

Electric Production Level

Electric Production Level

Coke Production Level

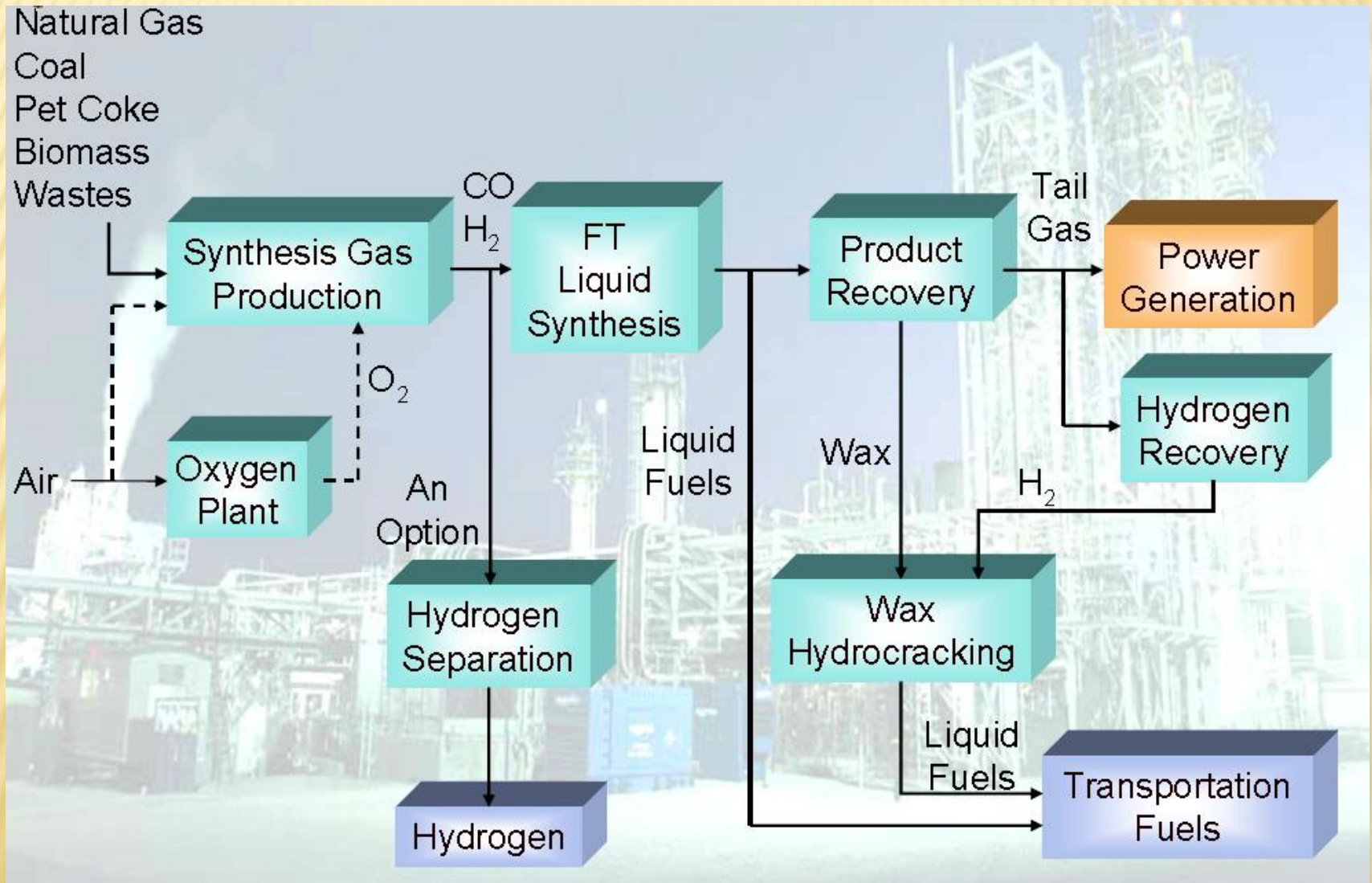
Liquid Fuel Production Level

Increasing Liquid Fuel Price

Increasing Coke Price

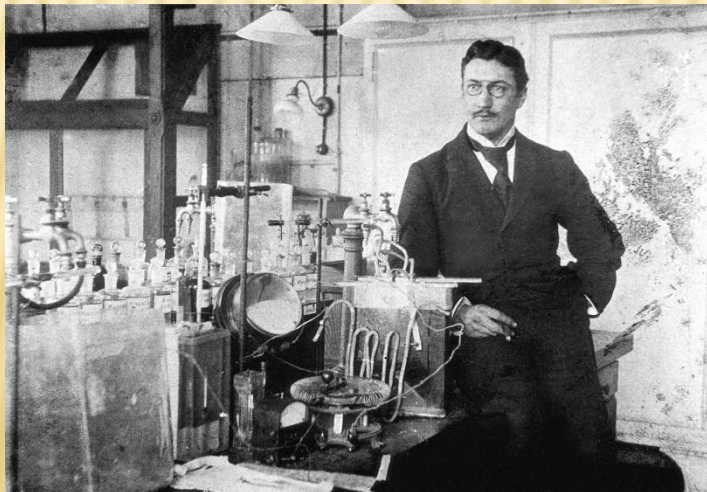
Increasing Electricity Price

# FT TECHNOLOGY



# HISTORY

- ✗ The Fischer-Tropsch process was developed by German researchers Franz Fischer and Hans Tropsch in 1923 and used by Germany and Japan during World War II to produce alternative fuels and overcome their limited access to oil.
- ✗ Germany utilized the technology to produce 6.5 million tons, or 124,000 barrels a day.



*Franz Fischer at  
work in 1918*

# SASOL

- ✖ Located in South Africa
- ✖ Started up in 1955
- ✖ Lurgi gasifiers (97)
- ✖ Fischer-Tropsch process converts syngas to liquid fuels
- ✖ Now processes 90,000 tons coal/day into 160,000 barrels/day of transportation fuels



# SASOL

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- ✘ South Africa used the Fischer-Tropsch process to supplement gasoline supply and to reduce dependence on imported crude oil in the 1950's when the world political climate jeopardized its supply.
