Thermodynamics will govern future trends in energy economics

Oil Shale Symposium

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Declarative Statements

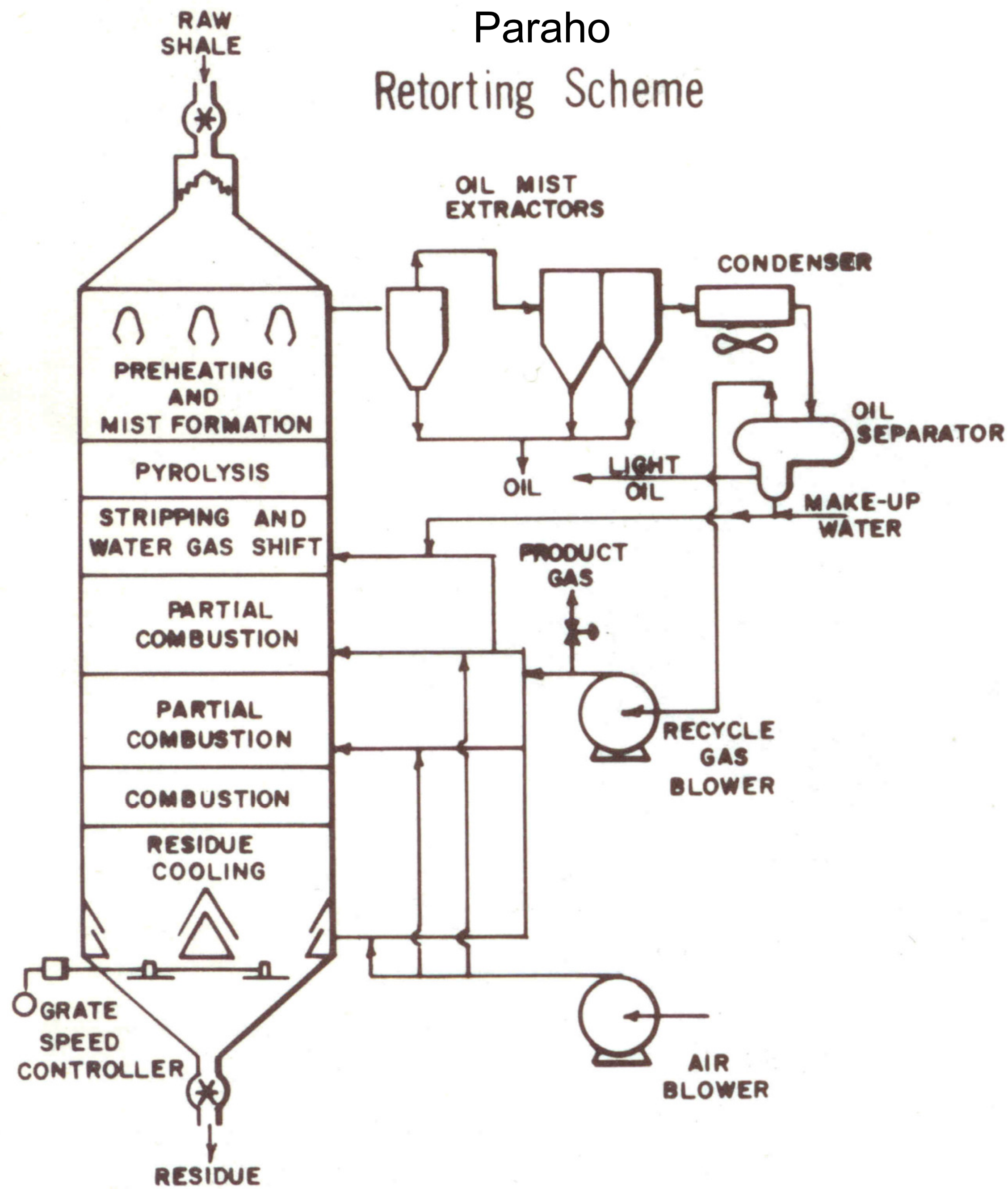
- Energy is the foundation of all wealth
  - How much wealth is created depends on how efficiently energy is used
- There are only two meaningful categories of energy use
  - Energy consumed in the production of end-use energy
  - End-use energy

