A METHOD OF REDUCING CO_2 EMISSIONS FROM OIL SHALE RETORTING

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17th OIL SHALE SYMPOSIUM

Colorado School of Mines

October 2007

STRONG OPPOSITION TO U. S. OIL SHALE DEVELOPMENT EXISTS DESPITE THE PROSPECTS FOR REDUCING FOREIGN OIL DEPENDENCE

News Release June 25, 2007

- Western Colorado Congress
- Western Resource Advocates
- Colorado Environmental Coalition
- Natural Resources Defense Council
- The Wilderness Society
- Wilderness Workshop

"Potential air pollution impacts of a 1,000,000 barrel-per-day oil shale industry could include the release of **more than 105,000,000 tons of carbon dioxide**, or a roughly 80 percent increase in the amount of CO_2 emitted by all existing electric utility generating units in 2005 in Colorado, Wyoming and Utah **combined**."

CO_2 EMISSIONS FROM OIL SHALE RETORTS TYPICALLY RESULT FROM:

Combustion of carbon containing fuels for pyrolysis heat

- Carbon on spent shale
- Shale pyrolysis gas
- Supplemental carbonaceous fuels

Decomposition of carbonates in the spent shale

- Dolomite above 560 °C
- Calcite above 620 °C

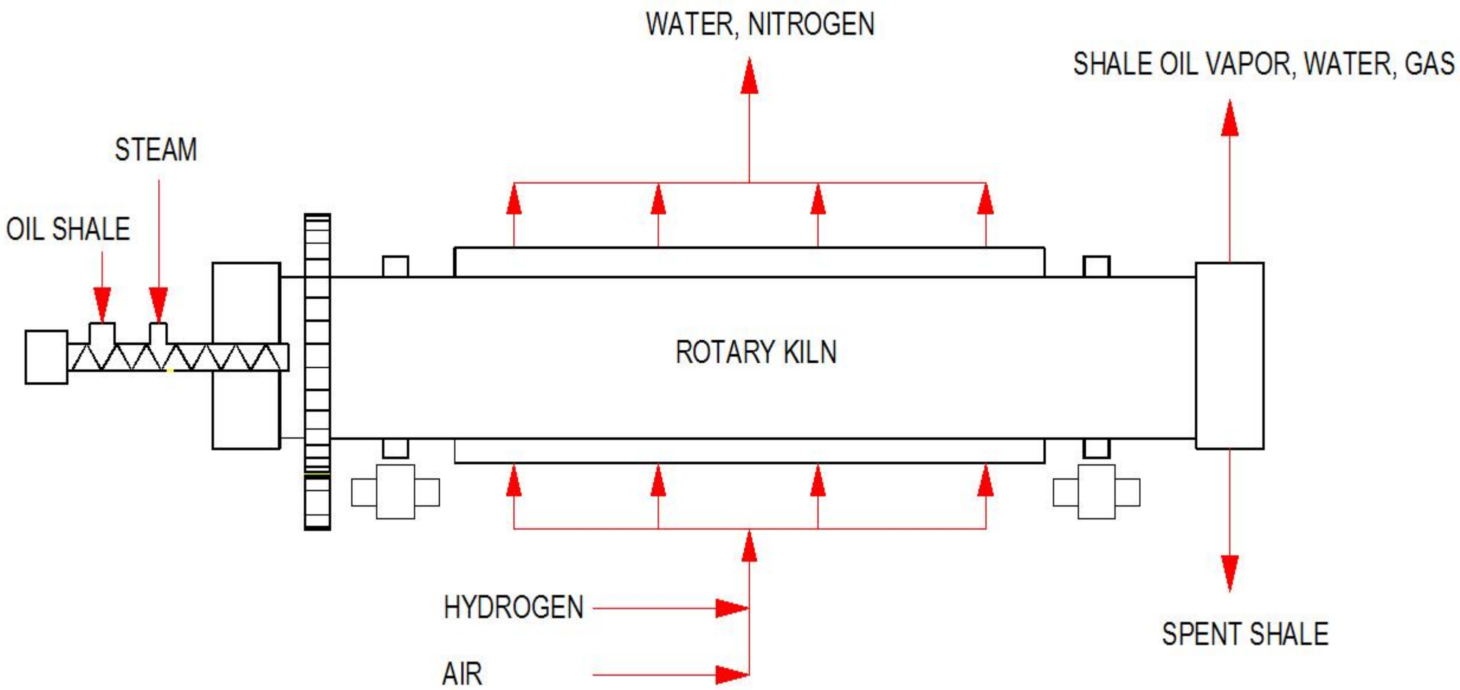
OUR METHOD FOR REDUCING CO_2 EMISSIONS IS SIMILAR TO THE FUTUREGEN APPROACH FOR ELECTRIC POWER GENERATION