- ✘ The initial SASOL operation had substantial chemical by-product production and the successful marketing of these high-quality chemicals helped offset the economic penalty associated with gasoline production by the Fischer-Tropsch method.
- ✘ As research and development was conducted simultaneously with the commercial operation, SASOL developed its own catalysts which had higher efficiency of conversion than commercial catalysts purchased initially.
- ✘ SASOL I currently produces about 6,000 bbl/day of liquid hydrocarbons, with gasoline representing some 50 percent of total energy output, the remainder being a number of high-quality chemical components.

# ECONOMICS

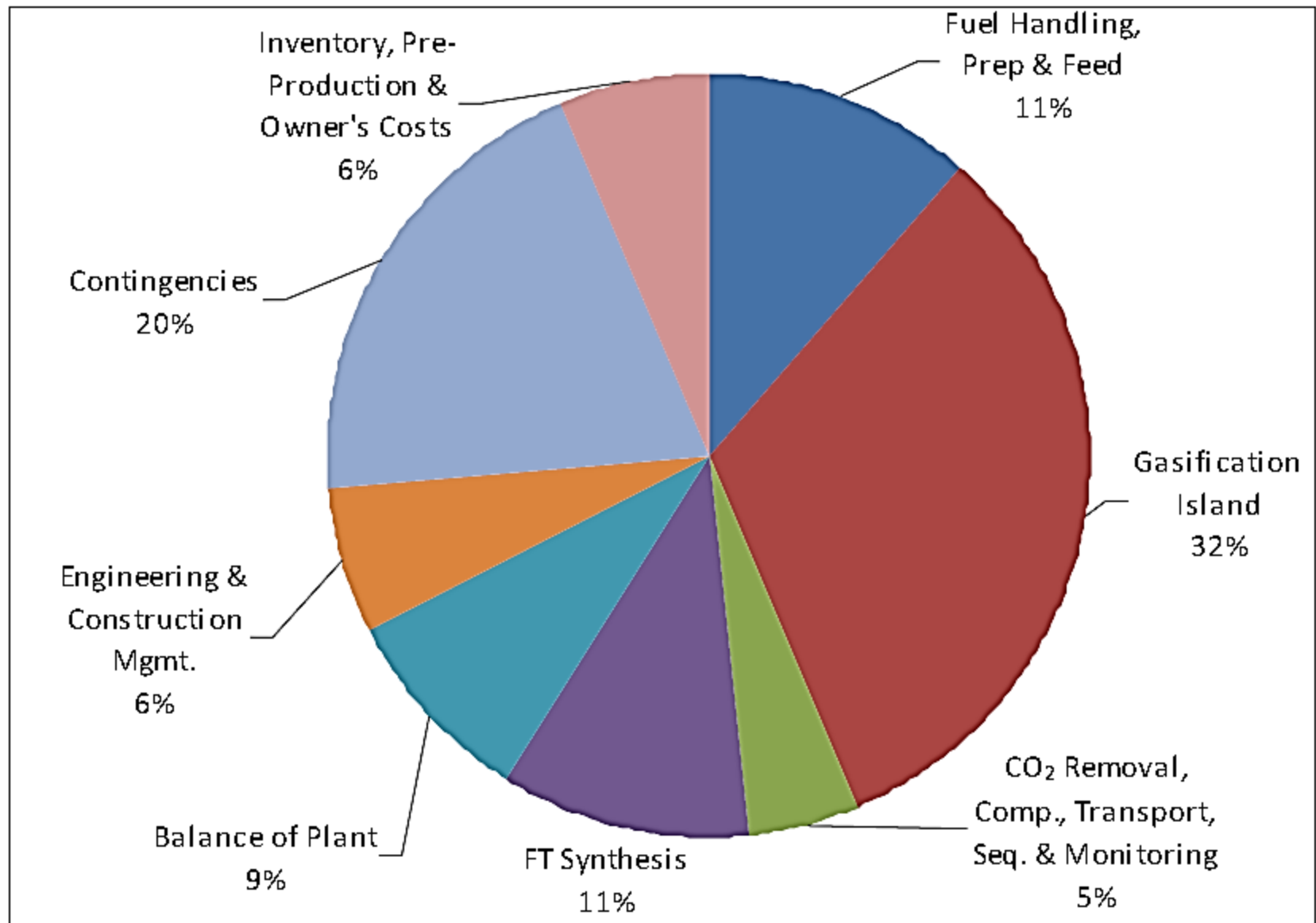
- ✕ The largest component of the final cost of FT gasoline is capital (56 percent) followed by coal (30 %) and operating and maintenance (14 percent).
- ✕ The largest element of the capital cost component is the oxygen plant (27 percent), followed by the synthesis unit (15 percent), the purification unit (13 percent), the power plant (10 percent), the acid gas removal unit (7 percent), the tail gas reforming unit (5 percent), and the gasification and sulfur recovery units (3.5 percent each)
- ✕ The costs of gasoline from Fischer-Tropsch, located in Illinois, Texas, and Wyoming and coming on stream in 1985, are projected to be:

