Development of a Multipurpose Coke Plant for Synthetic Fuel Production

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Acknowledgement: The authors wish to thank the Center for Coal Technology Research and the Illinois Clean Coal Initiative for their support and advice which has greatly assisted this effort.

Slot Battery

Coke Oven

HEAT RECOVERY, SUN - INDIANA HARBOR COKE COMPANY

NON RECOVERY, STAMPED, SHANXI PROVINCE, CHINA

Zones of a Blast Furnace

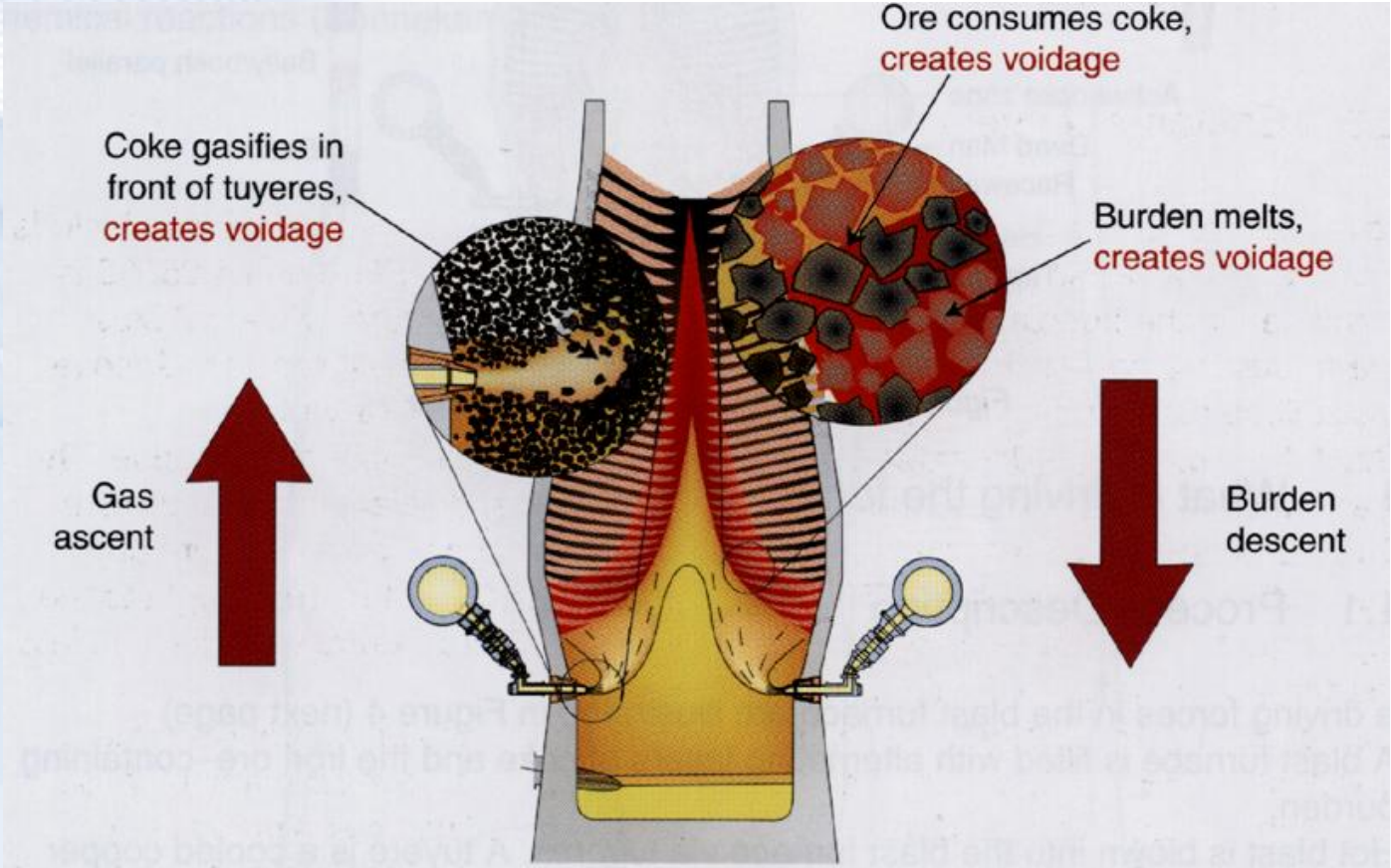


Figure 4: The driving force of a blast furnace: the counter current process creates voidage at the indicated areas causing the burden to descend

Source: Modern Blast Furnace Ironmaking, Verlag Stahleisen GmbH, 2004

Coke is an Essential Part of Iron Making and Foundry Processes

- Currently there is a shortfall of 5.50 million tons of coke per year in the United States.
- Shortfall is being filled by imports, mainly from China and, to a lesser extent, from Japan.
- The result is high volatility in coke prices and a general trend to dramatic price increases.
  - Coke FOB to a Chinese port in January 2004 was priced at $60/ton, but rose to $420/ton in March 2004 and in September 2004 was $220/ton. Estimates in early 2008 of up to $450/ton FOB port.

Coke Usage is Increasing

- 2005 forecasts indicate that the US will produce 11,500,000 net tons of coke, but will require 17,000,000 net tons for blast furnace, foundry, and related uses.
  - At present, essentially no Indiana coal is being used for coke production. In 2002, Indiana's steel industry used an estimated 10.7 million tons of coal.
    - 8.1 million tons was used for coke production.
    - Most from West Virginia and Virginia.

Goals

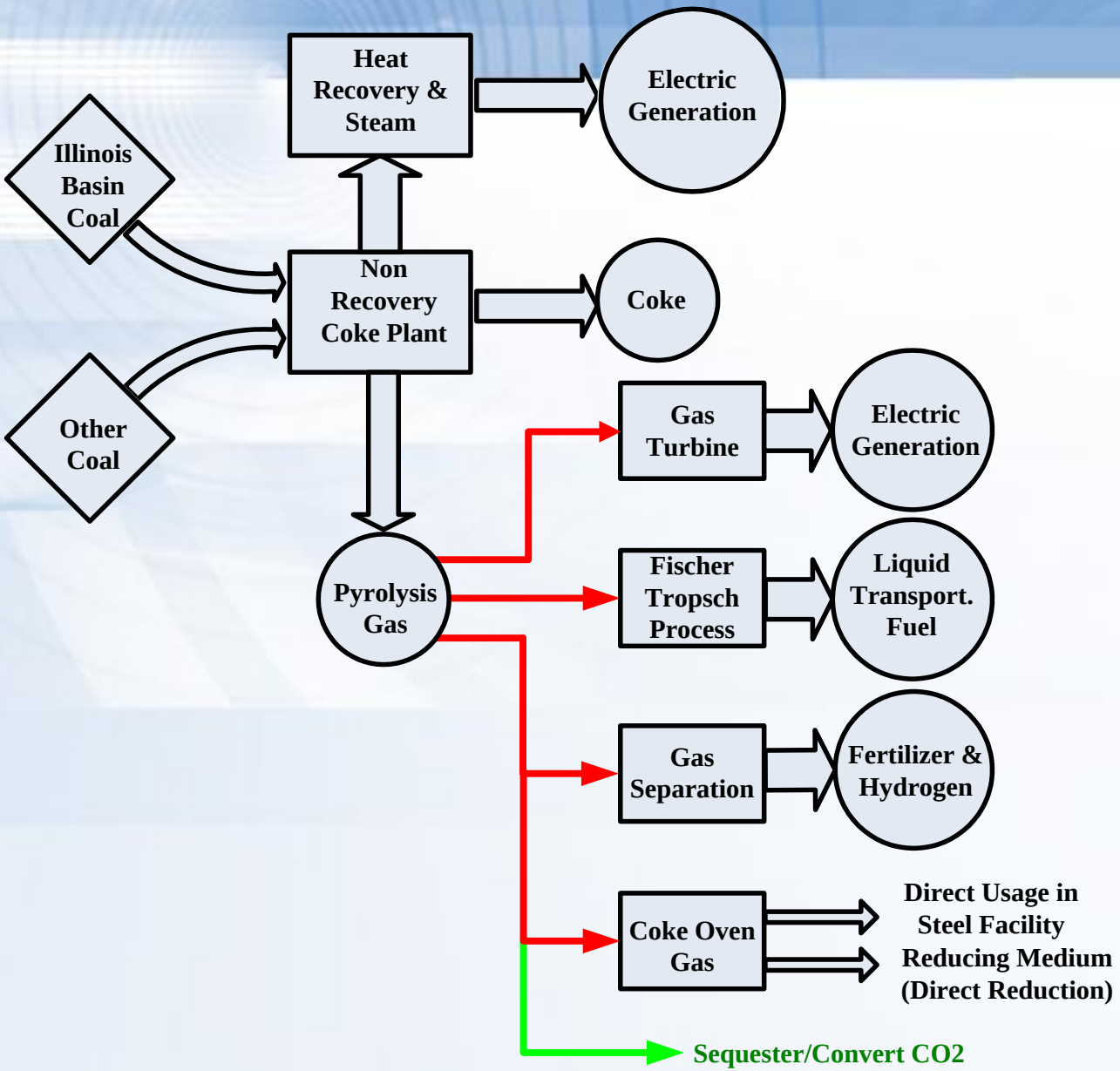
- Develop multipurpose Heat Recovery coke plant that maximizes the use of non coking coals (up to 50%).
- Combine the best of recovery and non recovery coke making technology to maximize the value of coke oven gas (COG).
- Produce new value from methane as heating fuel or reducing agent for direct reduction, production of diesel oil, fertilizer, hydrogen
- Electric power from waste heat gas
- Reduce carbon footprint by converting CO_2 to marketable chemical product.