"The intention of the FutureGen plant is to produce hydrogen from gasification of coal and sequester the carbon dioxide generated by the process . . . .

[new] combustion technologies [are] being evaluated for use in the 200 megawatt utility-size hydrogen [fueled] turbine that is a key component of the FutureGen plant."

Lawrence Berkeley National Laboratory News Release - August 1, 2007

OUR METHOD UTILIZES A ROTARY KILN FIRED INDIRECTLY WITH HYDROGEN



PATENT PENDING

WE HAVE STUDIED DIFFERENCES BETWEEN EARLY INDIRECT FIRED RETORTS AND MODERN RETORTS

Early retort designs heated shale by burning spent shale and gases in external combustion chambers surrounding the pyrolysis chamber

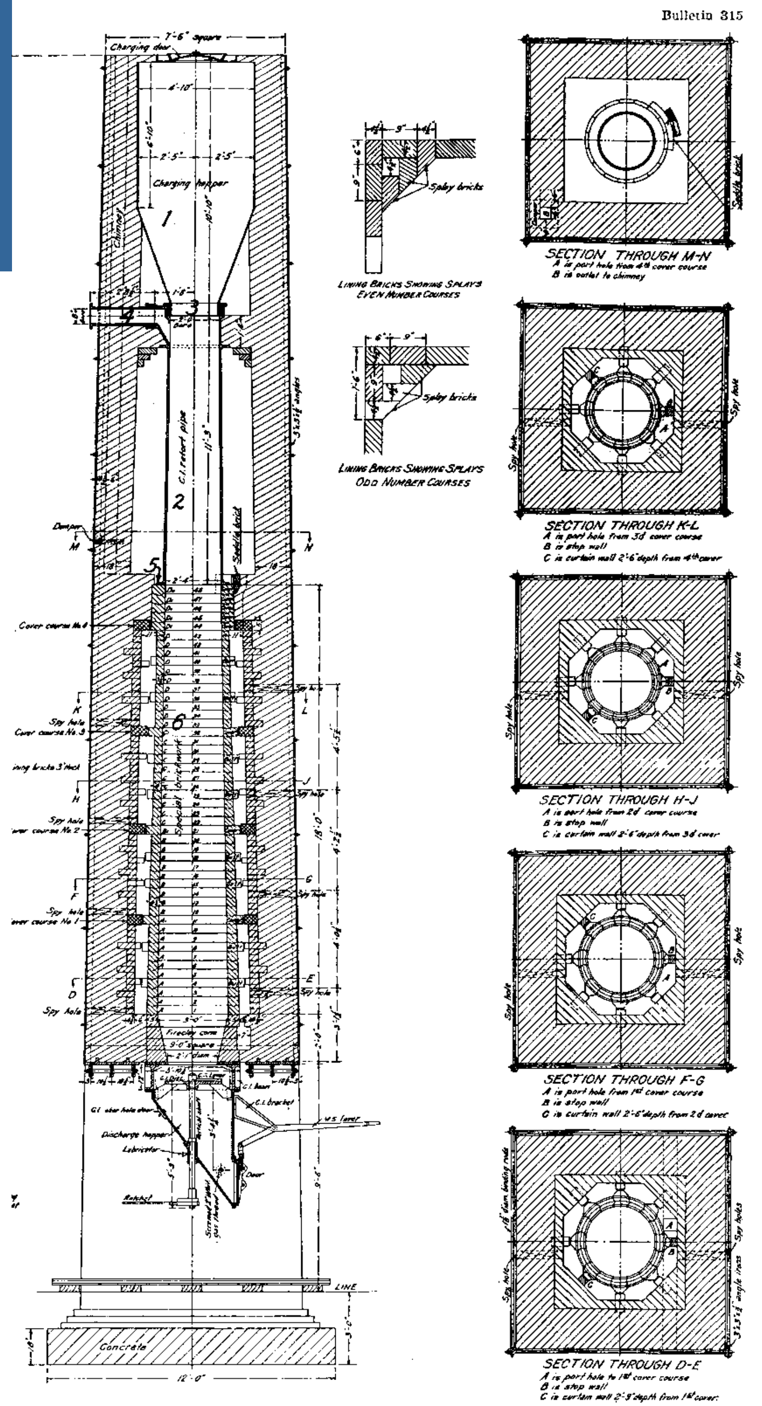
- PUMPHERTON Scotland 1894 - 1938
- DAVIDSON Estonia 1931- 1961