Year of Reference	Gasoline Source	Plant Gate Price (\$/gal)	Pump Price (\$/gal)
1978	Crude Fischer-Tropsch	0.47 (0.73-0.82) $\pm$ 25%	0.74 (1.00-1.09) $\pm$ 25%
1985	Crude Fischer-Tropsch	0.93 (1.17-1.32) $\pm$ 25%	1.20 (1.44-1.59) $\pm$ 25%

Compares with an EPA mid case projection for conventional gasoline of \$.93/gallon at the plant gate in 1985 using 7 % per year inflation.

# Distribution of Total Overnight Capital Costs

## 15 wt% CBTL+CCS, 50k bpd



# FT DIESEL FUELS

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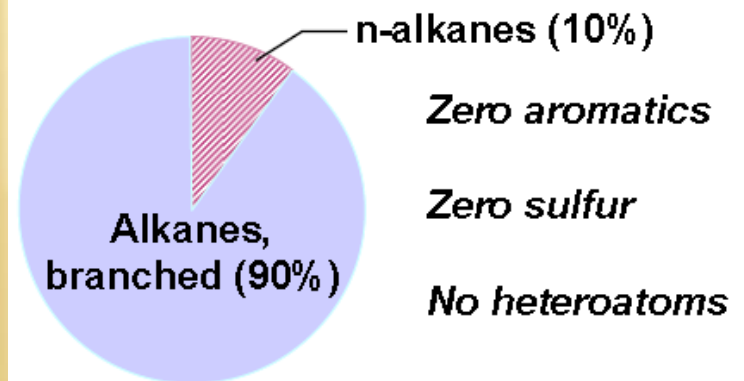
- ✖ Primary product zero S, minimal aromatics
- ✖ Predominantly straight chain (high cetane number >70)
- ✖ Fuels fully compatible with existing fuels
- ✖ Suitable for aviation
- ✖ Emissions from diesel engines greatly superior to even CARB diesel performance
- ✖ Excellent blending stocks

# FT FUELS REDUCE EMISSIONS

## ✖ Less Pollutant Emissions

- + 2.4% less CO<sub>2</sub>
- + 50% to 90% less particulate matter (PM)
- + 100% reduction in SO<sub>x</sub>
- + ~1% less fuel burn (increased gravimetric energy density)

Hydrocarbon types in Syntroleum S-5



# MILITARY APPLICATIONS

Fischer-Tropsch

**low emissions, high stability**

Current and advanced gas turbine aircraft  
(Jet A/JP-8 replacement)

