

# **Thermodynamics will govern future trends in energy economics**

***Oil Shale Symposium  
Colorado School of Mines  
October 19-21, 2009***

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# Declarative Statements

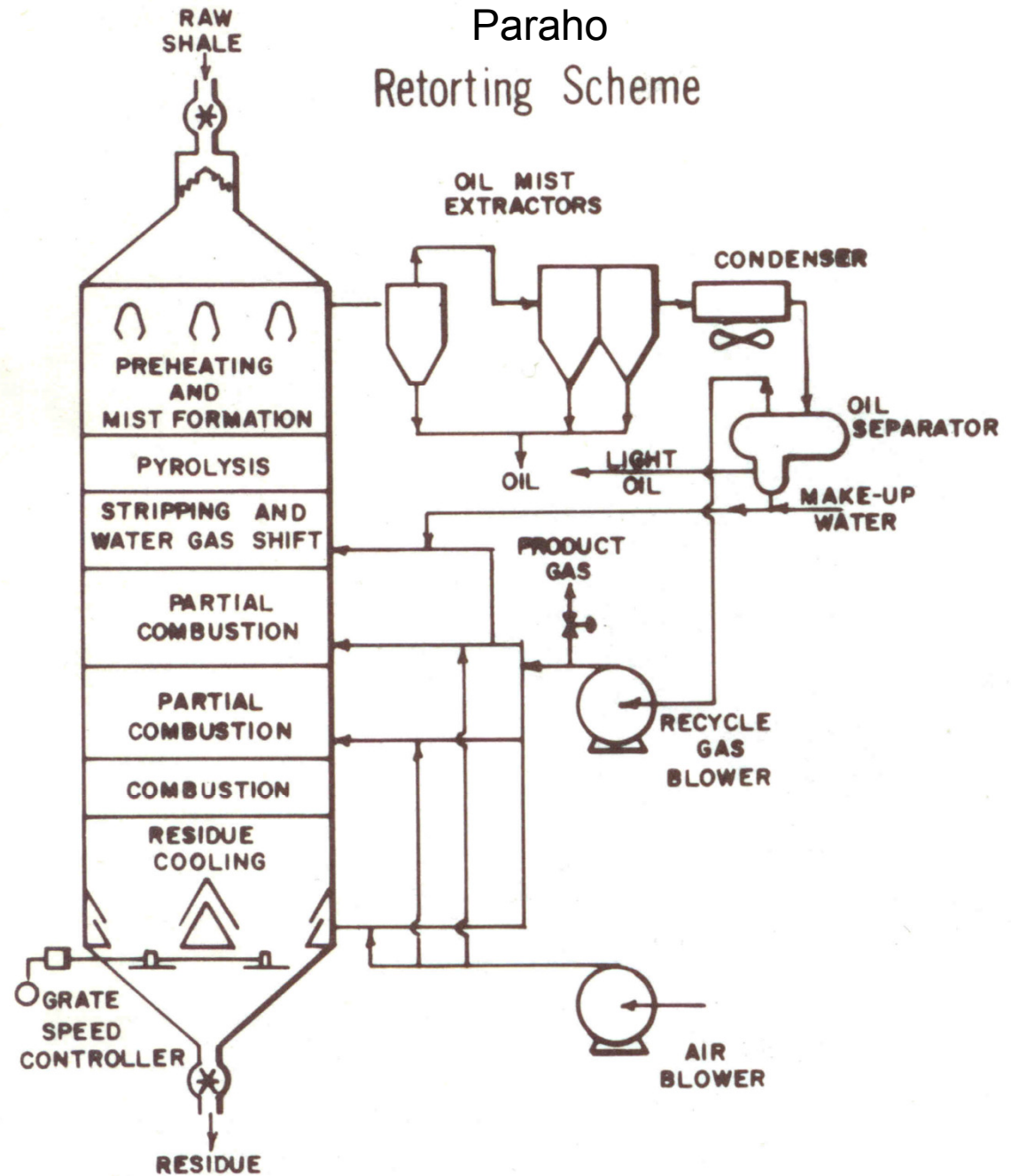
- Energy is the foundation of all wealth
  - How much wealth is created depends on how efficiently energy is used
- There are only two meaningful categories of energy use
  - Energy consumed in the production of end-use energy
  - End-use energy

This presentation is about energy consumed in the production of energy from oil shale