Coke Oven Gas

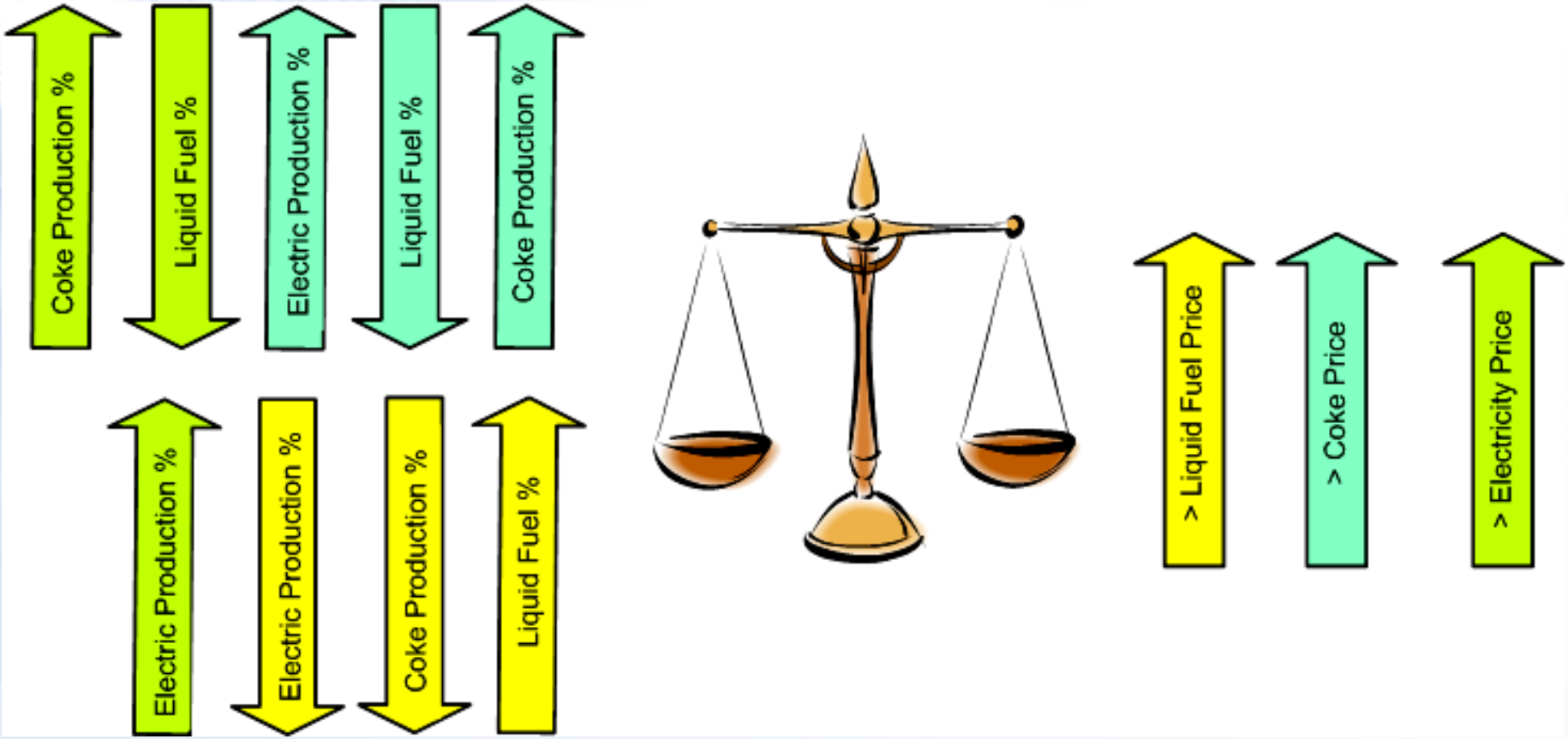
- **One metric ton of coal typically produces 600-800 kg of blast-furnace coke and 296-358 m^3 of coke oven gas.***