Fuels

2.2X – 5X increase in cooling

**High thermal stability,  
high H/C**

**reduced exhaust pollutants**

**high stability, endotherm**

**high cetane, >74**

**1200 Btu/lb cooling**

**No sulfur, no aromatics**

**No poisoning, less coking  
of reformer catalyst**

**Single Fuel for the Navy**

ISP=362.5



Hydrocarbon Rockets (RP-1  
replacement)

Hydrocarbon reformers  
(fuel cell power generation)



Army and Marine Equipment



Ships  
(JP-5/F-76 replacement)



Hypersonic Vehicles  
(JP-7 replacement)

# METHANE BALANCE

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- ✖ If methane produced exceeds local needs it can be reformed with steam and oxygen to yield H and CO which is recycled to the FT synthesis units.
- ✖ This reforming is thermally inefficient and results in a (about 14 %) loss of hydrocarbon produced from the reformed CH<sub>4</sub>

# CO<sub>2</sub> HANDLING

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- ✖ Physical solvent processes are used primarily for acid-gas removal from high-pressure natural-gas streams and for carbon dioxide removal from crude hydrogen and ammonia synthesis gases produced both by partial oxidation and steam-hydrocarbon reforming.
- ✖ Since solvent processes are most efficient when operated at the highest possible pressure, carbon dioxide removal from reformer effluents is best carried out after compression of the process gas to the ultimate pressure required for such processes as ammonia synthesis or hydrocracking.
- ✖ Under these circumstances, the molecular weight of the CO<sub>2</sub>-rich gas is sufficiently high to permit use of relatively inexpensive centrifugal compressors to reach the required discharge pressure.

# VERTICAL HEAT RECOVERY OVEN (CHINA)



# UPDATED TESTING PROCEDURES

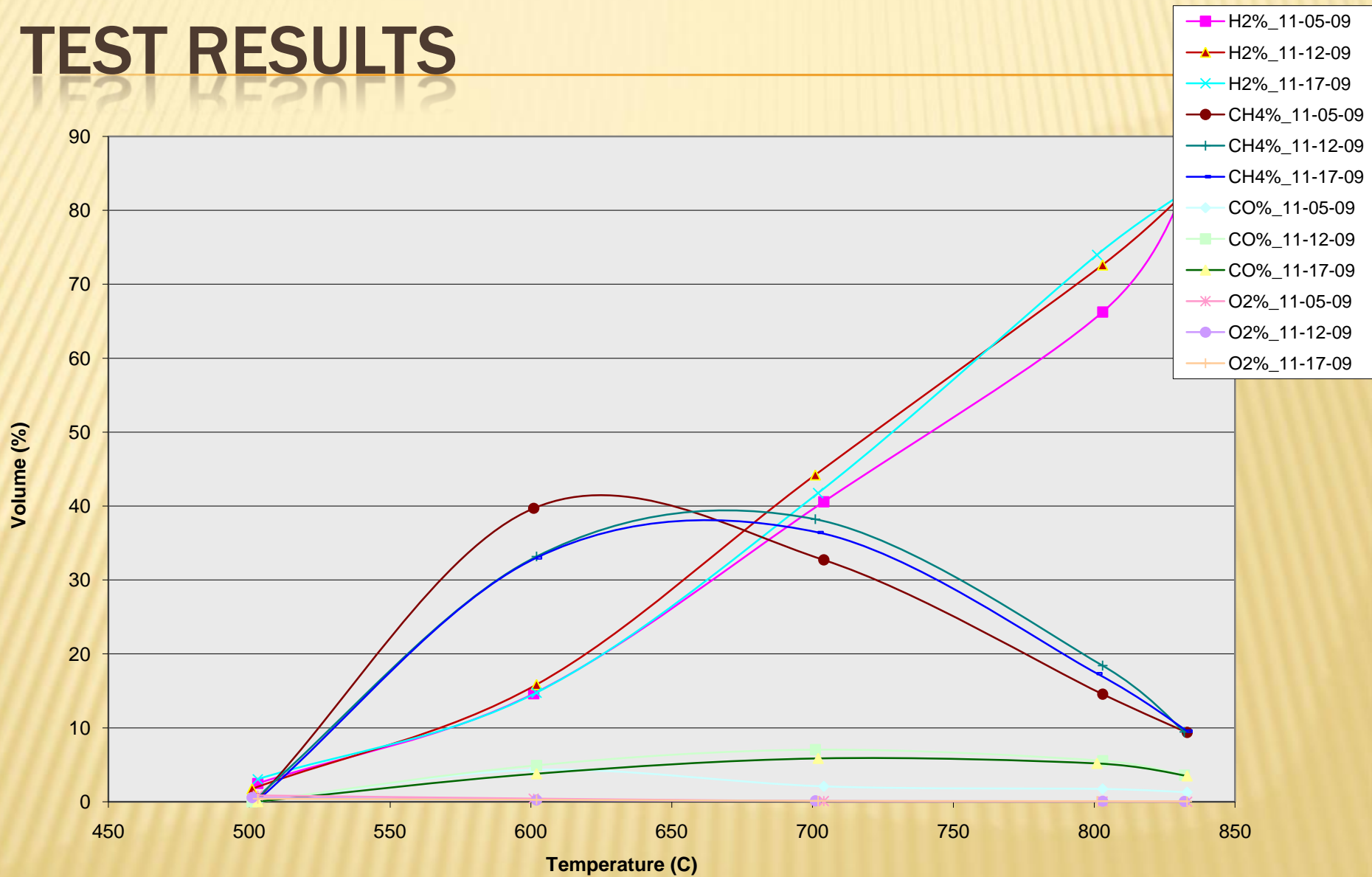
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- ❖ New furnace and test system
- ❖ Pyrolysis gas is now transmitted directly to the gas chromatograph through tubing connected to a selector valve.
- ❖ This has improved the accuracy of the data.
- ❖ An expansion of the test system to have the capability of testing up to 5 samples of coal simultaneously is planned.