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

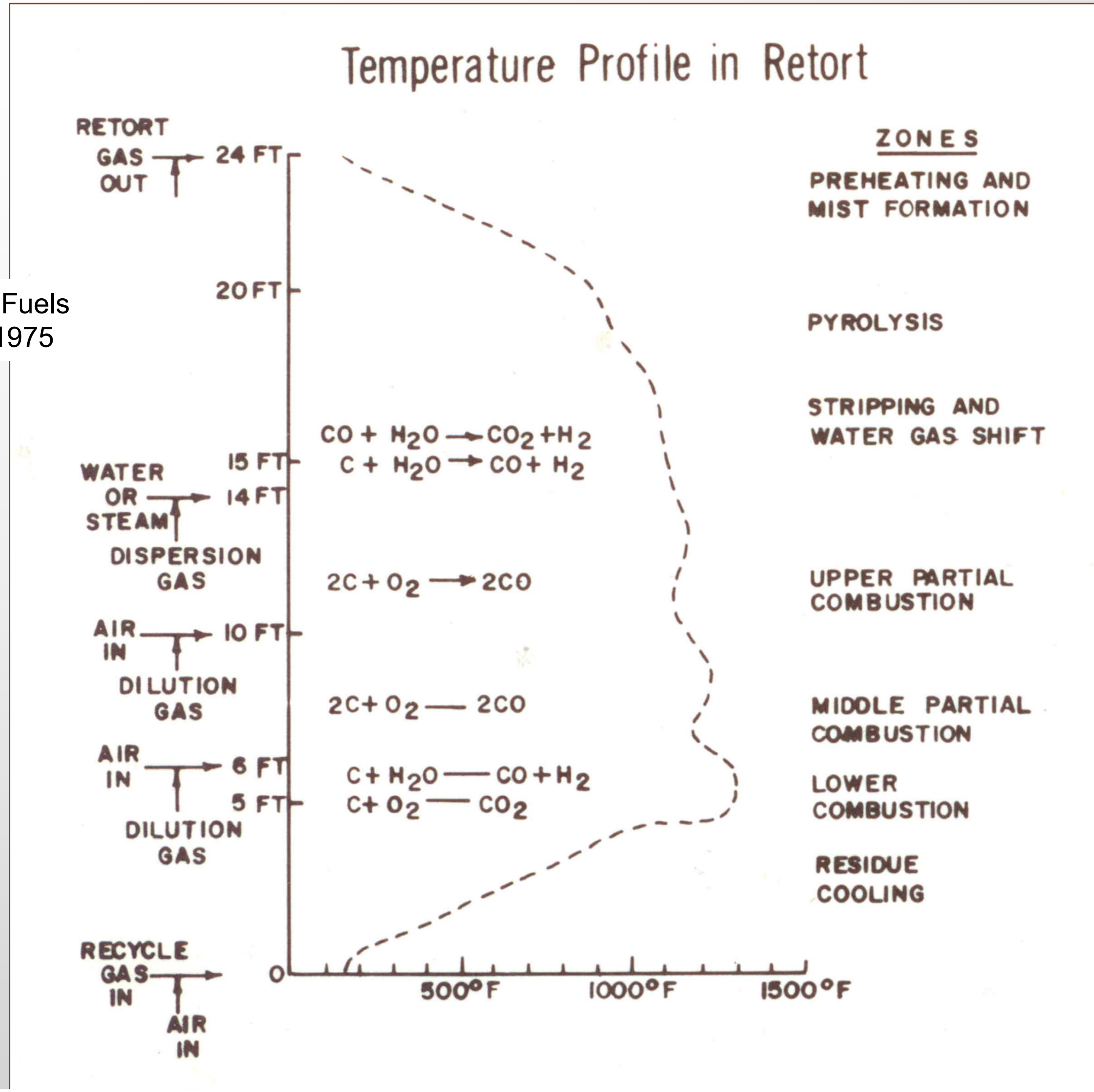
Energy costs in producing energy from oil shale