**The Making Shaping and Treating of Steel*, Association of Iron and Steel Engineers, Herbick & Held, Pittsburgh, 1985.

Process Value Streams



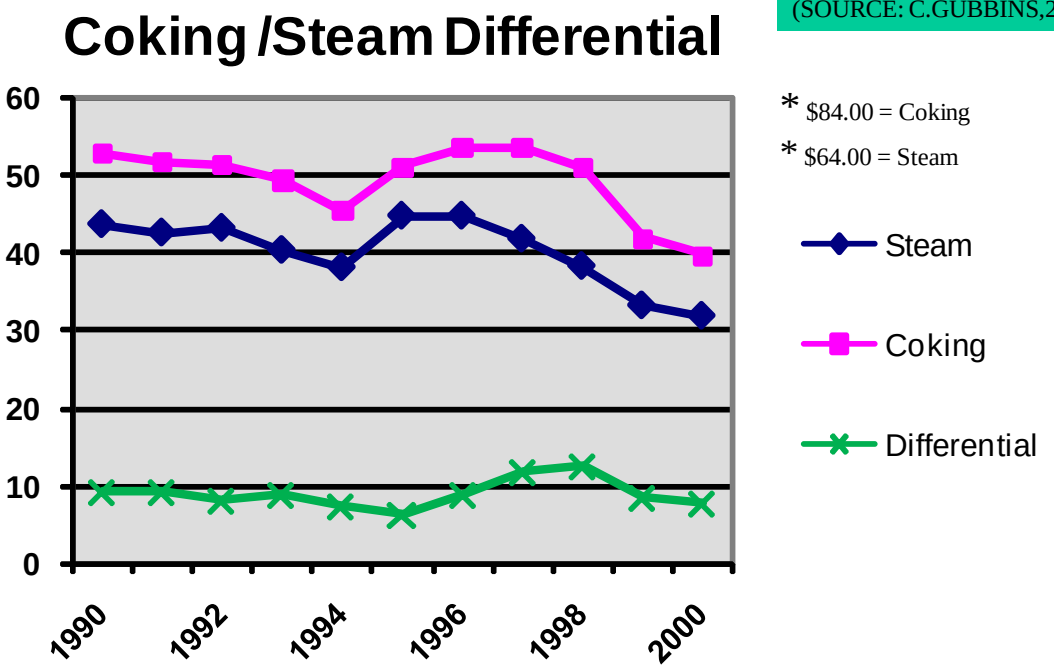
Process Value Streams



Economic and Quality Process Optimization

- **Develop model for blending coals in way that maximizes Indiana/Illinois Basin coal percentage (minimizes cost) within constraints**
  - Maintain acceptable CSR levels
  - Produce pyrolysis gas streams at various temperatures that have composition suitable for producing Fischer Tropsch liquids, fertilizer, and bulk hydrogen
  - Electricity production
- **Use the Model to formulate the design for a multipurpose coking facility that maximizes value for the entire process while meeting operating requirements**
- **Continue development of new approach to using nut coke in blast furnace operations that maximizes use of Indiana/Illinois Basin coal**

Coal Price Trends



(SOURCE: C.GUBBINS,2001)

* $84.00 = Coking
* $64.00 = Steam

2004 - Pittsburgh Seam Steam Coal -4th Qr 2004=$63.50; for 2005=$64 (Source:Argus Daily News)

Production Cost Example

Blend 1	Blend 2	Cost Difference	Savings
60% EHV 40% MVM	30% IN/IL 30% EHV 40% MVM		Coke plant using 2 MTPY coal
		$10/ton	$20M/Yr (2005: $40M/Yr)

History

- Before the coke property called CSR (coke strength after reaction with CO_2) 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 and the Future

- 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.

- <u>Research Results</u>
  - Indiana and Illinois coal can be used as part of a blend for production of coke in the Multipurpose Coking Facility currently being developed with properties suitable for use in modern large blast furnaces.
  - Reduced costs
  - New market for Indiana coal

	TC1931	TC1933	TC1935	TC1940	TC1941	TC1951	TC1952	TC1953	TC1954	TC1995
	30% Ill 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% Ill 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^3)	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		

Reasons for Superior Behavior of Indiana Brazil Coals

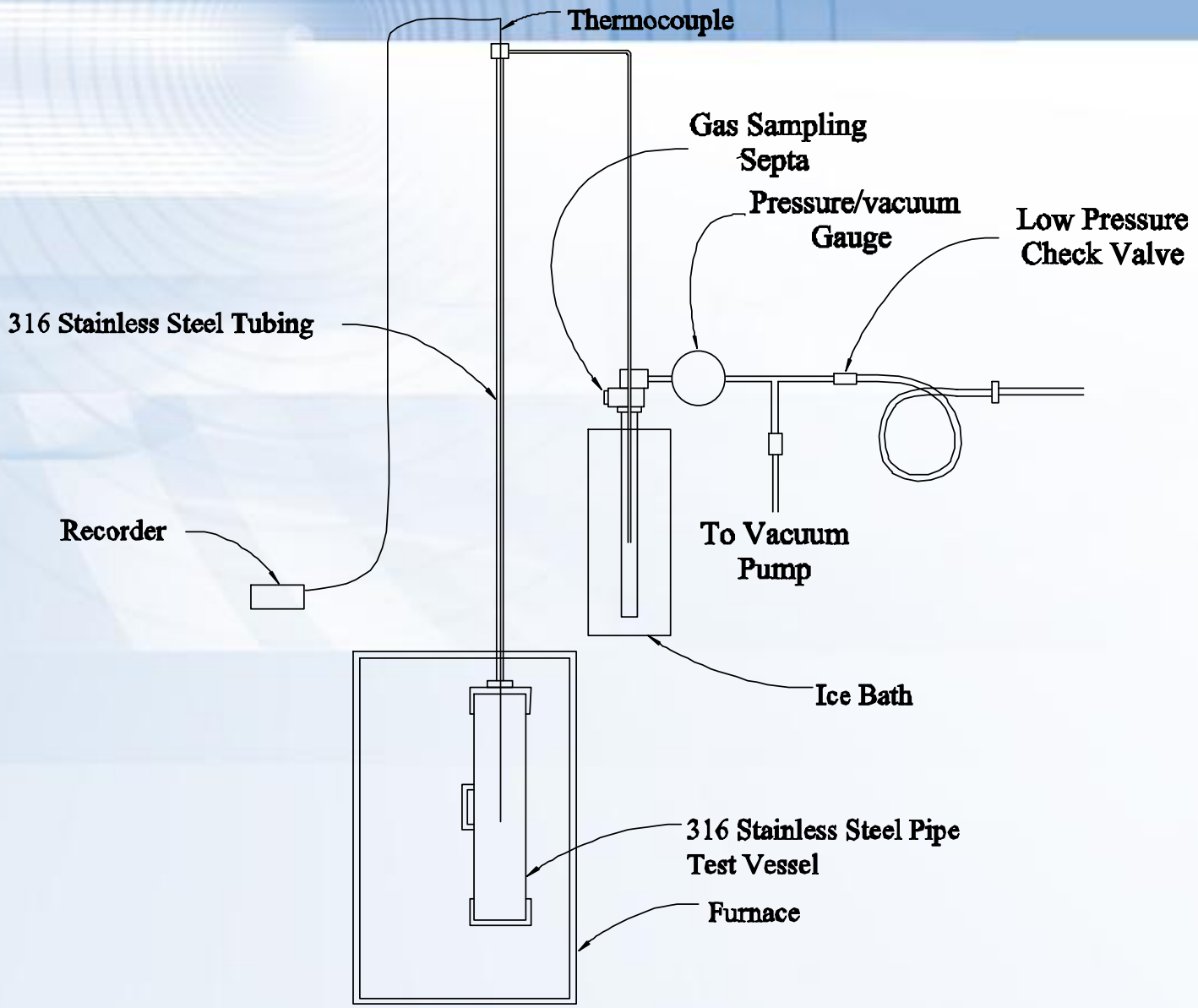
1. Presence of liptinite macerals (Valia and Hooper, 1994) contributes to higher fluid properties;
2. At comparable values of vitrinite reflectance, higher carbon content and lower O/C ratio (Walker et al., 2001);
3. Organic sulfur content correlates with plastic range, suggesting that organic sulfur promotes coking behavior;
4. Lower Block liptinites contribute a considerable amount of long chain, unbranched aliphatics to the overall kerogen composition of the seam. An increased cracking temperature would allow the Lower Block coal to maintain coherency and strength further into the coking process, and may assist plasticity (Walker and Mastalerz).