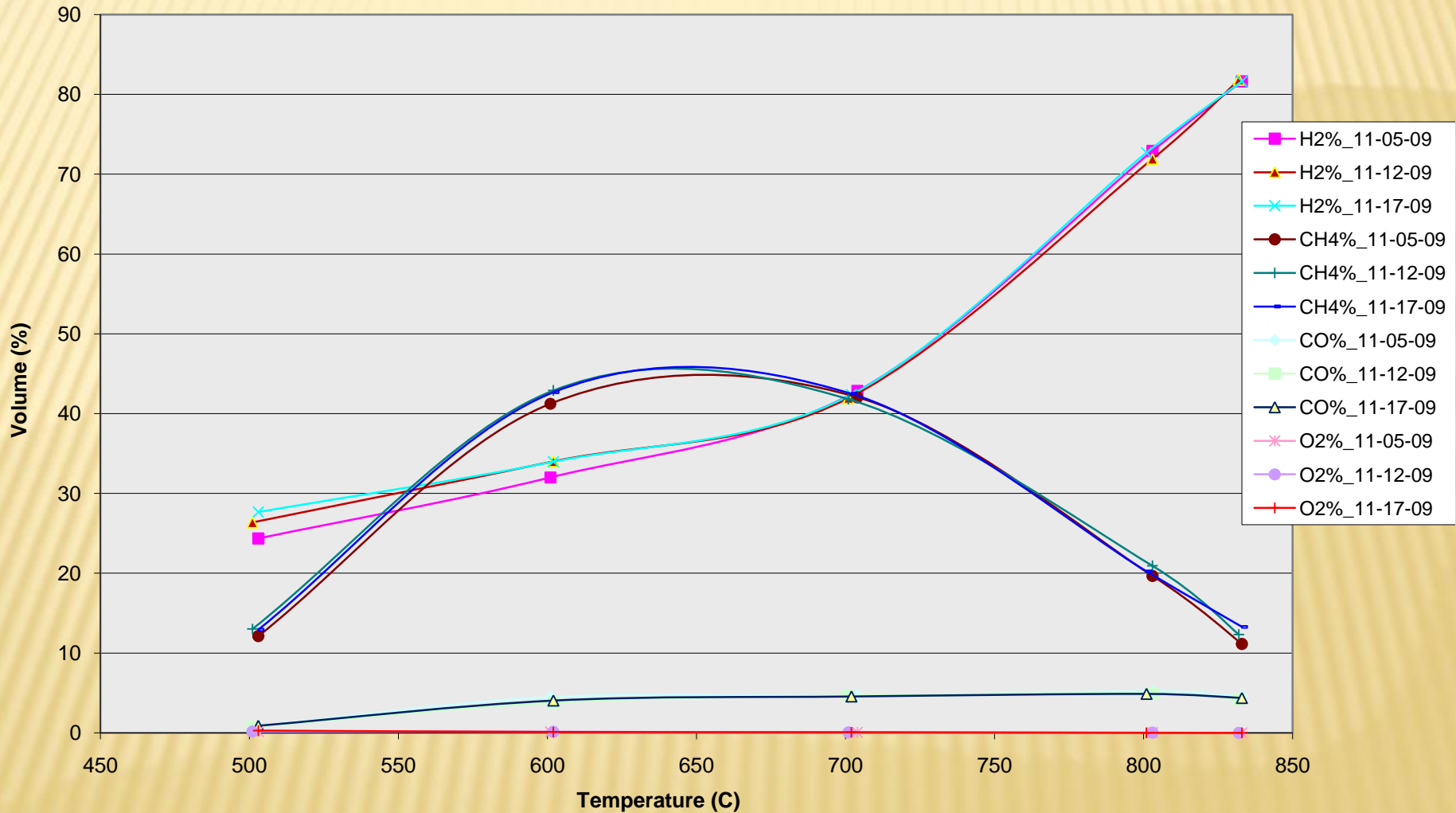
# UPDATED TESTING APPARATUS



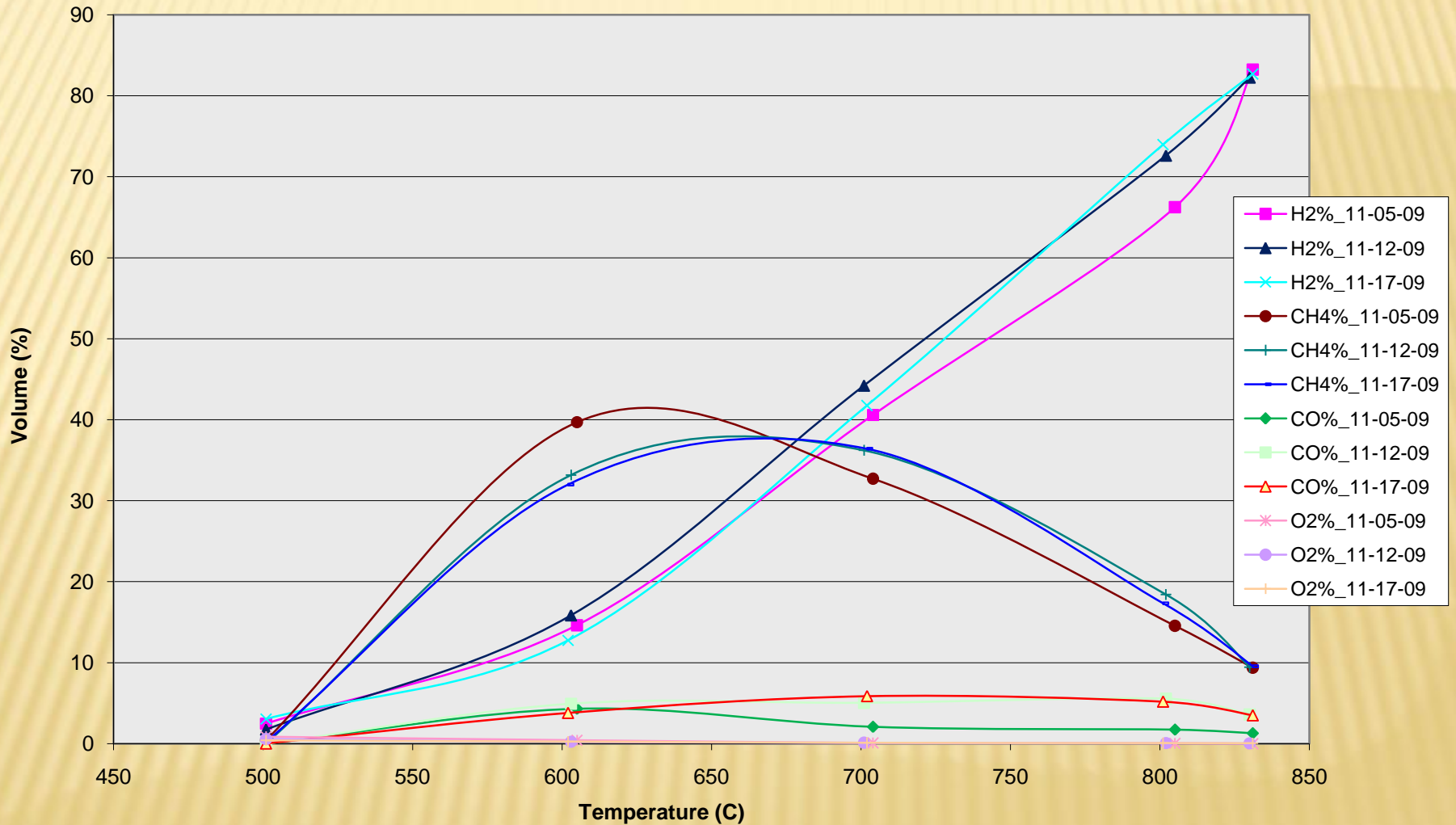
# TEST RESULTS



# TEST RESULTS



# TEST RESULTS



# BLEND

## Slot

New Battery

1

70% HV   Solar U 35% HV  
              Solar L 35% MV

30% L-MV

ICG 15% LV  
Elkview 15% MV

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Old Battery

2

60% HV   Solar U 30% HV  
              Solar L 30% HV

40% L-MV

Elkview 40% MV

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## Heat Recovery

3

70% M/LV---ICG 35% LV  
              Elkview 35% MV

30% HV

Wellmore 30% HV

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4

70% M/LV---ICG 35% LV  
              Elkview 35% MV

30% HV

Wellmore 15% HV  
Solar L 15% MV

# PRELIMINARY ANALYSIS RESULTS

			Individual Coals				Blend Coals		
		HV		MV	LV				
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Blend # 1	Blend # 2	Blend # 3	Blend # 4
Total Moisture	14.67	14.34	7.95	5.57	7.75	11.88	11.11	7.18	8.44
Ash	4.08	5.81	9.68	9.93	6.61	5.81	6.54	8.70	7.76