- 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



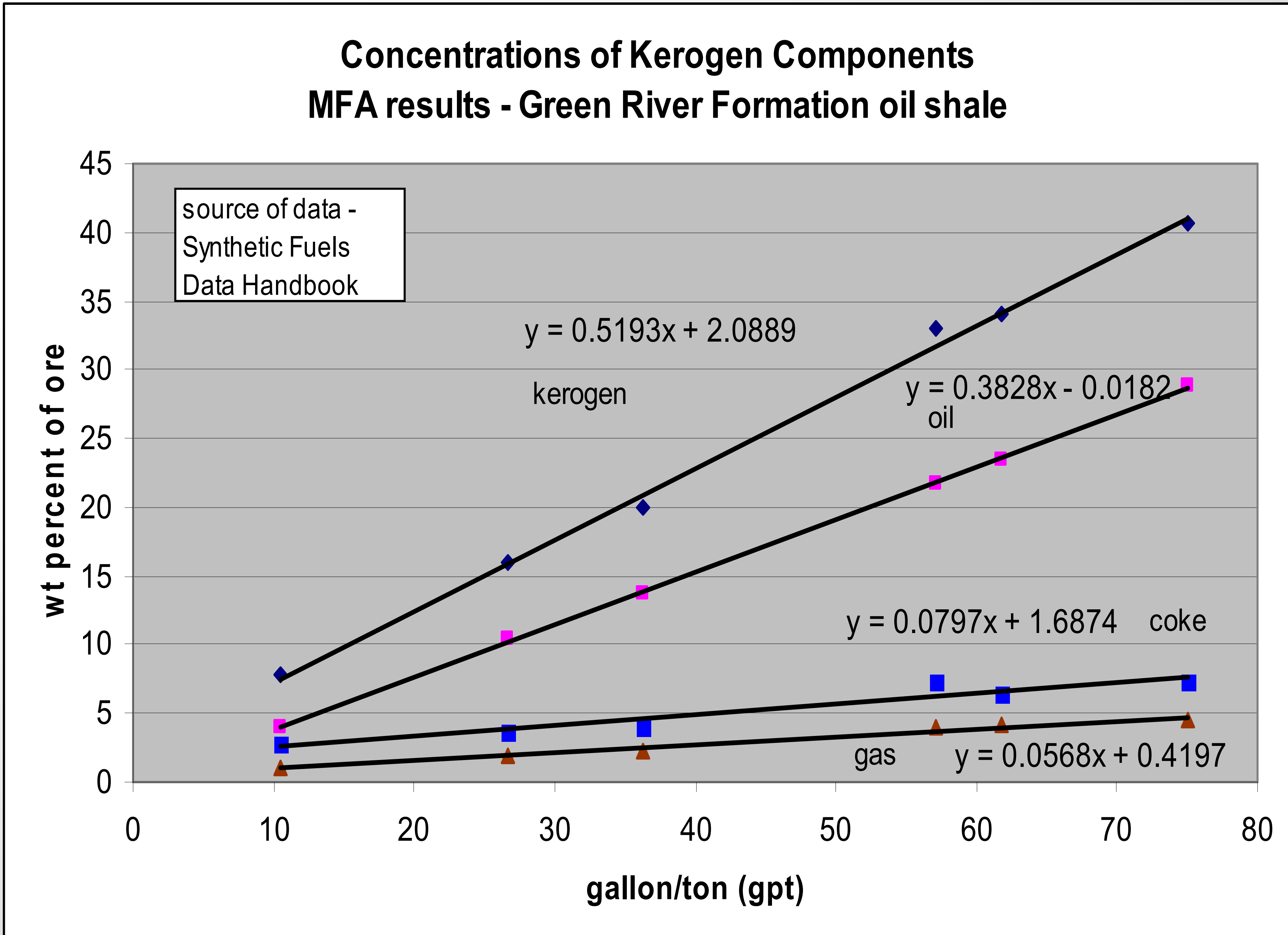
Source- Synthetic Fuels
Data Handbook - 1975



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
source of data - Synthetic Fuels Data Handbook
y = 0.5193x + 2.0889
kerogen
y = 0.3828x - 0.0182
oil
y = 0.0797x + 1.6874
coke
gas
y = 0.0568x + 0.4197
wt percent of ore
gallon/ton (gpt)
0
5
10
15
20
25
30
35
40
45
0
10
20
30
40
50
60
70
80

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_2) 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