Recent retorts heat shale by a combination of direct contact with hot flue gas and direct contact with spent shale recycled from a residual carbon burner

- GALOTER Estonia 1980 - 2007
- ATP Australia 1999 - 2003

PUMPHERSTON INDIRECT FIRED RETORT

Scotland
1894 - 1938



DAVIDSON INDIRECT FIRED ROTARY KILN RETORT
Estonia 1931 - 1961

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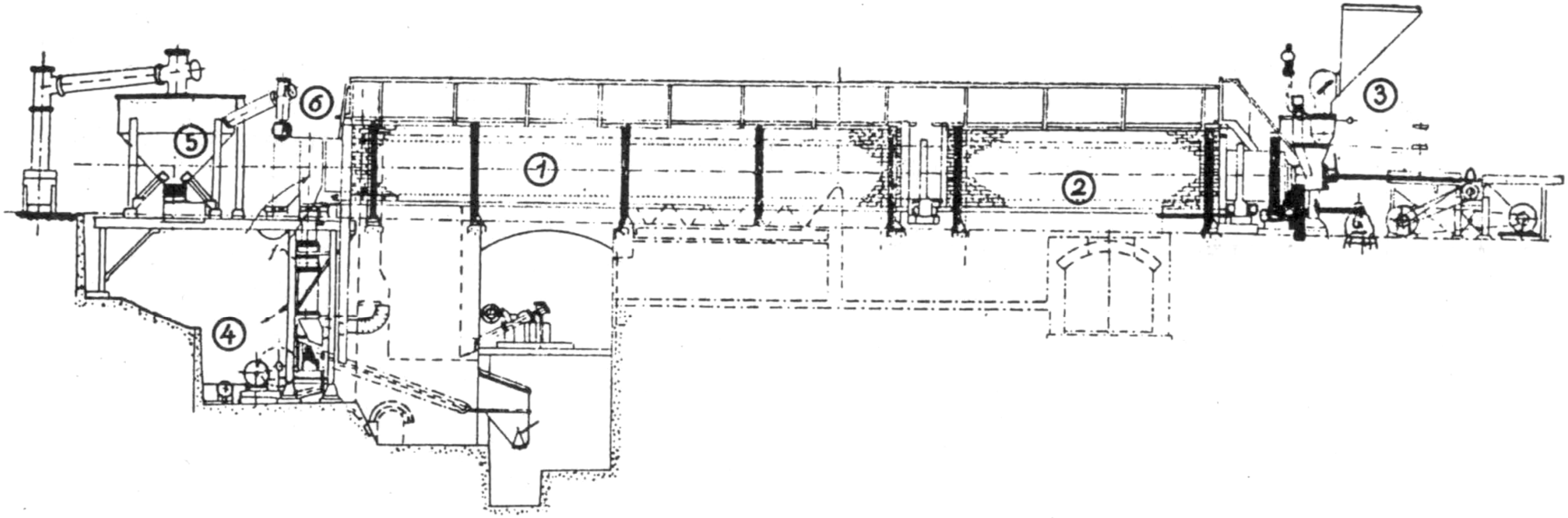


Joonis 5.8. Davidsoni pöörlev retort. 1 – utmiskamber; 2 – küttekolle; 3 – laadimisseade; 4 – poolkoksi väljalaadimisseade; 5 – tolmueraldamise kamber; 6 – auru- ja gaasisegu väljajuhtimise toru.