Volatile	39.27	38.09	20.26	29.28	15.87	33.67	34.44	21.89	24.67
Fixed Carbon	56.65	56.10	70.06	60.79	77.52	60.52	59.02	69.41	67.57
Sulfur	1.58	1.32	0.35	1.11	0.77	1.39	1.24	0.75	0.87
HV(BTU/lb)	14129	13873	14040	13980	14635	14154	14068	14195	14245
Carbon	78.32	77.70	80.57	78.86	86.05	79.18	78.91	81.43	81.44
Hydrogen	5.40	5.42	4.21	4.90	4.12	5.19	5.26	4.46	4.64
Nitrogen	1.59	1.67	1.16	1.61	1.31	1.62	1.65	1.41	1.45
Oxygen by difference	9.03	8.08	4.03	3.59	1.14	6.81	6.40	3.25	3.84
Initial Deformation Temperature (°F)	2176	2388	>2700	2259	>2700	2266	2104	2572	2633
Softening Temperature (°F)	2442	2419	>2700	2430	>2700	2302	2404	>2700	2689
Hemispherical Temperature (°F)	2464	2466	>2700	2507	>2700	2514	2534	>2700	>2700
Fluid Temperature (°F)	2502	2624	>2700	2665	>2700	2660	>2700	>2700	>2700
Mineral Analysis of Ash									
Silicon dioxide	43.90	54.59	61.63	53.97	57.77	48.96	50.03	57.42	56.35
Aluminum oxide	27.80	23.92	26.82	25.52	31.18	28.50	27.36	27.85	28.04
Titanium dioxide	1.30	1.23	1.58	1.26	1.85	1.41	1.23	1.52	1.53