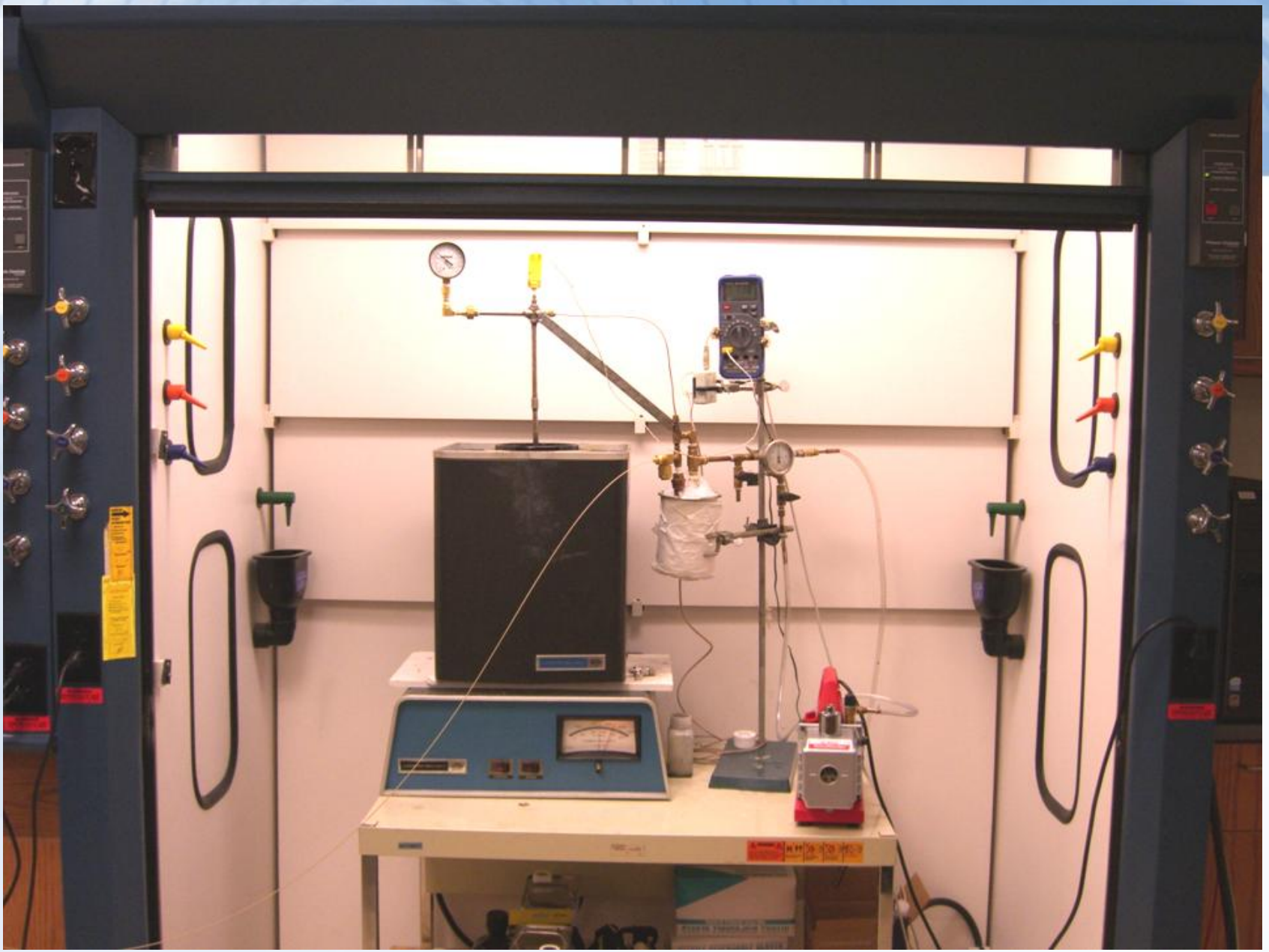
Coke Oven Gas

- **In a recovery coke oven, typically the coke oven gas has a composition of 58% hydrogen, 26% methane, 5.5% nitrogen, 2.25% acetylene, 2% carbon dioxide, 6% carbon monoxide, and .25% oxygen.**
- **One metric ton of coal typically produces 600-800 kg of blast-furnace coke and 296-358 m^3 of coke oven gas.**

Source:
Coke Oven Flow Gas Measurement, General Electric Industrial Sensing, Application Note 930-095B, March, 2005.
The Making Shaping and Treating of Steel, Association of Iron and Steel Engineers, Herbick & Held, Pittsburgh, 1985.