Figure 5.8. Davidson's revolving retort: 1 – distillation chamber; 2 – heating chamber; 3 – loader; 4 – semi-coke unloader; 5 – dedusting chamber; 6 – gas and steam mixture outlet.

INDIRECT HEATING OF OIL SHALE RETORTS WAS ABANDONED DUE TO LOW THROUGHPUT CAPACITY

Retort	Heating	tonnes/day	kg /sq m /hr
Pumpherston	Indirect	6	540
Davidson	Indirect	25	540
Fushun	Direct	110	590
Kiviter	Direct	1000	590
Paraho	Direct	400	1900
Petrosix	Direct	6800	2700
ATP	Combination	4500	3400
LLNL	Recycle	4	5400
Tosco	Recycle	1000	7800

FACTORS WE BELIEVE CONTRIBUTED TO LOW THROUGHPUT RATES OF INDIRECTLY FIRED RETORTS

Pumpherston

- Coarse shale
- 66% of shell heat transfer area is through 5 ½” thick brick
- Burner flue gas flow is counter to shale flow
- Small flue gas passages limited firing rate

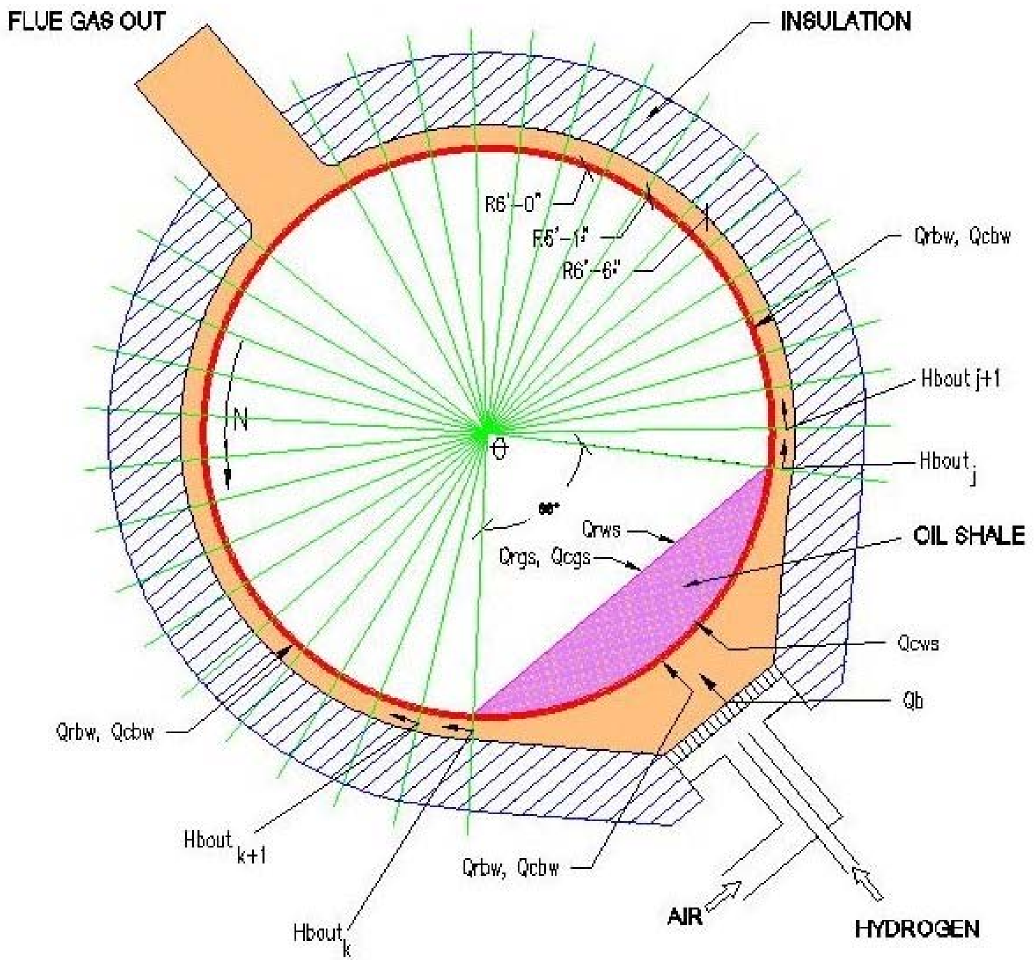
Davidson

- Coarse shale (25 to 125mm)
- Burner flue gas flow is counter to shale flow
- Low firing rate
- Low rotation rate