Iron oxide	24.24	16.73	4.17	10.92	4.75	15.70	14.21	6.13	7.91
Calcium oxide	0.99	0.73	2.22	1.57	1.30	1.24	1.70	2.05	1.66
Magnesium oxide	0.21	0.33	0.47	1.49	0.42	0.61	1.02	0.97	0.90
Potassium oxide	1.16	1.87	0.63	3.08	1.27	1.90	2.31	1.88	1.92
Sodium oxide	0.26	0.34	0.07	0.70	0.70	0.47	0.57	0.47	0.50
Sulfur trioxide	0.03	0.13	1.50	1.00	0.58	0.83	0.90	1.25	0.85
Phosphorus pentoxide	<0.01	<0.01	0.66	0.15	<0.01	<0.01	0.27	0.17	0.08
Strontium oxide	0.04	0.06	0.06	0.13	0.07	0.21	0.19	0.10	0.10
Barium oxide	0.04	0.05	0.14	0.15	0.05	0.08	0.14	0.13	0.11
Manganese oxide	0.02	0.01	0.03	0.04	0.03	0.04	0.05	0.04	0.03
Undetermined	0.01	0.01	0.02	0.02	0.03	0.05	0.02	0.02	0.02
MAA Basis	Ignited	Ignited	Ignited	Ignited	Ignited	Ignited	Ignited	Ignited	Ignited
Alkalies as Na2O, Dry Coal Basis	0.04	0.09	0.05	0.27	0.10	0.10	0.14	0.15	0.14
Base Acid Ratio	0.35	0.23	0.08	0.18	0.07	0.23	0.22	0.11	0.12
Silica Value	63.32	75.42	89.96	79.43	89.93	73.61	74.72	86.24	84.32
MAA Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
MAA T250 (F)	2418	2658	2875	2692	2825	2582	2601	2790	2760