- Sum of Net Energy consumed 961.3

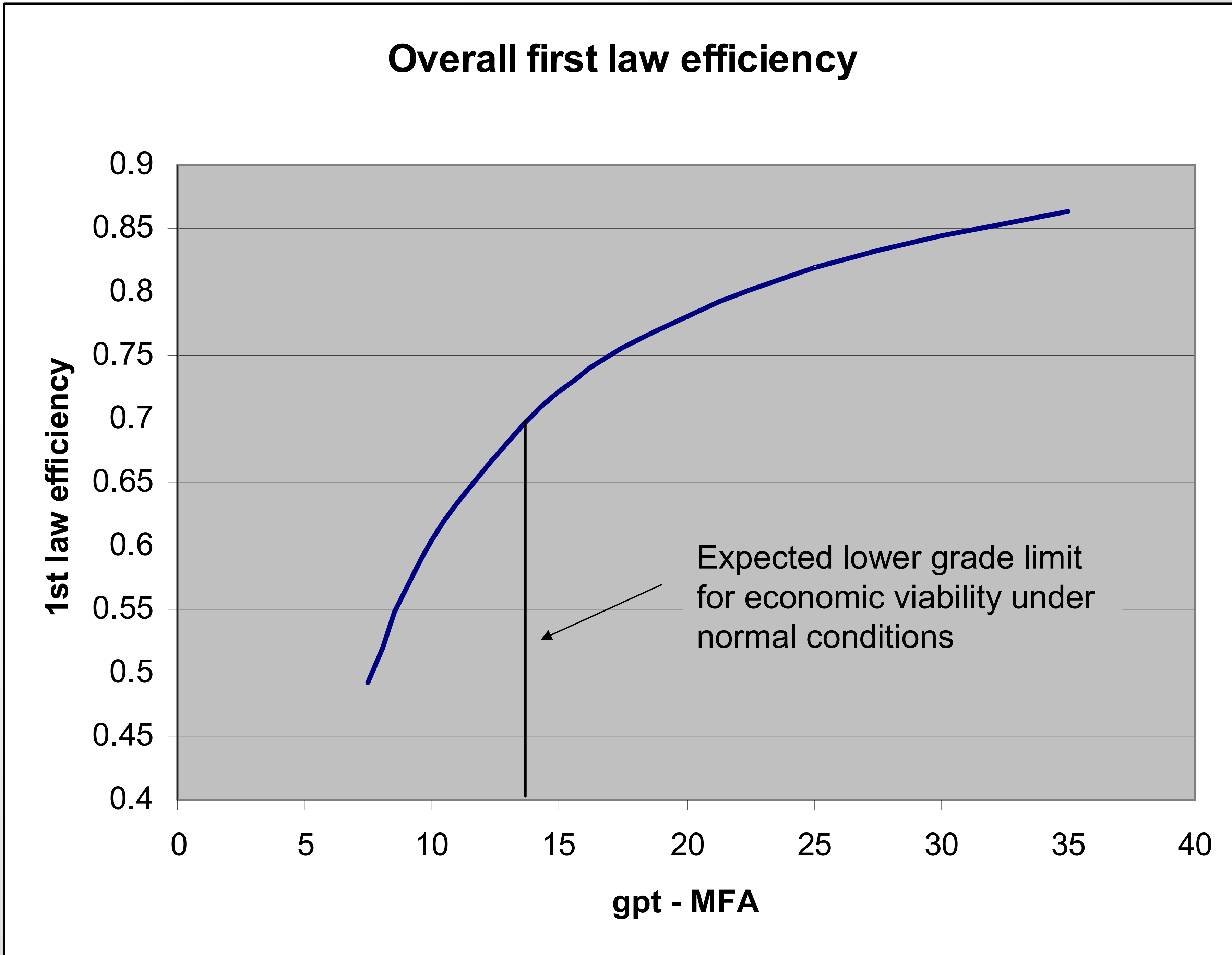
*Source- Bunger and Russell, accepted for publication, ACS books 2009

Energy balance*
25 gpt, gas combustion retort
basis – 1 short ton, <u>millions</u> of BTUs