# Energy costs in producing energy from oil shale

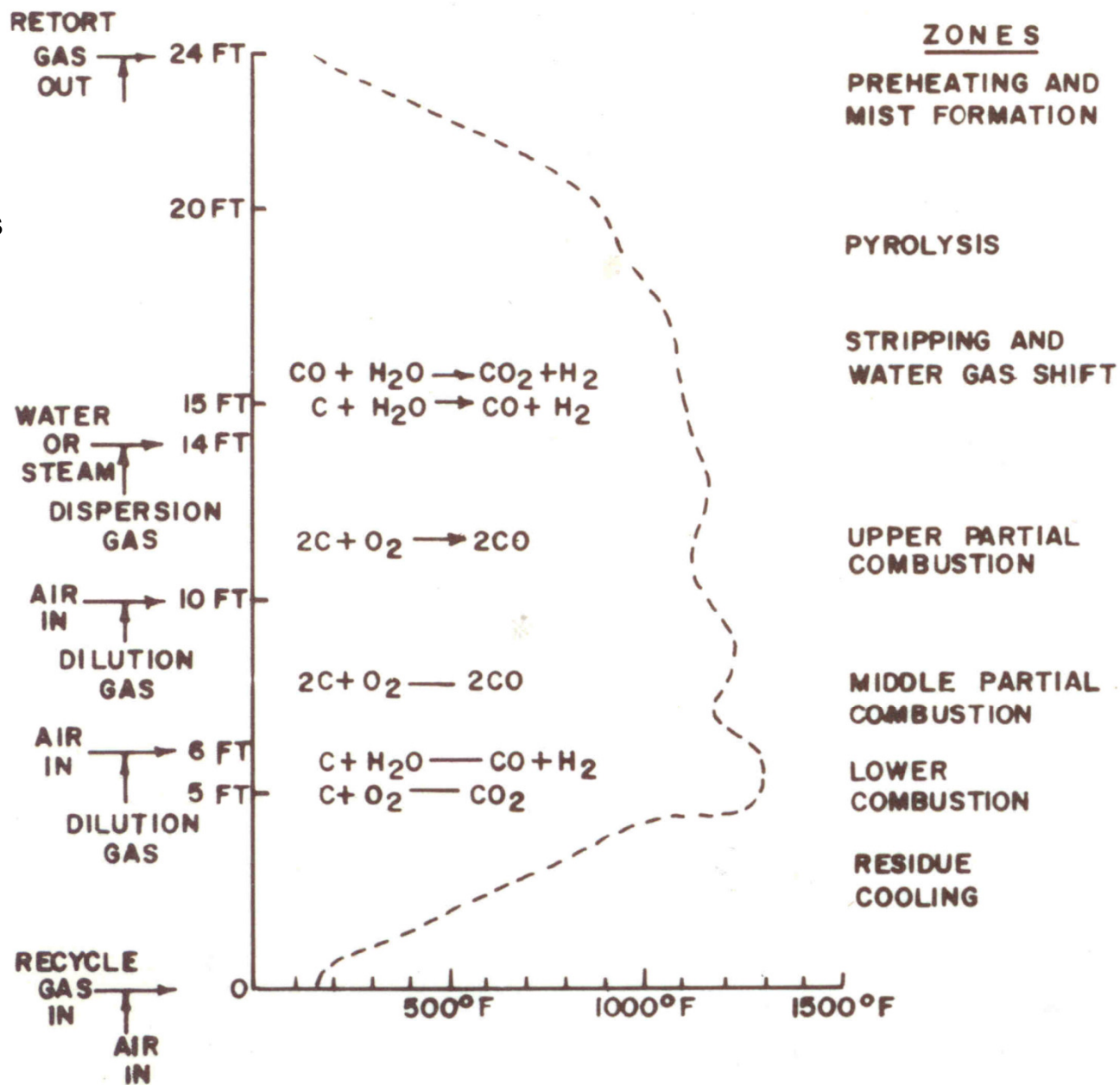
- Mining or drilling
  - Quantity of power, diesel fuel, and explosives depends principally on grade and overburden/pay
- Retorting
  - Quantity of heat and power depends principally on grade of ore, and end-temperature
- Upgrading and refining
  - Quantity of heat, power and hydrogen depends principally on heteroatom, aromatic and ash content of raw oil