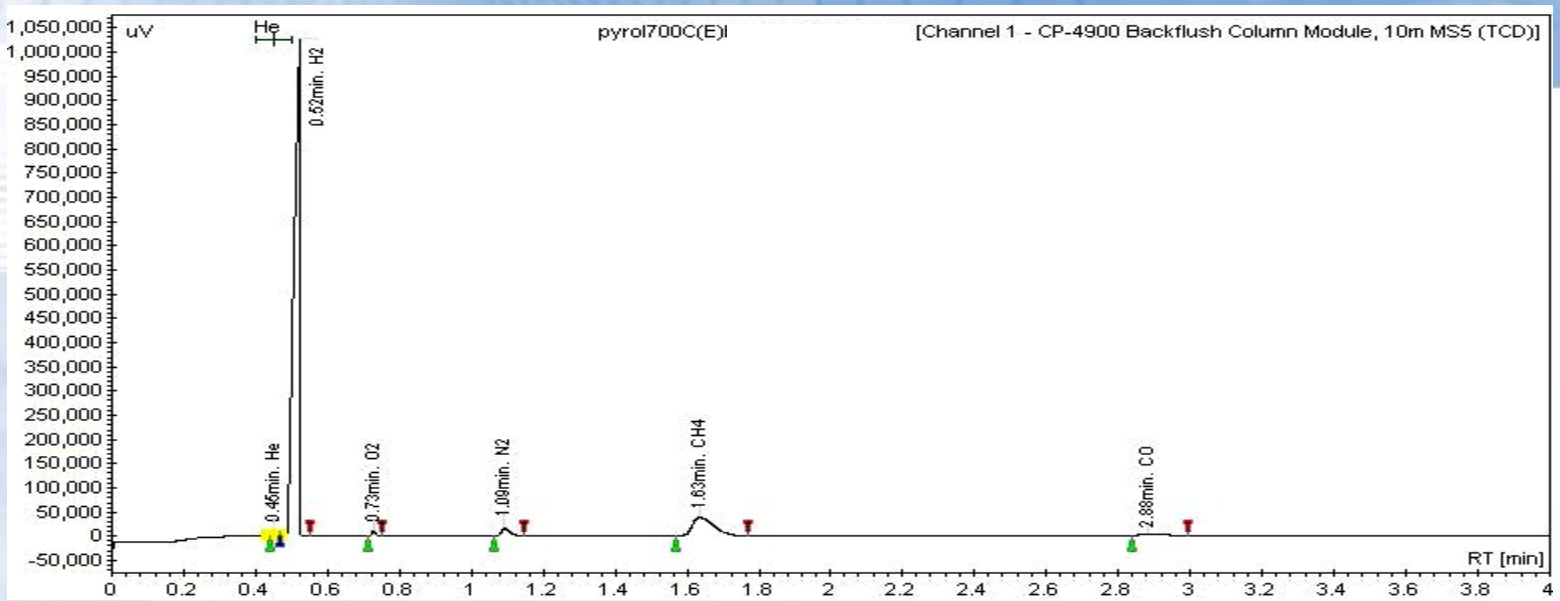
Purdue Coal Pyrolysis Testing Apparatus

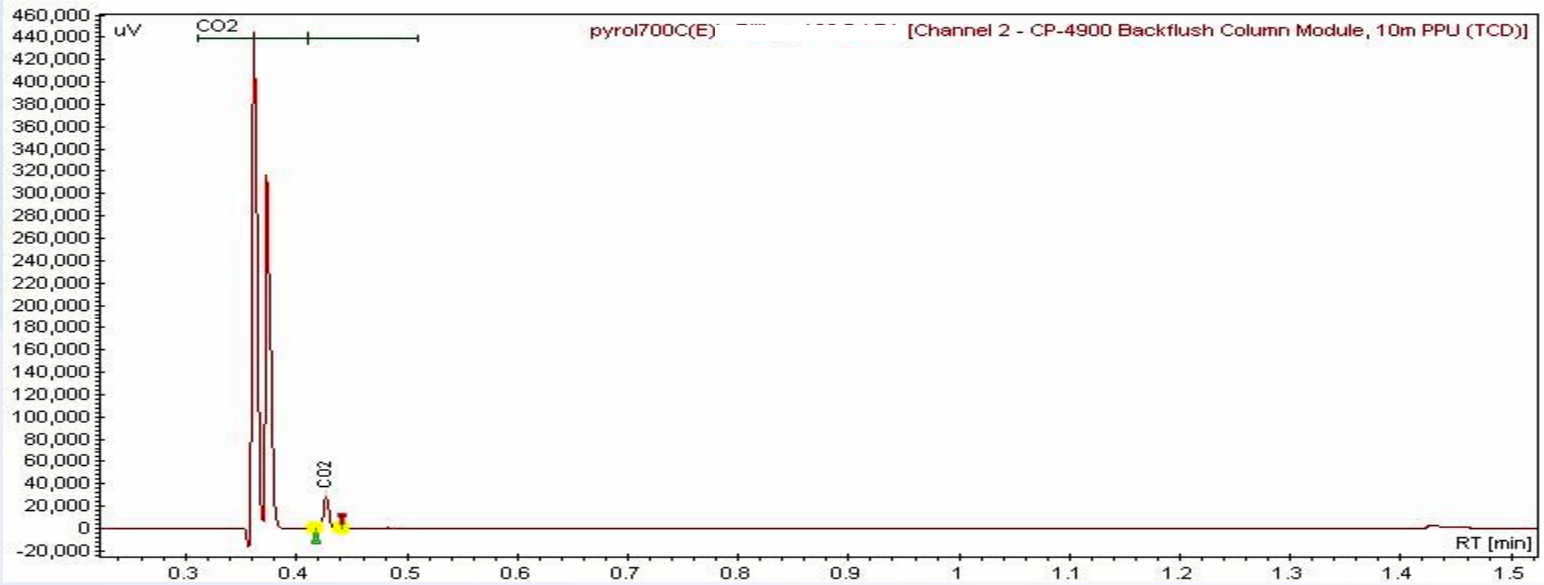




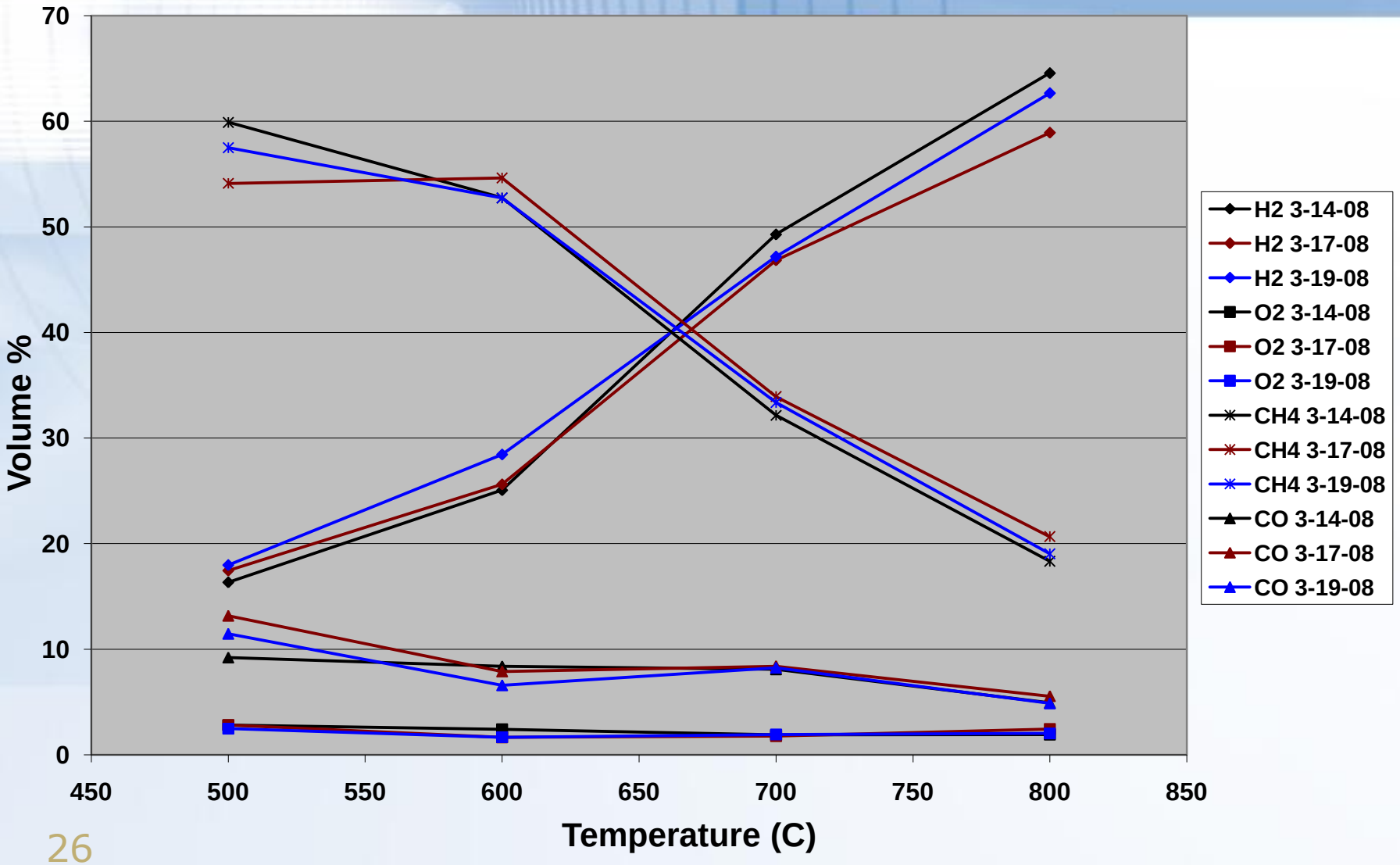

Concept

Pyrolysis Gas Chromatogram