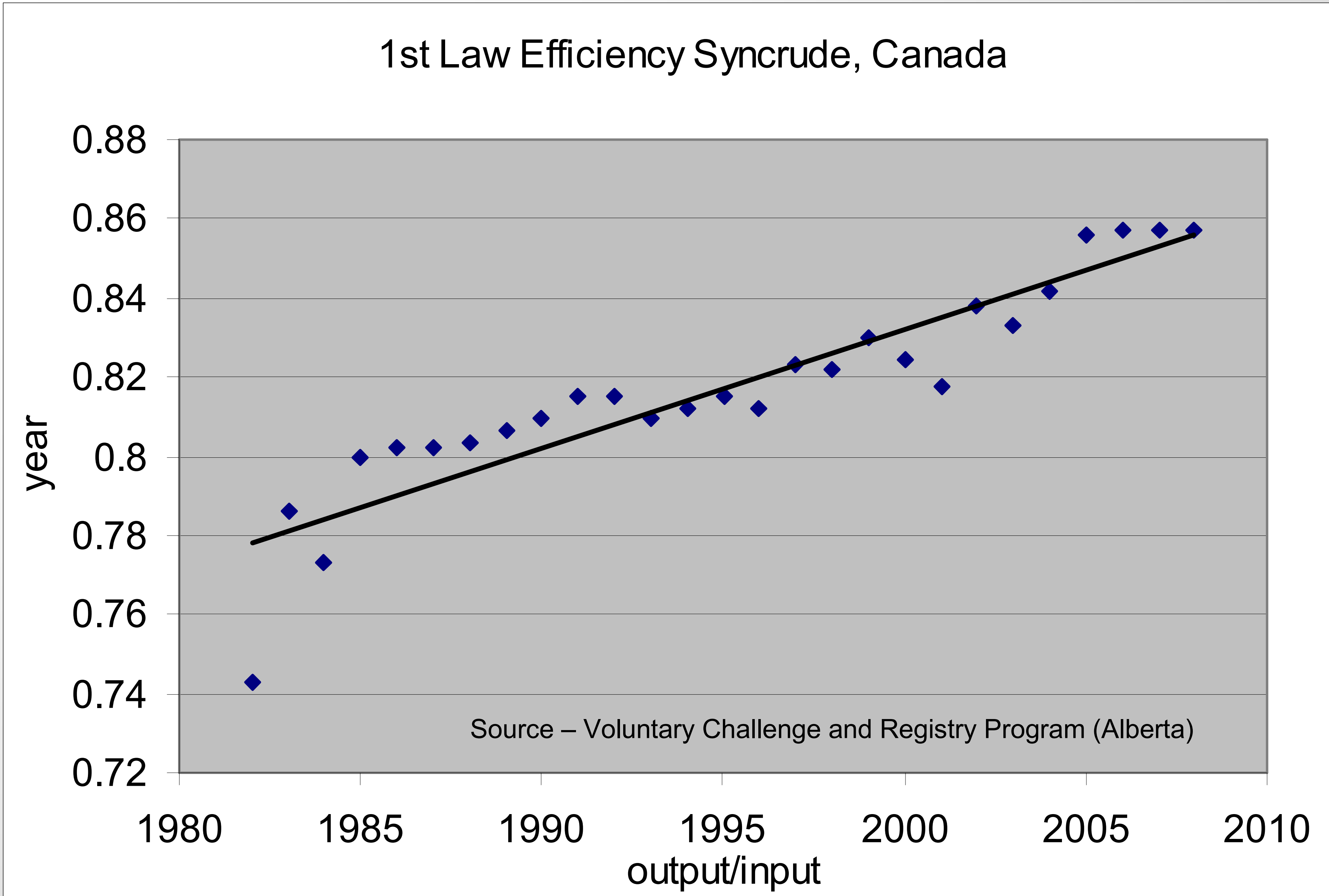
• Kerogen in	• 5.342
• Gas produced for sale	• 0.728
• Oil produced for sale	• 3.522
• Excess power for sale	• 0.131
• Total Useful Output	• 4.381
• Net energy consumed	• 0.961
• Total produced and consumed	• 5.342

1st law efficiency
= 4.381/5.342
= 82%

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



Overall first law efficiency
1st law efficiency
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0
5
10
15
20
25
30
35
40
gpt - MFA
Expected lower grade limit for economic viability under normal conditions