# Paraho Retorting Scheme



Source- Synthetic Fuels  
Data Handbook - 1975

# Temperature Profile in Retort



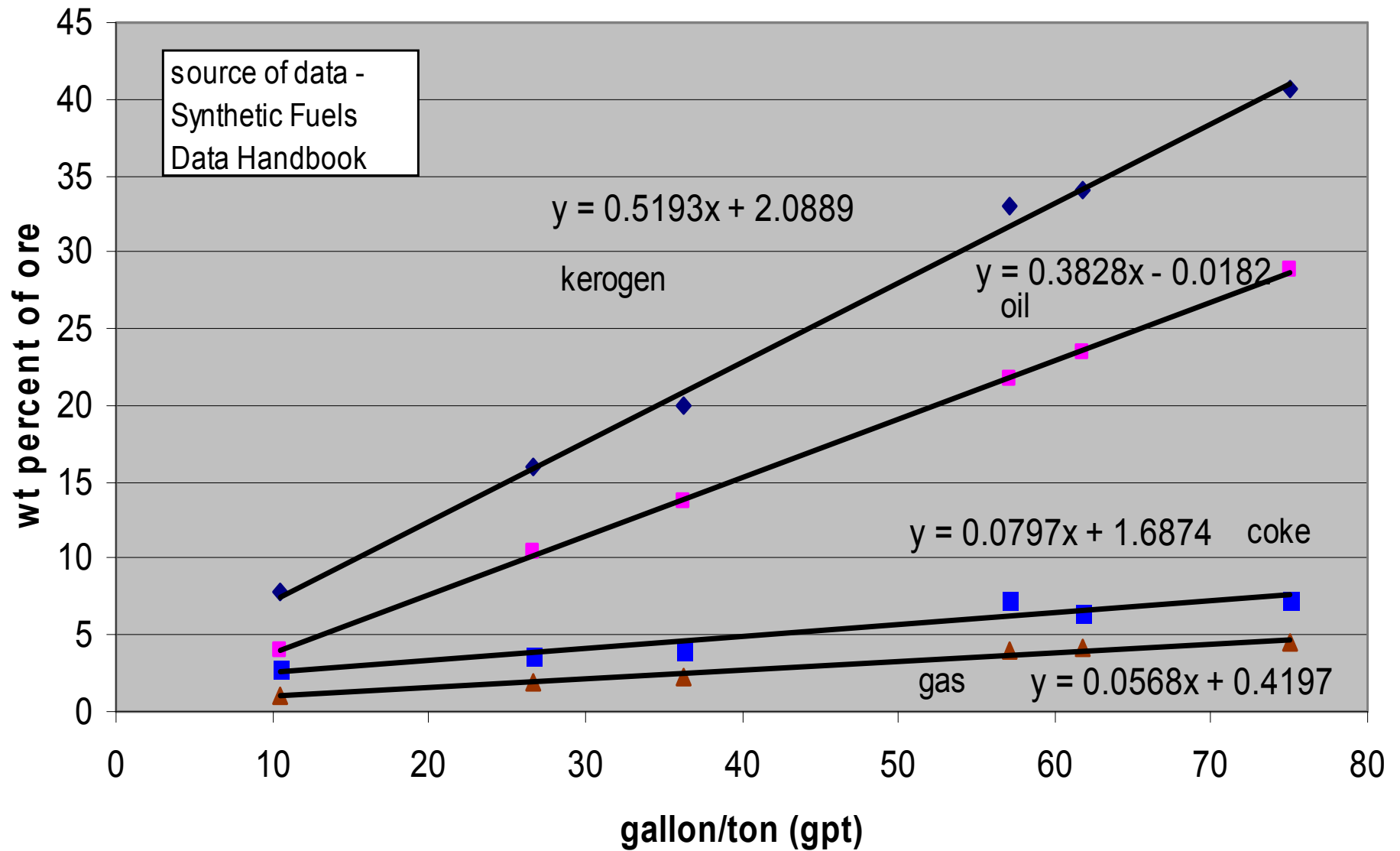
Source- Synthetic Fuels  
Data Handbook - 1975

# Retort Energy

- Heat demand
  - Heating of ore
  - Evaporation of water and distillate
  - Endotherm of kerogen pyrolysis
  - Endotherm of mineral decarbonation
  - Heating of combustion air
  - Losses to surroundings, including residual heat in process streams
- Power demand
  - Ore movement
  - Air blowers
  - Gas and water cleaning
  - Pumps
- Recoverable Heat
  - Sensible heat of hot ore
  - Sensible heat of hot gas

# Concentrations of Kerogen Components

## MFA results - Green River Formation oil shale



Net energy demand\*  
25 gpt, gas combustion retort  
basis – 1 short ton, thousands of BTUs

• Fuel	
– Mining (diesel)	35.7
– Retort (coke)	464.2
– Upgrading (heat and H <sub>2</sub> )	73.8
• Power (as thermal energy using 40% conversion efficiency)	
– Mining (shovels, conveyance, ore prep)	122.7
– Retort (ore movement, blowers, gas and water cleaning)	196.6
– Upgrading (compression, pumping)	68.3
	<hr/>
• Sum of Net Energy consumed	961.3