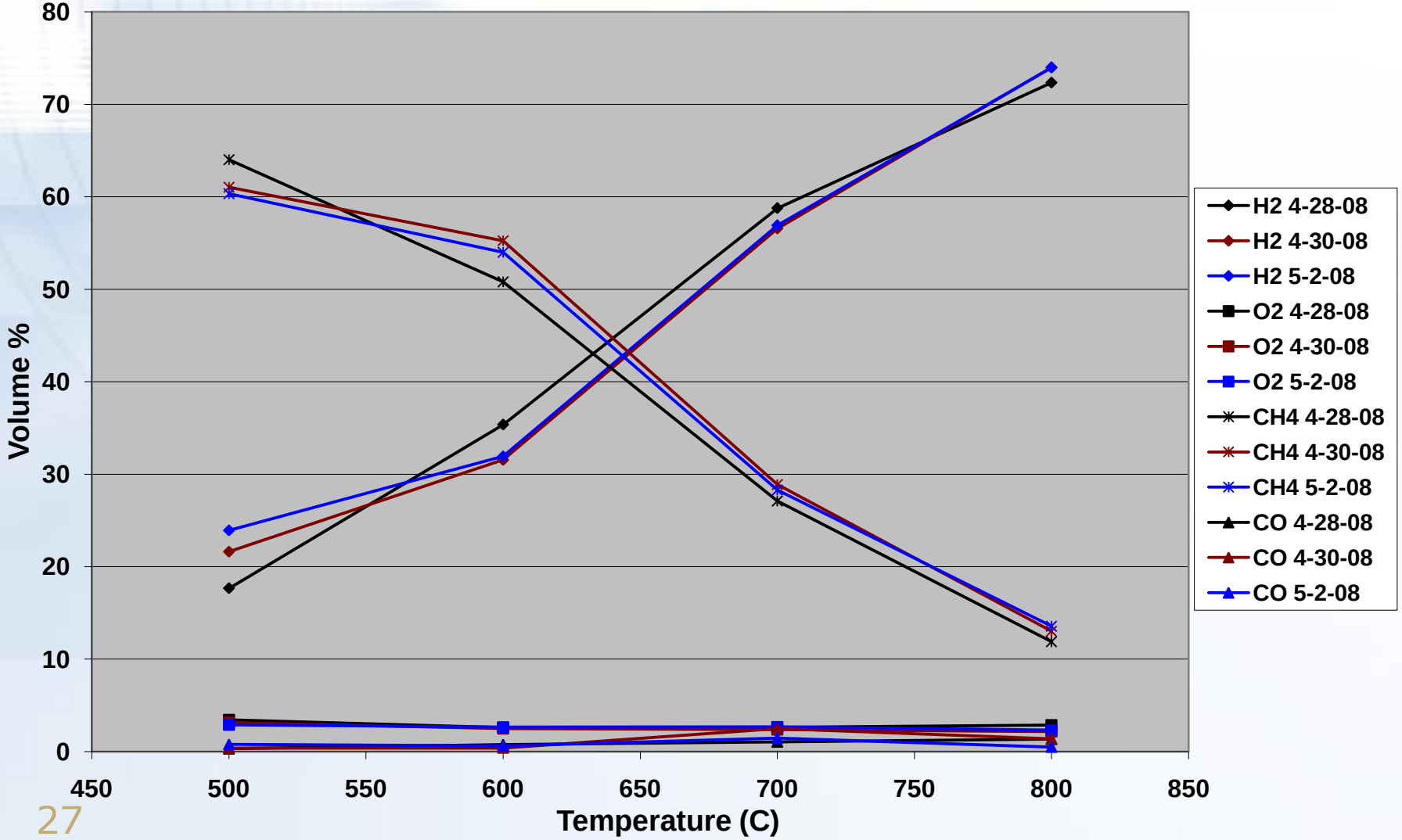




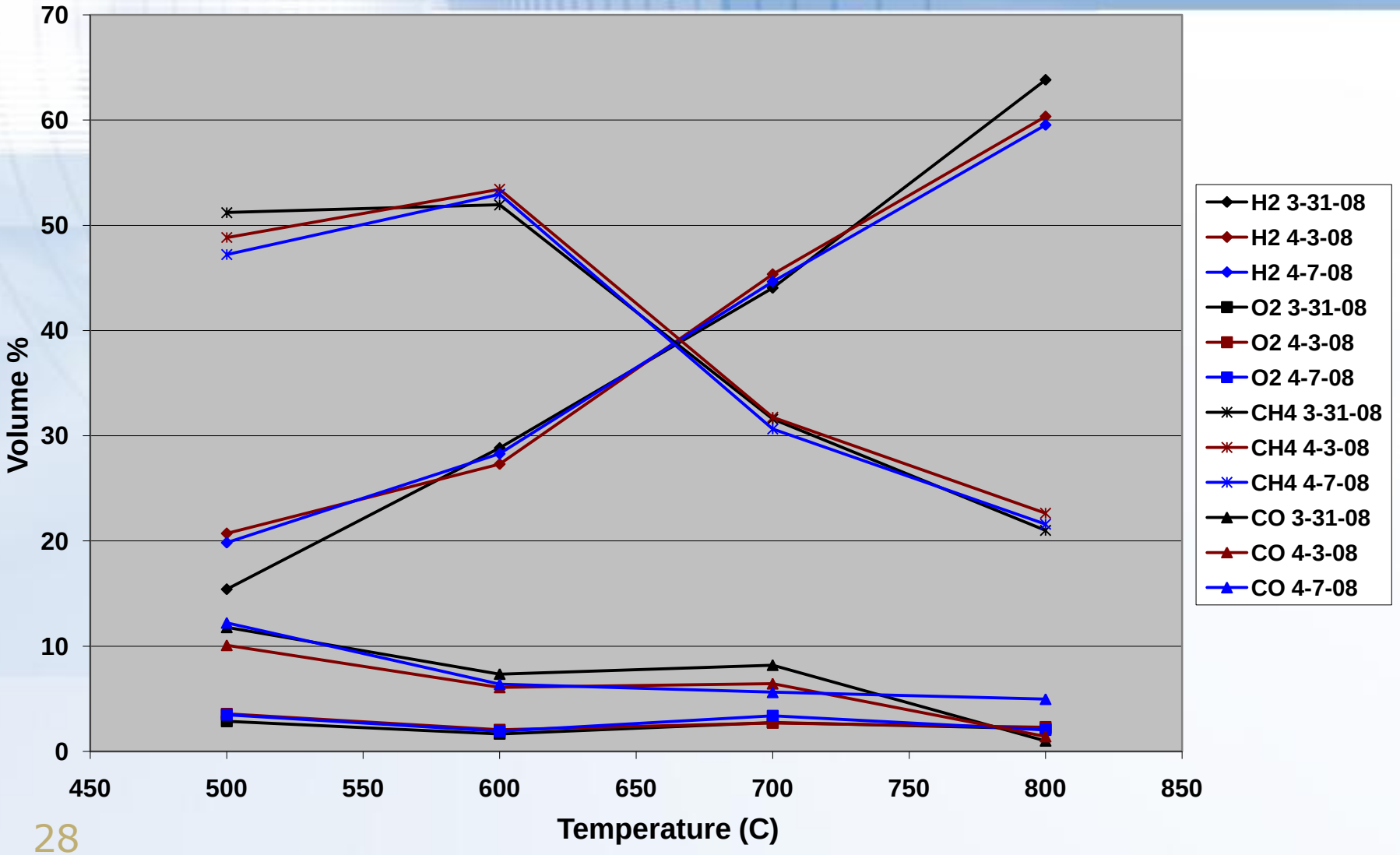
Indiana Coal Pyrolysis Data



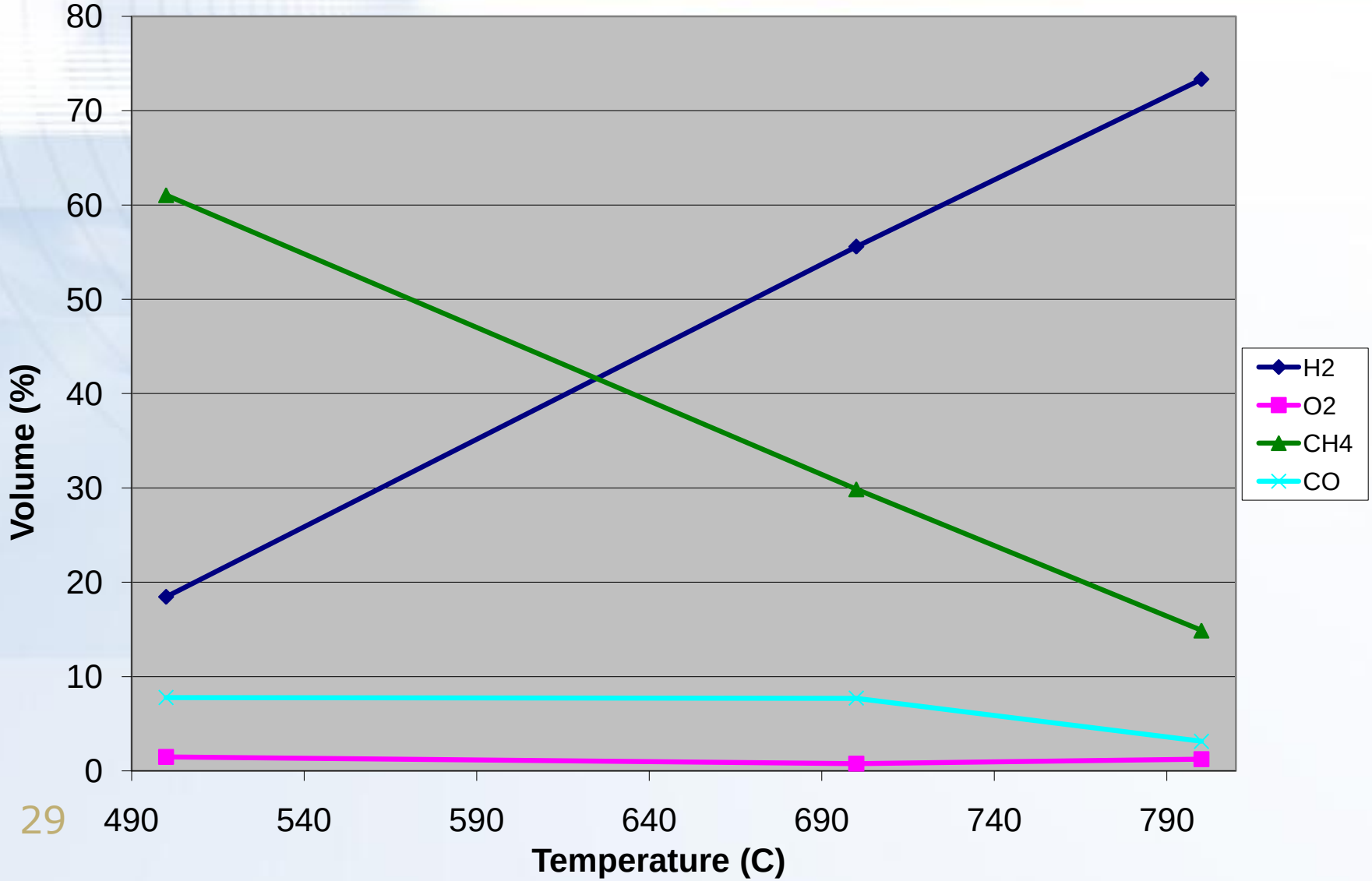
Eastern Metallurgical Coal Pyrolysis Data