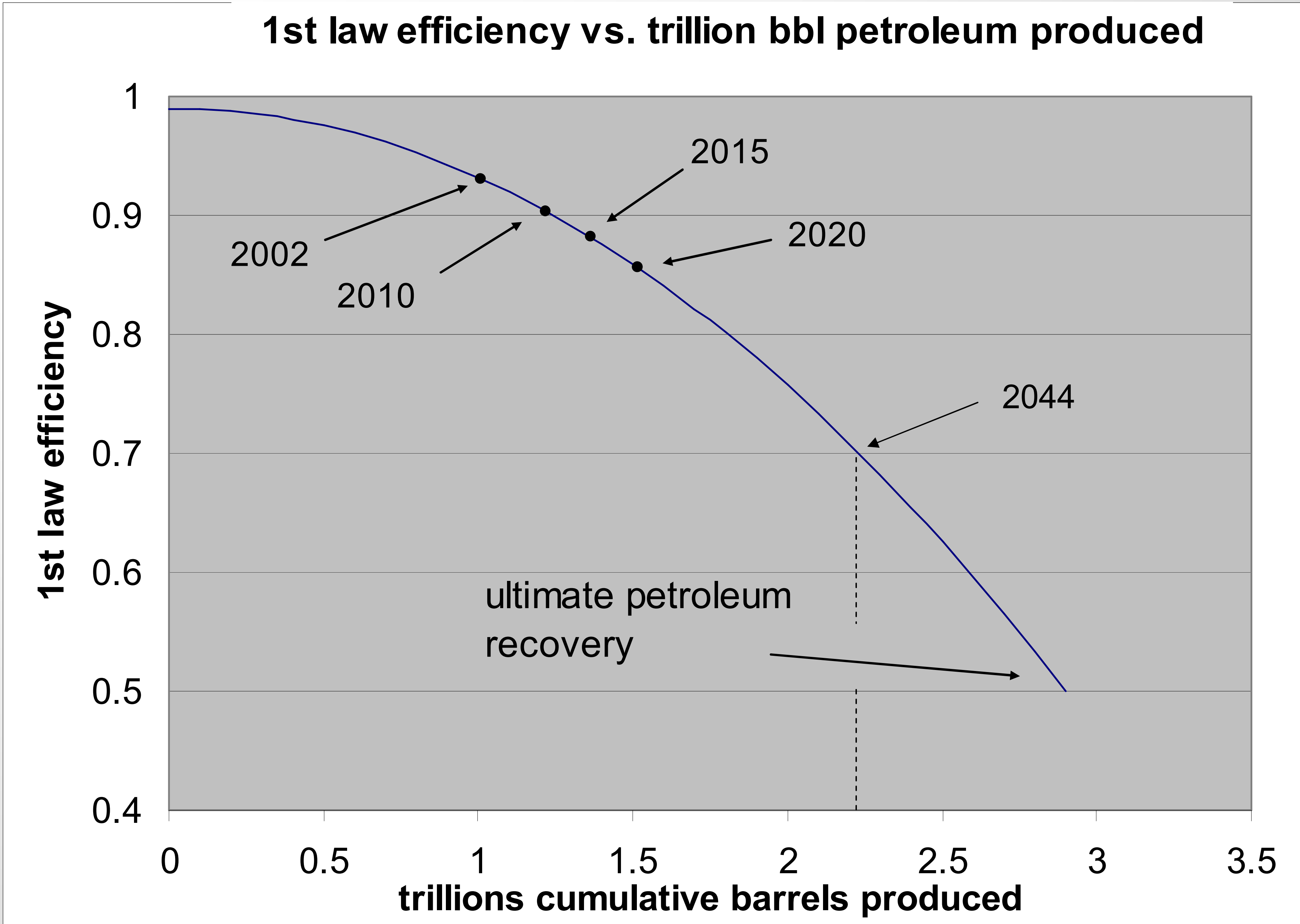


1st Law Efficiency Syncrude, Canada
0.88
0.86
0.84
0.82
0.8
0.78
0.76
0.74
0.72
year
Source – Voluntary Challenge and Registry Program (Alberta)
1980
1985
1990
1995
2000
2005
2010
output/input