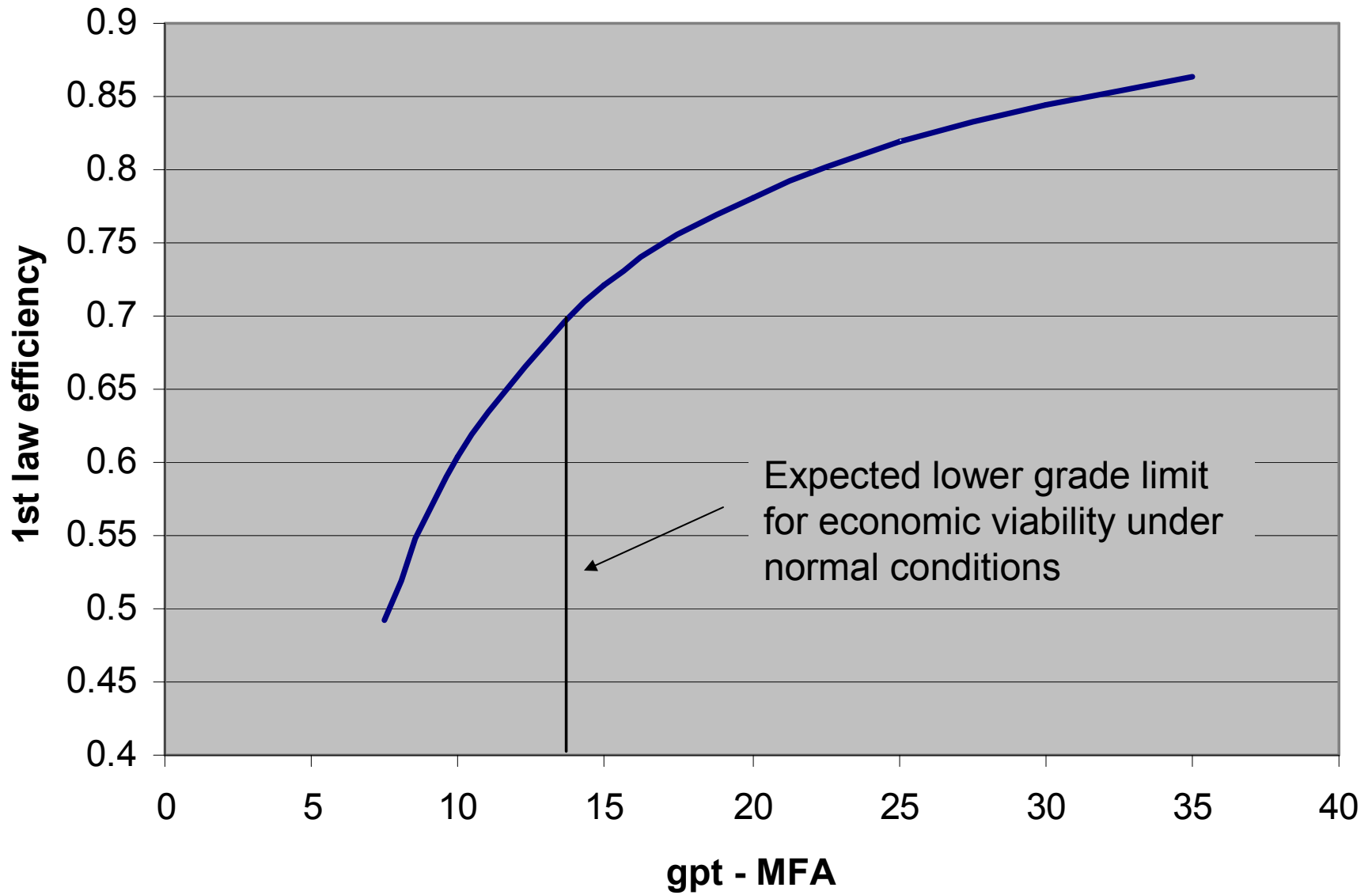
\*Source- Bungler and Russell, accepted for publication, ACS books 2009

Energy balance\*  
25 gpt, gas combustion retort  
basis – 1 short ton, millions of BTUs