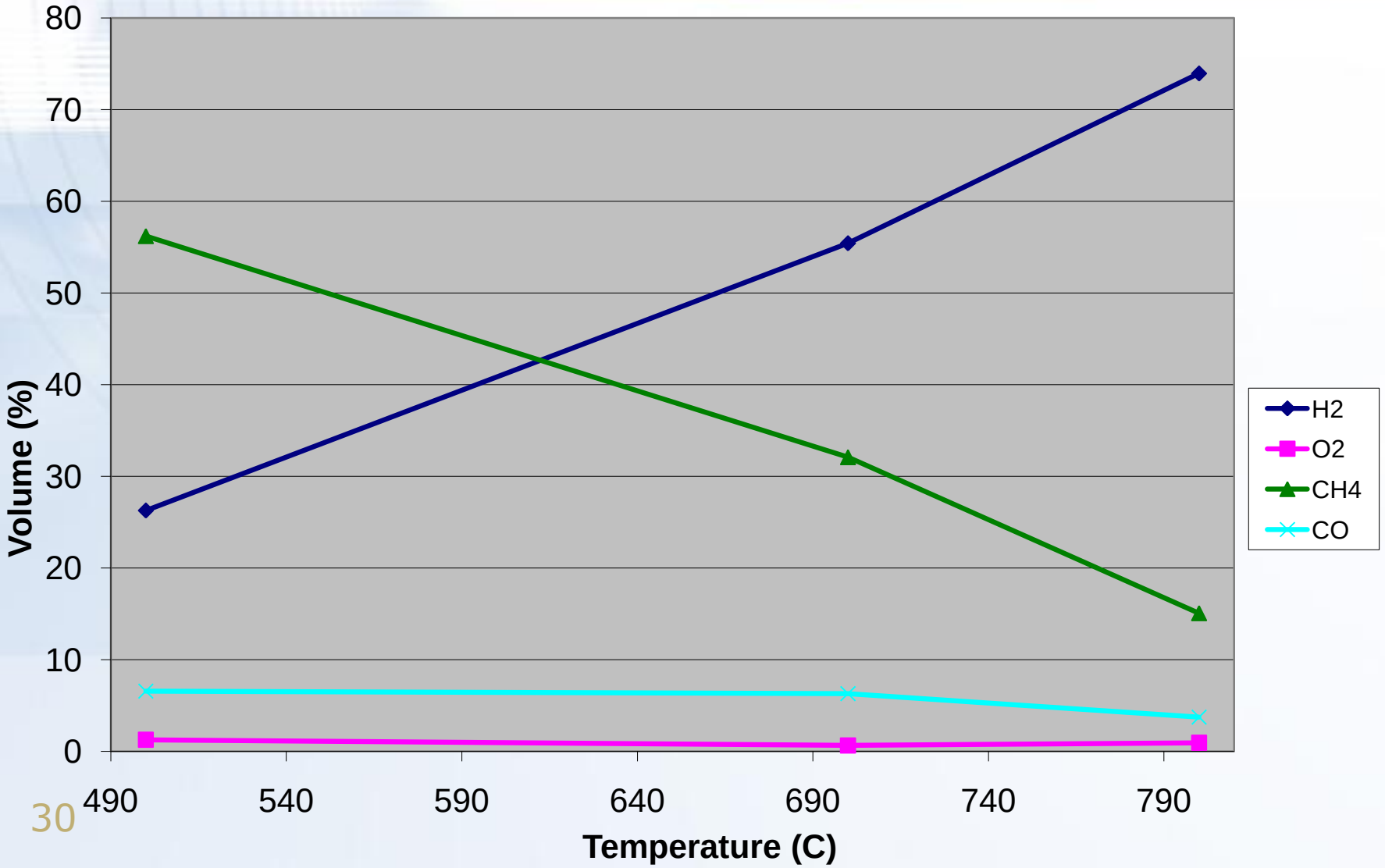
IN Coal Blending Test Pyrolysis Data



Blend of 40% Indiana Coal with Eastern Metallurgical Coal



Blend of 40% Illinois Coal with Eastern Metallurgical Coal



Slow Pyrolysis Kinetics

$$\frac{dV}{dt} = \frac{K_0 V_0}{m'} 10^{\left[-\frac{E}{RT} - \frac{K_0 R T^2}{mE} e^{-\left(\frac{E}{RT}\right)}\right]}$$

(1975 data)

m' = heating rate = $\frac{dT}{dt}$

V = volume of any particular gas released at time t (not total volatiles)

K_0 = rate constant for release of a particular component, including tar, sec^{-1}