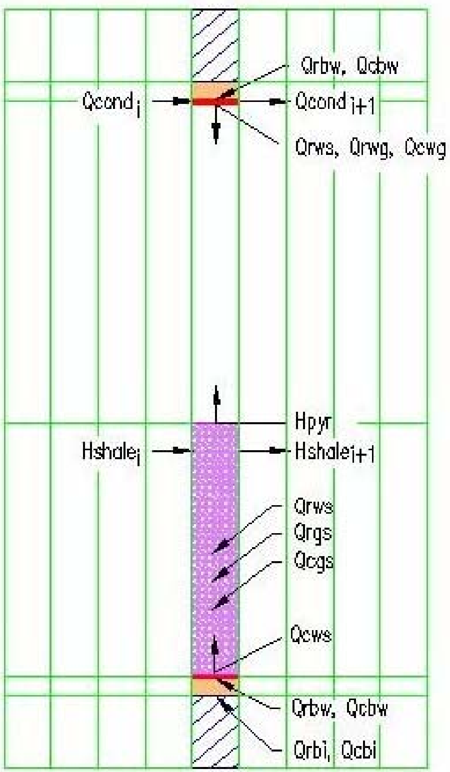
COMPANIES CURRENTLY OFFERING INDIRECTLY FIRED ROTARY KILNS

- **ALSTOM POWER (BARTLETT-SNOW)**
- **METSO CORPORATION**
- **FEECO INTERNATIONAL**
- **HEYL & PATTERSON**
- **THERMAL PROCESSING SOLUTIONS**