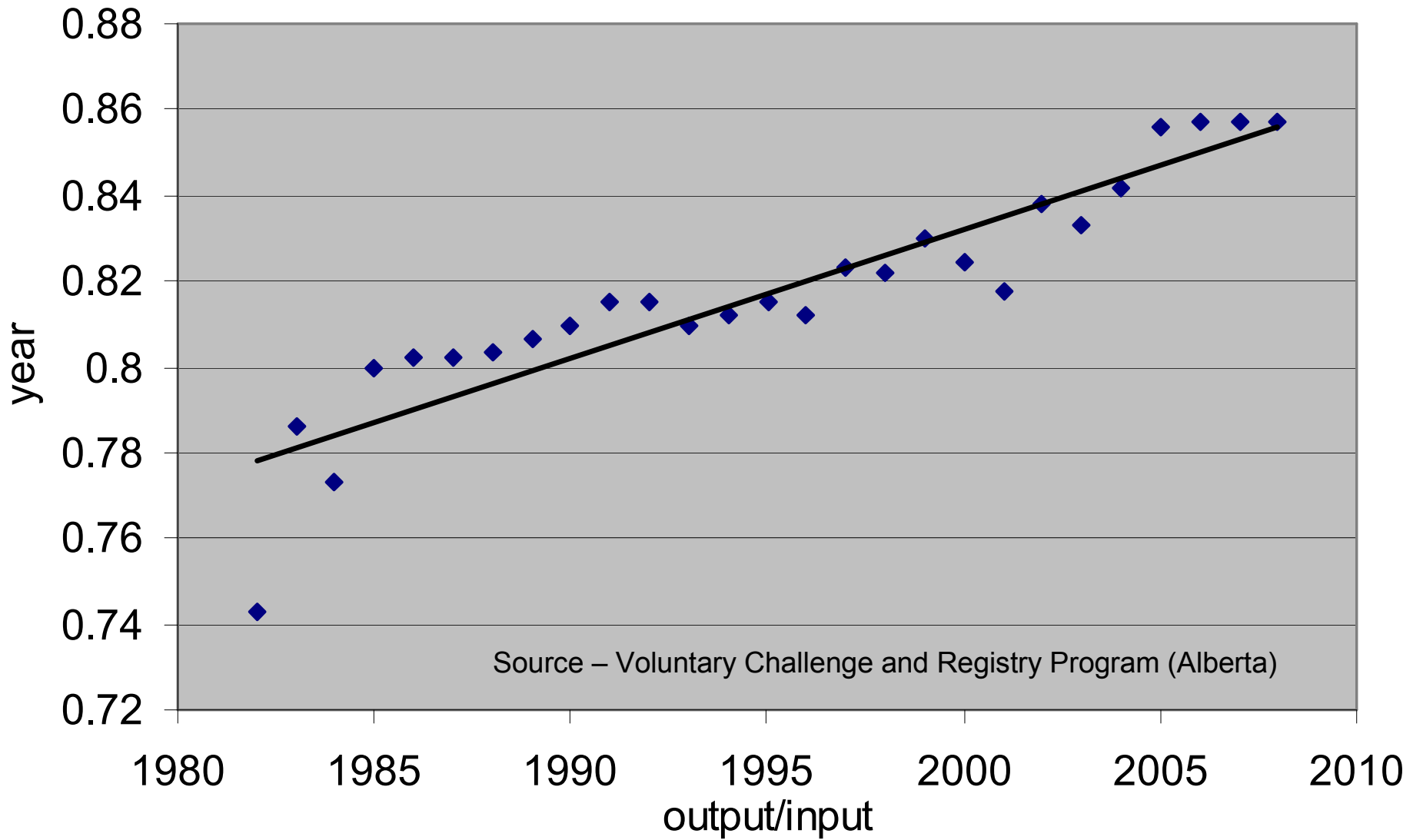
• Kerogen in	• 5.342	
• Gas produced for sale	• 0.728	
• Oil produced for sale	• 3.522	
• Excess power for sale	• <u>0.131</u>	1 <sup>st</sup> law efficiency
• Total Useful Output	• 4.381	= 4.381/5.342
		= 82%
• Net energy consumed	• <u>0.961</u>	
• Total produced and consumed	• 5.342	