# PRELIMINARY ANALYSIS RESULTS

			Individual Coals				Blend Coals		
		HV		MV	LV				
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Blend # 1	Blend # 2	Blend # 3	Blend # 4
FSI	5.5	3	6.5	6.5	5.5	5.5	6.5	7.5	6.5
Vitrinite type(V-Type)									
V-4	20.00	3.00				14.00	6.00		
V-5	74.00	67.00				43.00	43.00		7.00
V-6	6.00	27.00				10.00	16.00		4.00
V-7		3.00					5.00	1.00	
V-8				3.00				8.00	3.00
V-9			3.00	27.00		10.00	14.00	21.00	20.00
V-10			14.00	58.00		7.00	12.00	21.00	8.00
V-11			14.00	12.00		1.00	4.00	2.00	10.00
V-12			4.00					3.00	4.00
V-13			23.00					6.00	1.00
V-14			33.00					3.00	5.00
V-15			9.00			2.00		8.00	5.00
V-16					61.00	6.00		13.00	20.00
V-17					39.00	7.00		14.00	13.00
Fluidity									
Softening Temperature ( °C)			426	378	450	388	382	412	410
Solidification ( °C)			499	489	510	464	481	505	500
Range ( °C)			73	111	60	76	99	93	90
Temperature at Maximum			471	444	484	440	442	467	465
Maximum Fluidity ddpn			26	60,111	7	162	1056	507	259

# PREVIOUS COAL BLENDING TEST RESULTS

	TC1931	TC1933	TC1935	TC1940	TC1941	TC1951	TC1952	TC1953	TC1954	TC1995
	30% III 30%EHV 40% EMV	30% Ind 30% EHV 40% EMV	80% Ind 20% PC	45% Ind 15% EHV 40% EM	45% Ind 15% EHV 40%WCM	30% Ind 30% EHV 40%WCM	30% III 30% EHV 40%WCM	20% Ind 10% PC 30% EHV 40%WCM	20% III 10% PC 30% EHV 40%WCM	50% Ind 50%LVM
Moisture (%)	2.94		2.5	4.98	5.15	4.48	4.03	3.29	3.24	3.4
Grind (% , - 3.35mm)	97.1	93.3	87.6	90.7	91.1	91.9	92.7	94.6	96.9	91.0
Dry oven bulk density (kg/m <sup>3</sup> )	792	816	754	801	788	801	804	804	805	794
Max oven wall pressure (kPa)	5.65	6.27	2.55	4.62		3.45	4.07	4.07	3.58	7.23
Coking time (h)	16.87	16.37	16.05	17.13	17.03	17.05	17	16.6	16.1	17.02
Stability	61	60	42	58	63	57	61.1	60.5	60.7	62
CSR	61	68	24	57	65	65	70	72	71	66
CRI	30	22	44	32	24		21	20		28
Hardness	70	70	51.3	70	68	70	70	69	68	72
Coke size (mm)	61.73	65.53	70.9	70.74	69.3	62.8	59	61.3	64.2	62.6
Coke yield (%)	73.58	70.15	69.6	73.39	74.6	74.9	76.3	78	76.9	74.9
SHO contraction %	-7.99	-9.57	-11.94	-11.13	-10.14	-12.82	-7.93	-10.59	-12.93	
Coke sulfur (%)						0.66		0.93		
Coke ash (%)						11.1		8.9		

# CONCLUSION

- ❖ Results indicate that it is highly likely that a coking/coal gasification process can be developed that would produce metallurgical grade coke using 30%+ Indiana coal.
- ❖ By using a new blending approach that optimizes coke properties and pyrolysis gas composition it is possible to use Indiana coal blended with other coals to enhance coke oven and modern blast furnace operations and reduce costs.
- ❖ This technology has the opportunity to develop a new market for Indiana Coal
- ❖ Results indicate that it is possible to use pyrolysis gas generated from a coke oven feed with a blend of Indiana and other coal to produce electricity, liquid transportation fuels by means of a Fischer-Tropsch process, fertilizer, electricity, and hydrogen.
- ❖ Methods to isolate carbon dioxide from the process and use it to produce a marketable chemical product with nano catalysis technology is being investigated.

# RESEARCH NEXT STEPS

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- ❖ Continue patent application process
- ❖ Complete pyrolysis testing of Indiana Coals and Blends
- ❖ Continue testing with washed coal samples. Develop optimal blends of Indiana and conventional metallurgical coal, and perform pyrolysis and coke characteristic testing.
- ❖ Consider using petroleum coke for FT and other products.
- ❖ Perform large scale testing at a one ton level and demonstrate feasibility of producing coke and Fischer-Tropsch liquids and other value streams from pyrolysis gas.
- ❖ Perform testing at a commercial coke oven and demonstrate capability to enhance coke oven operations and to produce FT and other product value.
- ❖ Commercialize the process.

# CONTACT INFORMATION

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