WE HAVE DEVELOPED A DETAILED COMPUTER MODEL TO EVALUATE COMMERCIAL ROTARY KILNS



CROSS SECTION



AXIAL SECTION

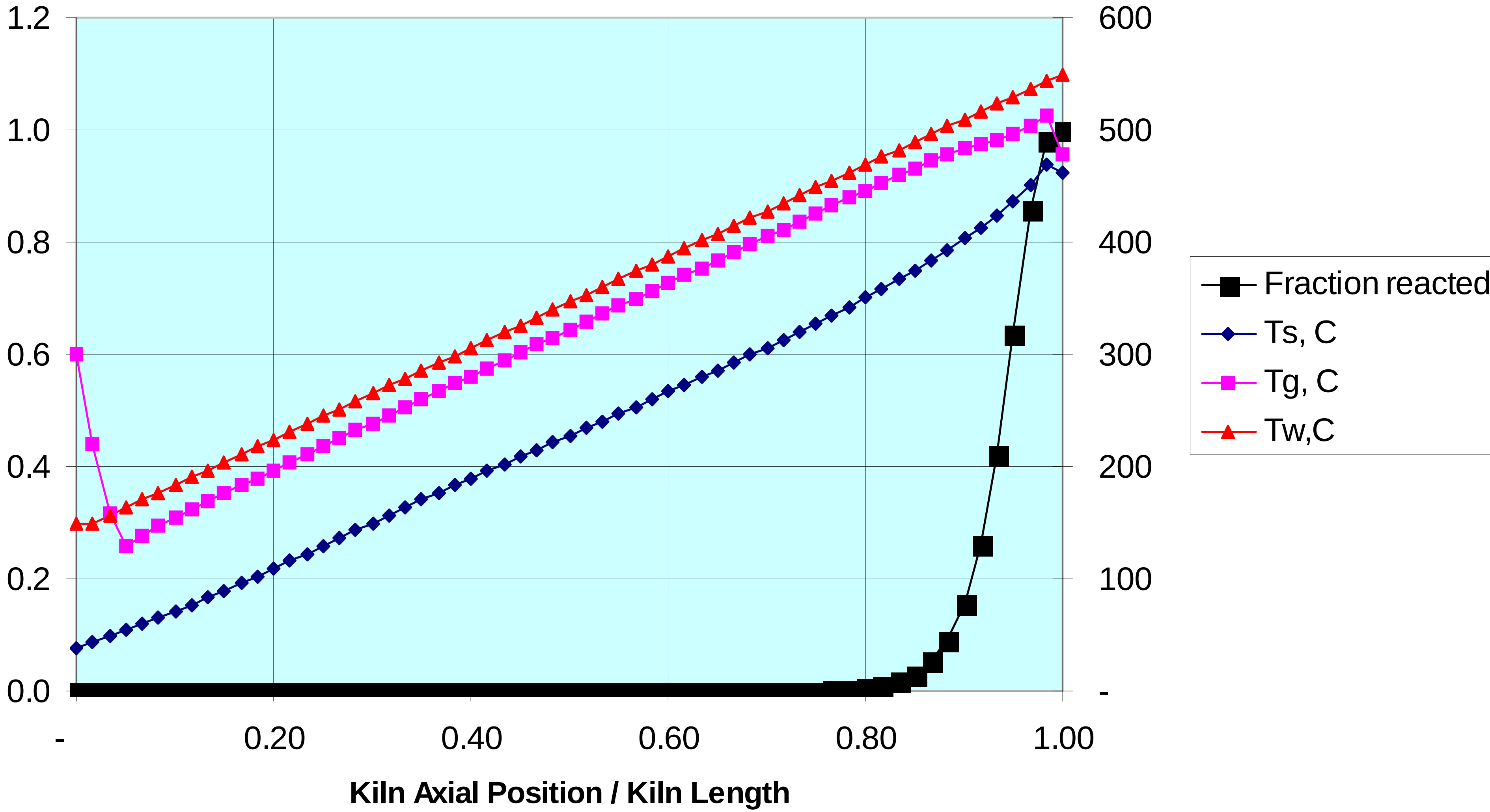
OUR MODEL BUILDS ON RECENT MODELS FOR BOTH DIRECTLY FIRED AND INDIRECTLY FIRED KILNS

- Silcox, et al, **Mathematical and Physical Modeling of Rotary Kilns with Application to Scaling and Design**, 1992
- Patisson, et al, **Coal pyrolysis in a rotary kiln: Part II, Overall model of the furnace**, 2000
- Martins, et al, **Modeling and simulation of petroleum coke calcination in rotary kilns**, 2001
- Li, et al, **A Mathematical Model of Heat Transfer in a Rotary Kiln Thermo Reactor**, 2005
- Mujumdar, et al, **Modeling of rotary cement kilns: Applications to reduction in energy consumption**, 2006