\*Source- Bungler and Russell, accepted for publication, ACS books 2009

# Overall first law efficiency



# 1st Law Efficiency Syncrude, Canada

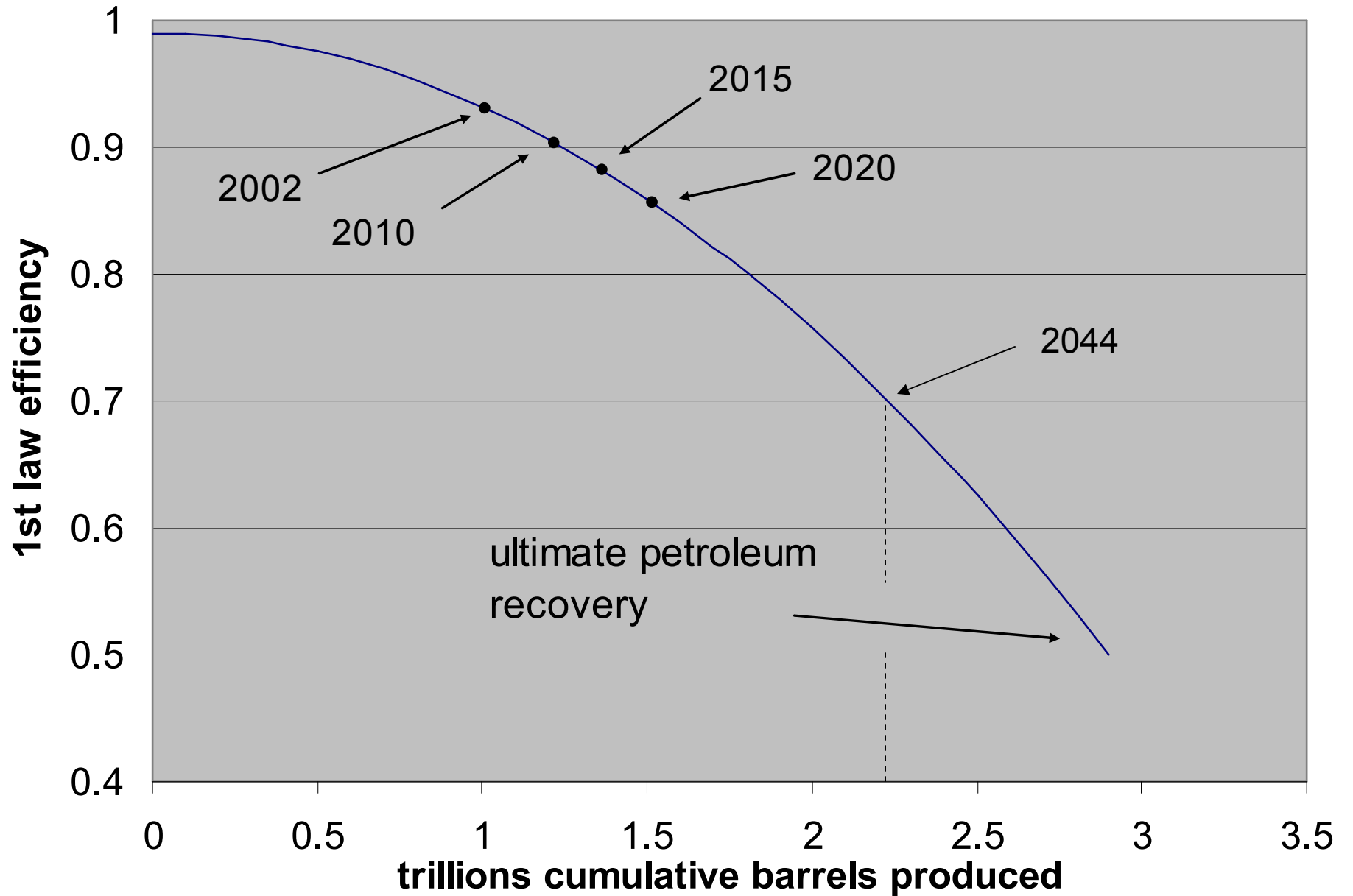


# We already know the trends in petroleum

- Energy is becoming more difficult to produce (the easy oil is gone).
  - More remote, deeper, increasing EOR
- Quality is trending downward
  - higher boiling, more S and N, increasing variability)
- Fuel specifications are tightening (lower S, lower aromatics)

All three trendlines add economic and energy costs to produce an end-use fuel.

# 1st law efficiency vs. trillion bbl petroleum produced



# Governing Equations

(JWBA price model)

1<sup>st</sup> Law production efficiency (E)

$E = \text{bbl-produced} / (\text{bbl-produced} + \text{bbl-consumed})$ , and

Energy intensity of production (e)

$$e = (1-E)/E$$

Define P = minimum price for oil, and

C = the non-energy (labor, materials, overhead, etc.) cost portion of the price, then

$$P = C/(1-e), \text{ and}$$

C is calculated from experience-based information:

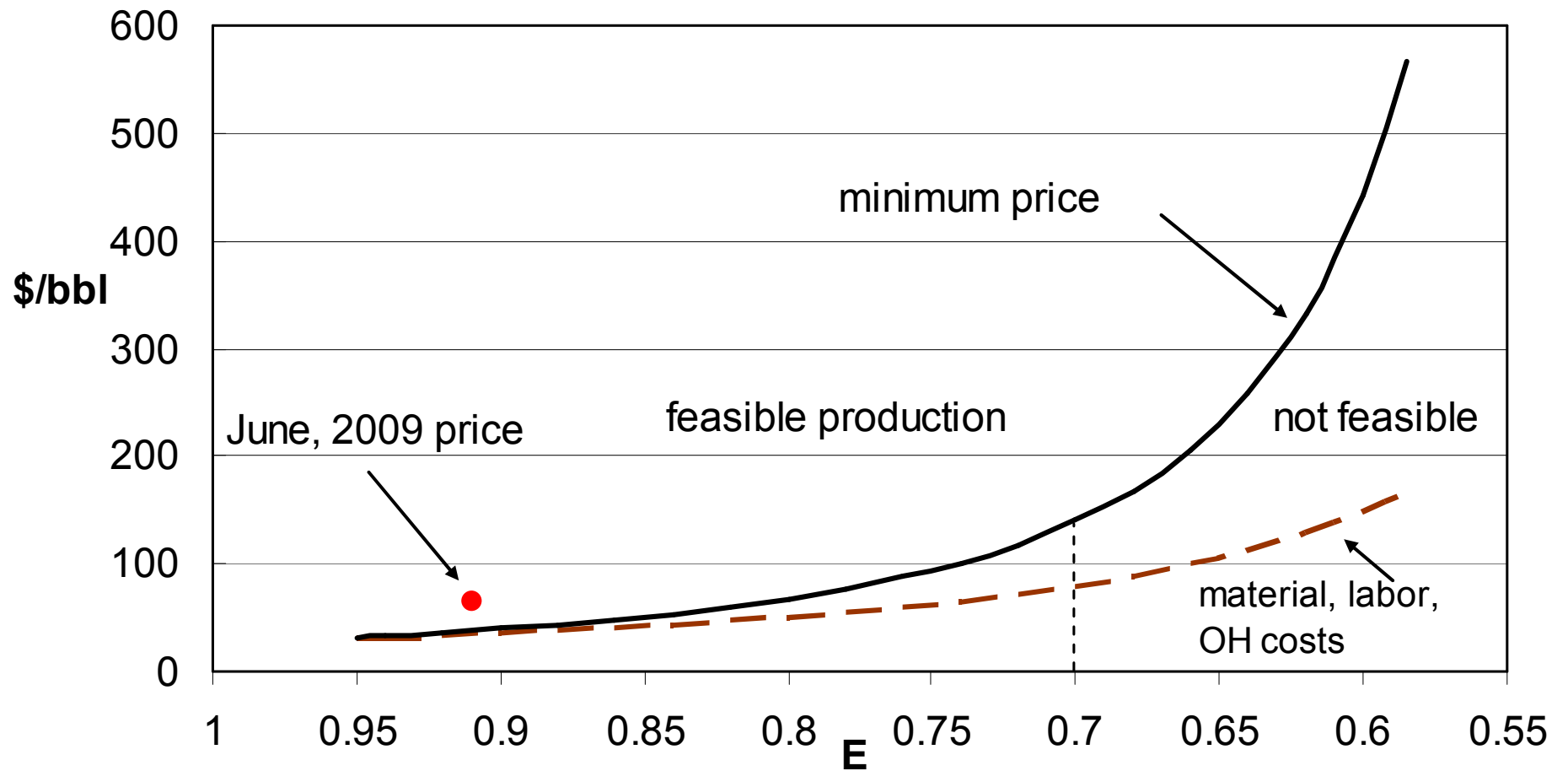
$$C = Ae^{Be}$$

where A and B are derived from the data

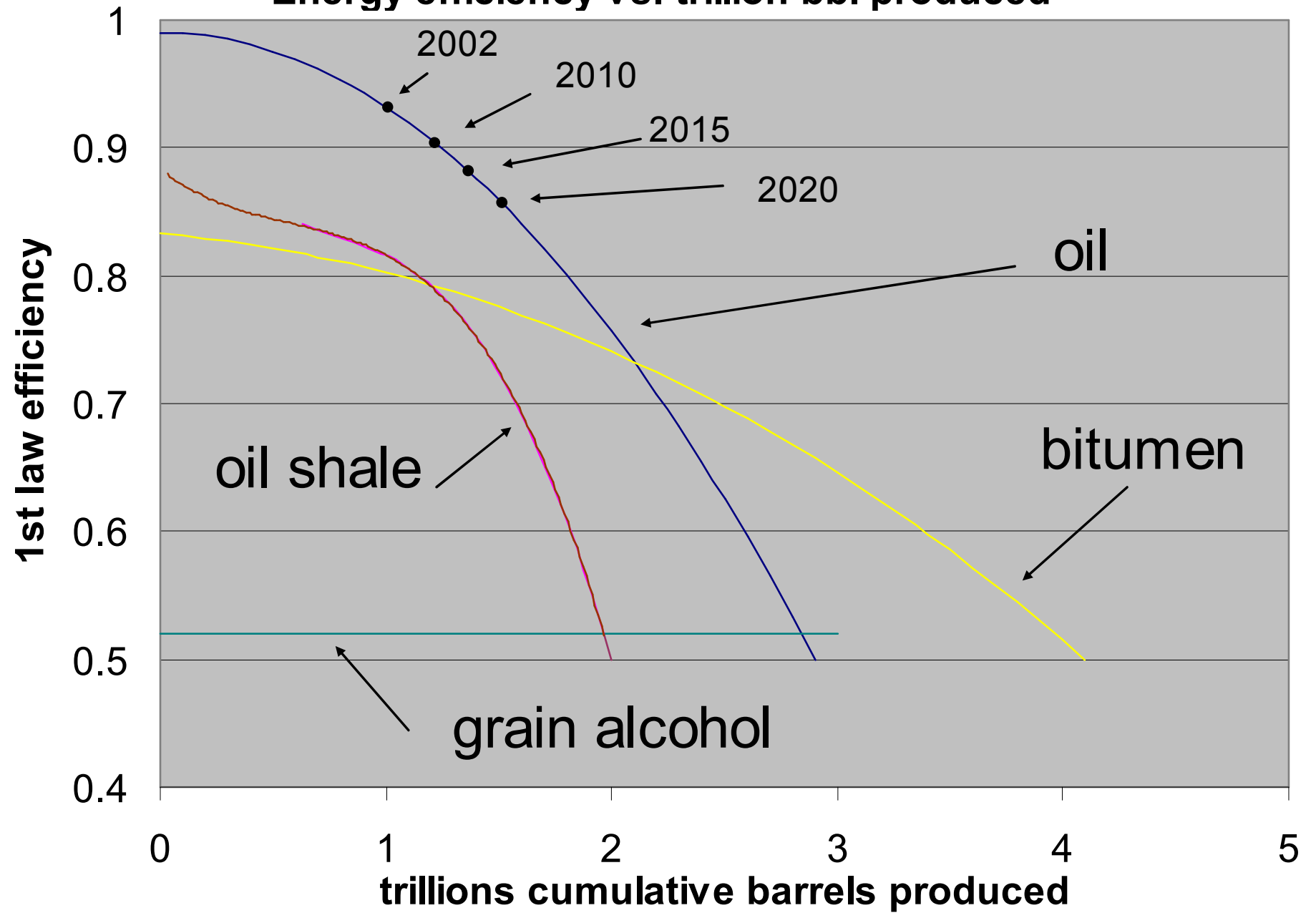
P = \$35/bbl when E = 0.93 (typical petroleum) and,