E = activation energy kJ/mol

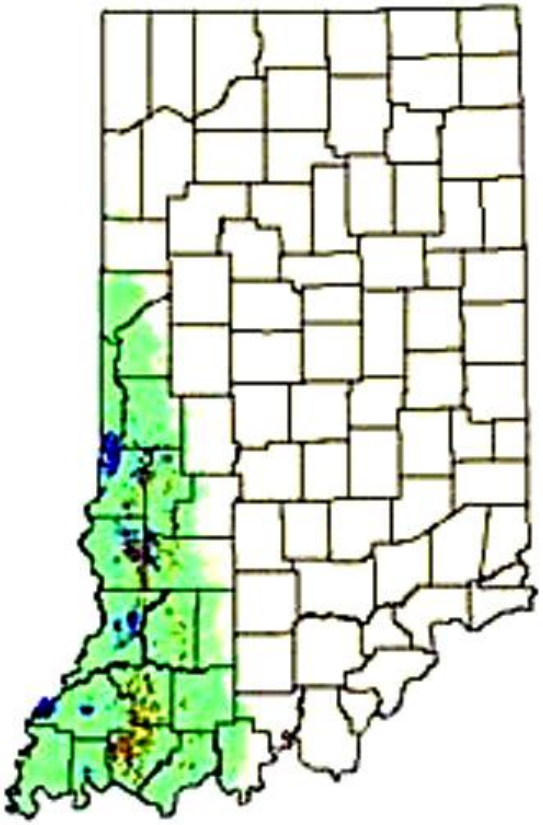
R = gas constant, kJ/mol °K

m = order of reaction

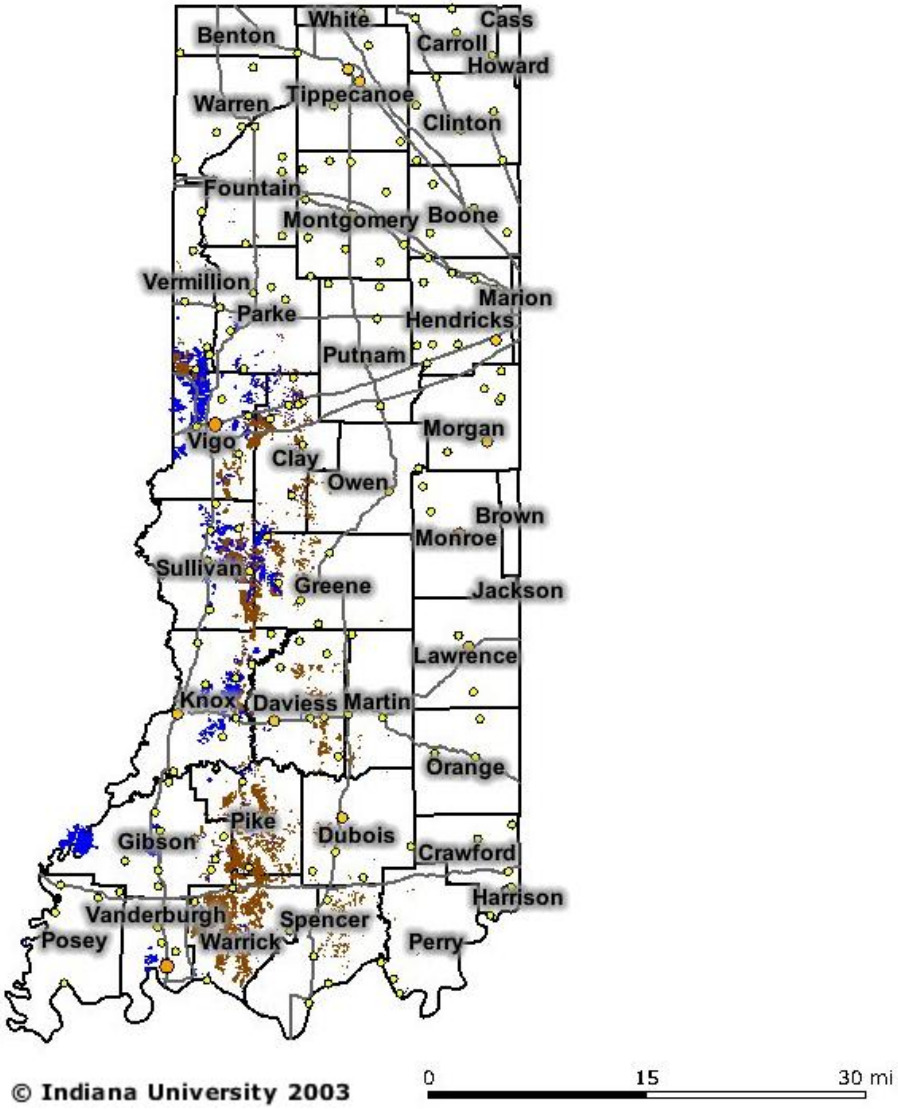
Gas	K_0	E
H_2	20	22.3
CH_4	1.67×10^5	31.0
CO_2	550	19.5
CO	55	18.0

Source:Coal Conversion Technology, Wen,C., Lee, E.

Transportation Issues



Index map of Indiana showing the coal-bearing rocks of the Pennsylvanian System in green, underground coal mines in blue, and surface coal mines in brown.



CSL Pilot Oven

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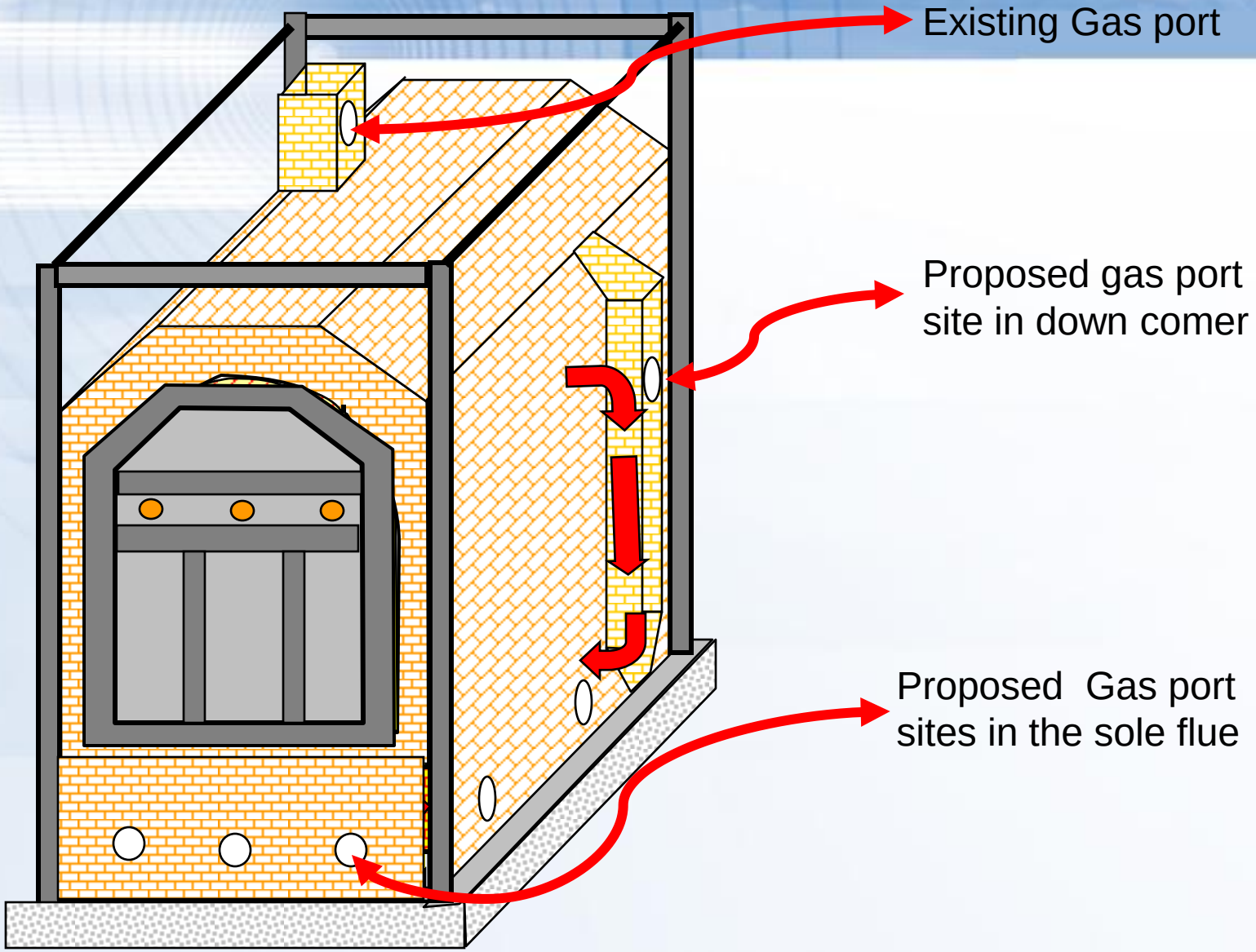

Thank You !

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