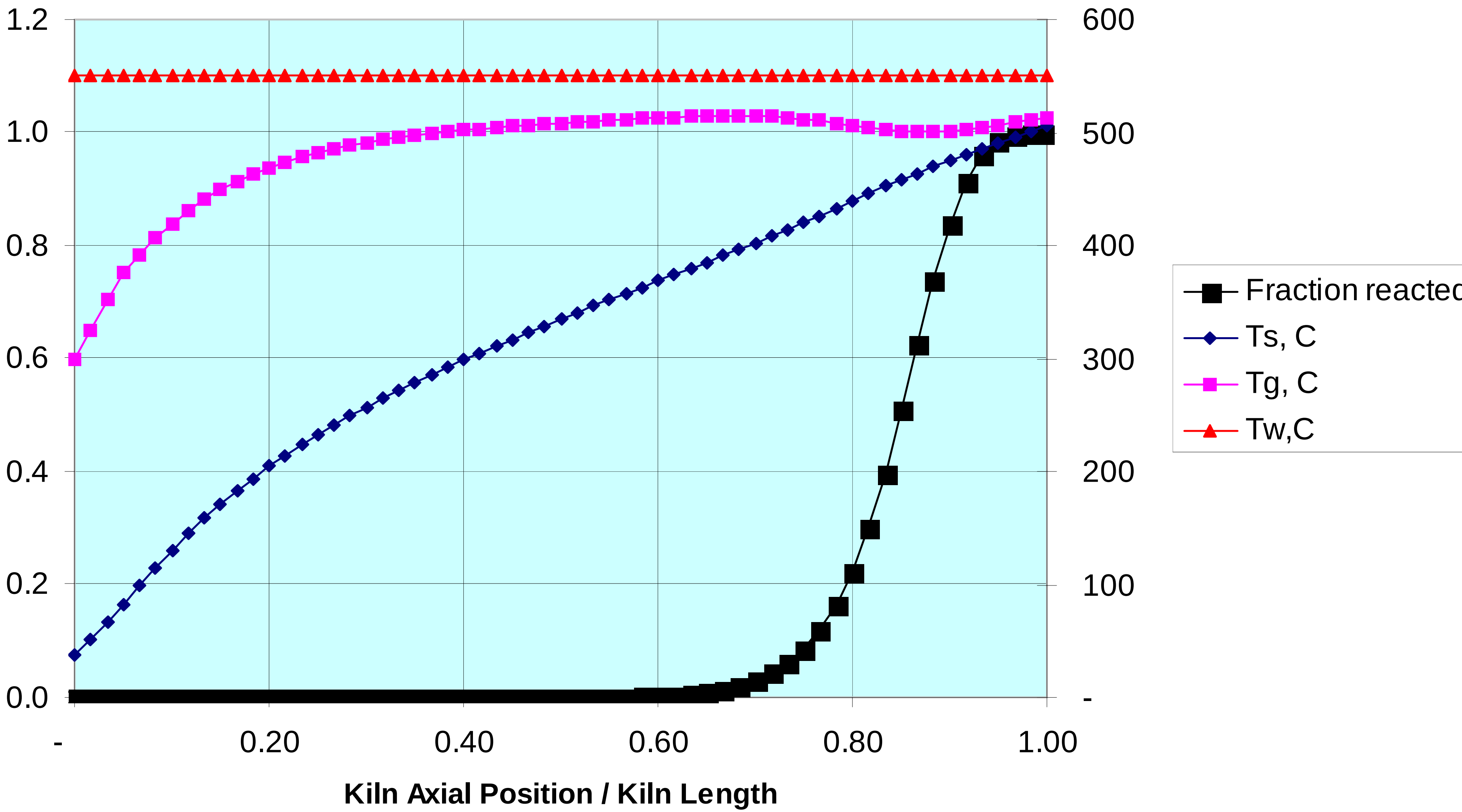
IMPORTANT MODEL PARAMETERS

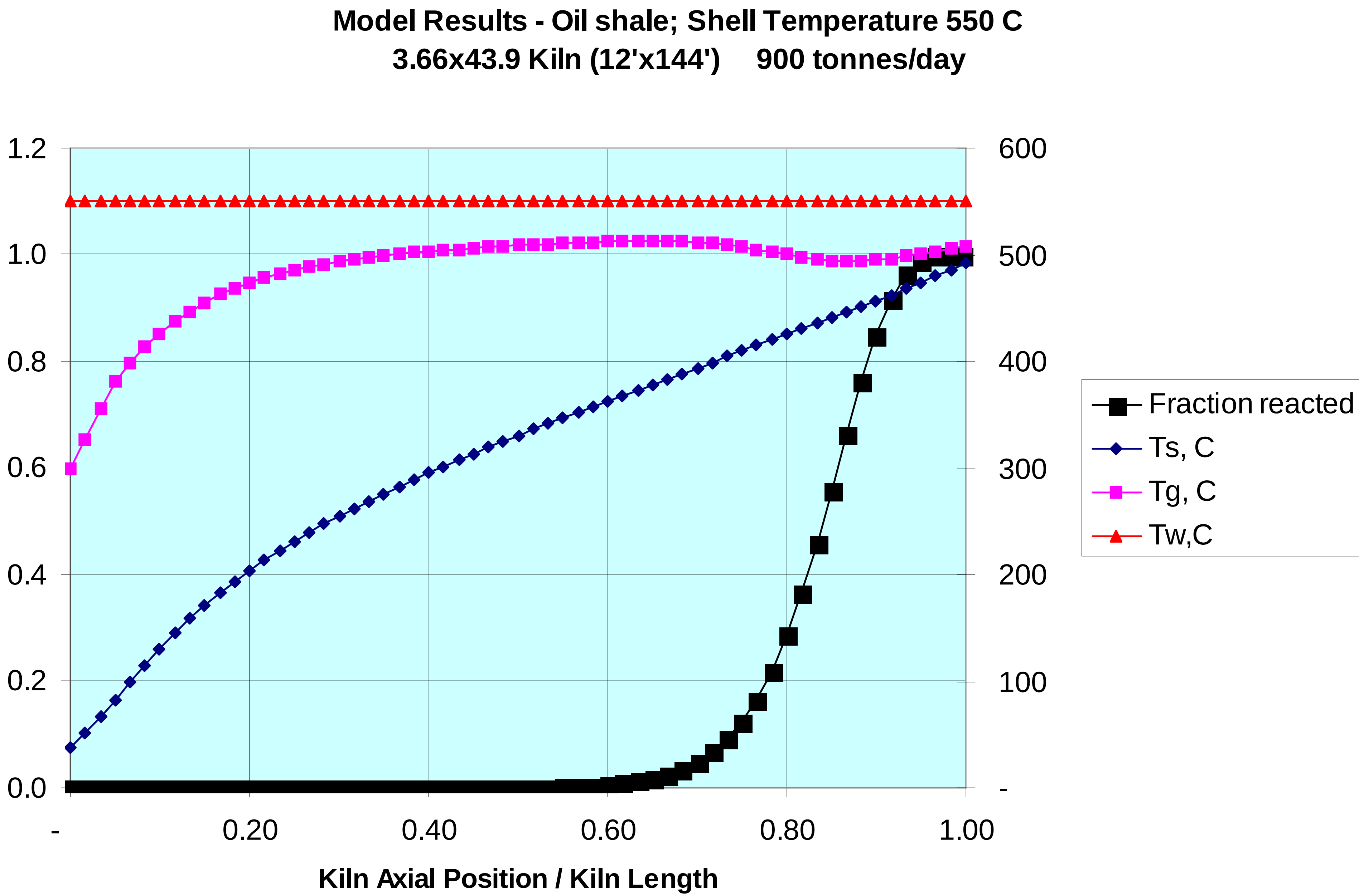
- **Kiln throughput rates**
  - Internal diameter and length
  - Rotation rate
  - Fraction filled
  - Angle of repose
- **Heat transfer rates**
  - Contact of oil shale particles with kiln surface
    - Particle size, thermal diffusivity
  - Burner flame radiation to kiln surface
- **Variation of solid and gas heat capacities with temperature**
- **Pyrolysis reaction kinetics**

Model Results - Davidson Kiln Simulation
Kiln Size 1.6x22 (5.3'x72')   25 tonnes oils shale per day
Counterflow heating, Coarse Particles



Model Results - Davidson Size Kiln, Fine Particles, Shell Temperature 550 C
Kiln Size 1.6x22 (5.3'x72') 215 tonnes/day





Model Results - Oil shale; Shell Temperature 550 C
3.66x43.9 Kiln (12'x144') 900 tonnes/day
1.2
1.0
0.8
0.6
0.4
0.2
0.0
600
500
400
300
200
100
-
-
0.20
0.40
0.60
0.80
1.00
Kiln Axial Position / Kiln Length
Fraction reacted
Ts, C
Tg, C
Tw,C

MODEL CALCULATIONS AND COMMERCIAL QUOTATIONS BOTH INDICATE COMPETITIVE THROUGHPUT RATES CAN BE ACHIEVED WITH MODERN INDIRECTLY FIRED KILNS

	Diameter,m	Length m	tonnes /day	kg/ sq m / hr
Davidson	1.6	22	25	540
Commercial Quotation	1.5	9	120	2500
Model Computation	1.6	22	215	4800
Model Computation	3.7	44	900	3600

CONCLUSIONS

CO_2 emissions from surface oil shale processing can be **dramatically reduced** by the use of hydrogen fired rotary kilns (patent pending)

Both manufacturer quotations and computer modeling indicate advanced firing technology can be employed to achieve rotary kiln throughput rates that **greatly exceed** rates of the Davidson kilns operated from 1931 – 1961.

Experimental work should be done to verify promising computer modeling results.

Thank You

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