P = \$60/bbl when E = 0.82 (typical oil sands)

### Estimated Minimum price vs. First Law Production Efficiency (E)

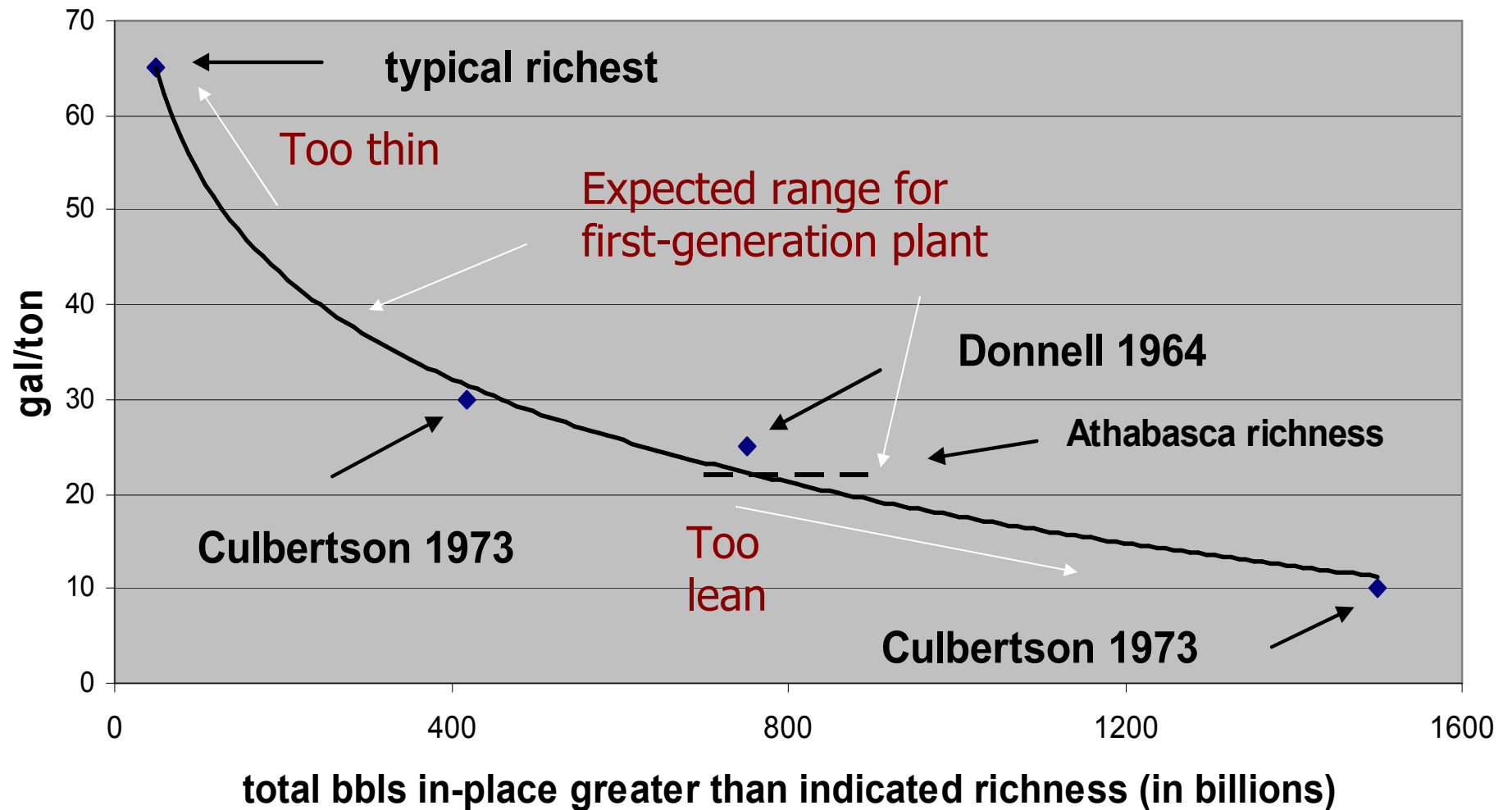


**Energy efficiency vs. trillion bbl produced**



# Green River Formation Oil Shale

## Richness vs Total Resource



# Conclusions

- 1<sup>st</sup> Law efficiency sets the floor price for energy
- Oil shale will soon have thermodynamic parity with petroleum (and with that, economic parity).
- The best oil shale is richer than the best oil sands, which gives oil shale equivalent, or better, first-law efficiencies. (Oil sands are already economic because of their long-term production assurances.)
- First-law efficiencies of oil shale will improve with experience, and won't begin to decline until the industry is forced to feed leaner ores, decades from now.
- Government policies that run counter to fundamental thermodynamics create inefficiencies that must be subsidized, adding unnecessary costs to society.