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
1st law efficiency
trillions cumulative barrels produced
1
0.9
0.8
0.7
0.6
0.5
0.4
0
0.5
1
1.5
2
2.5
3
3.5
2002
2010
2015
2020
2044
ultimate petroleum recovery

Governing Equations

(JWBA price model)

1st Law production efficiency (E)

E = bbl-produced / (bbl-produced + 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

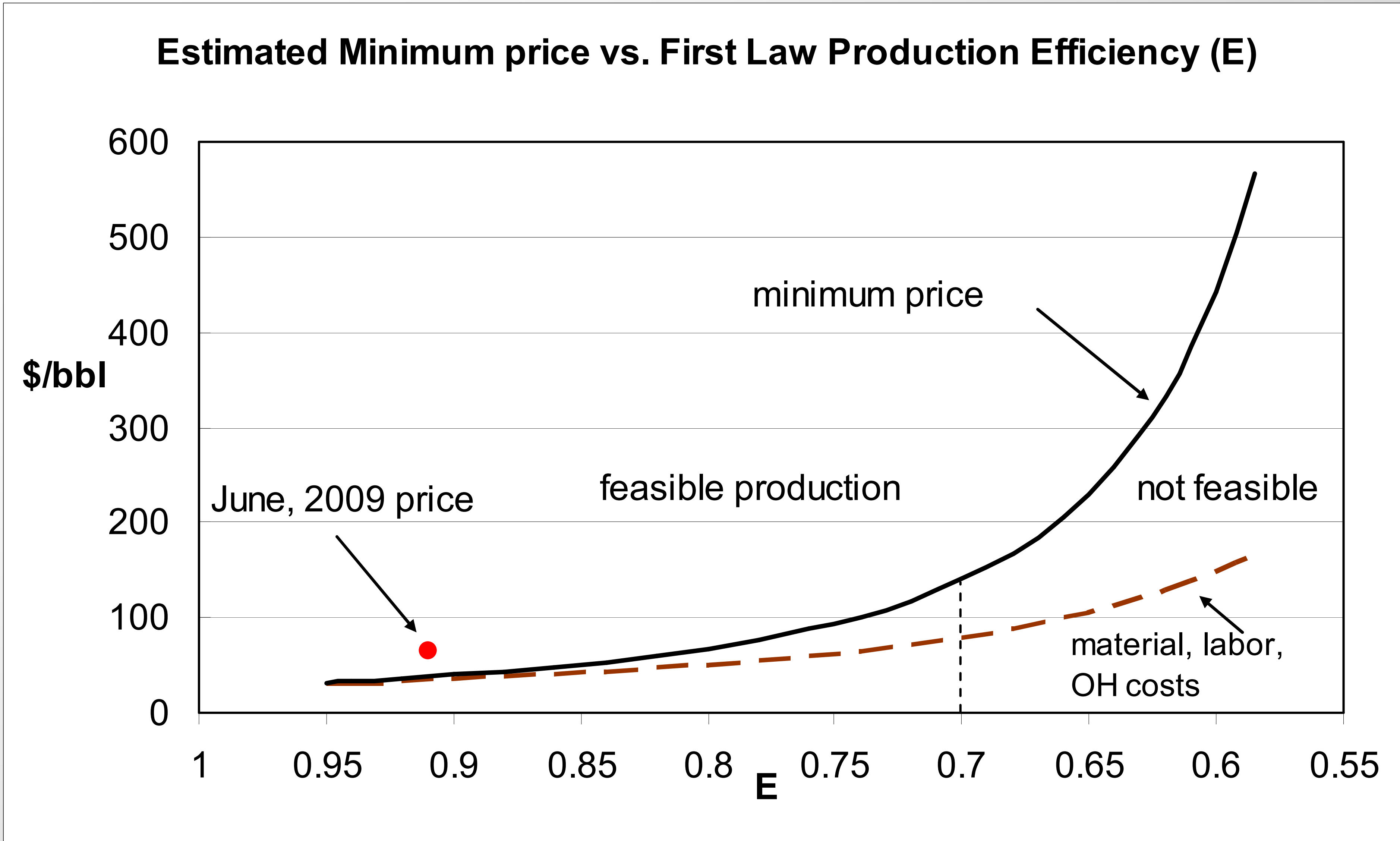
P = C/(1-e), and

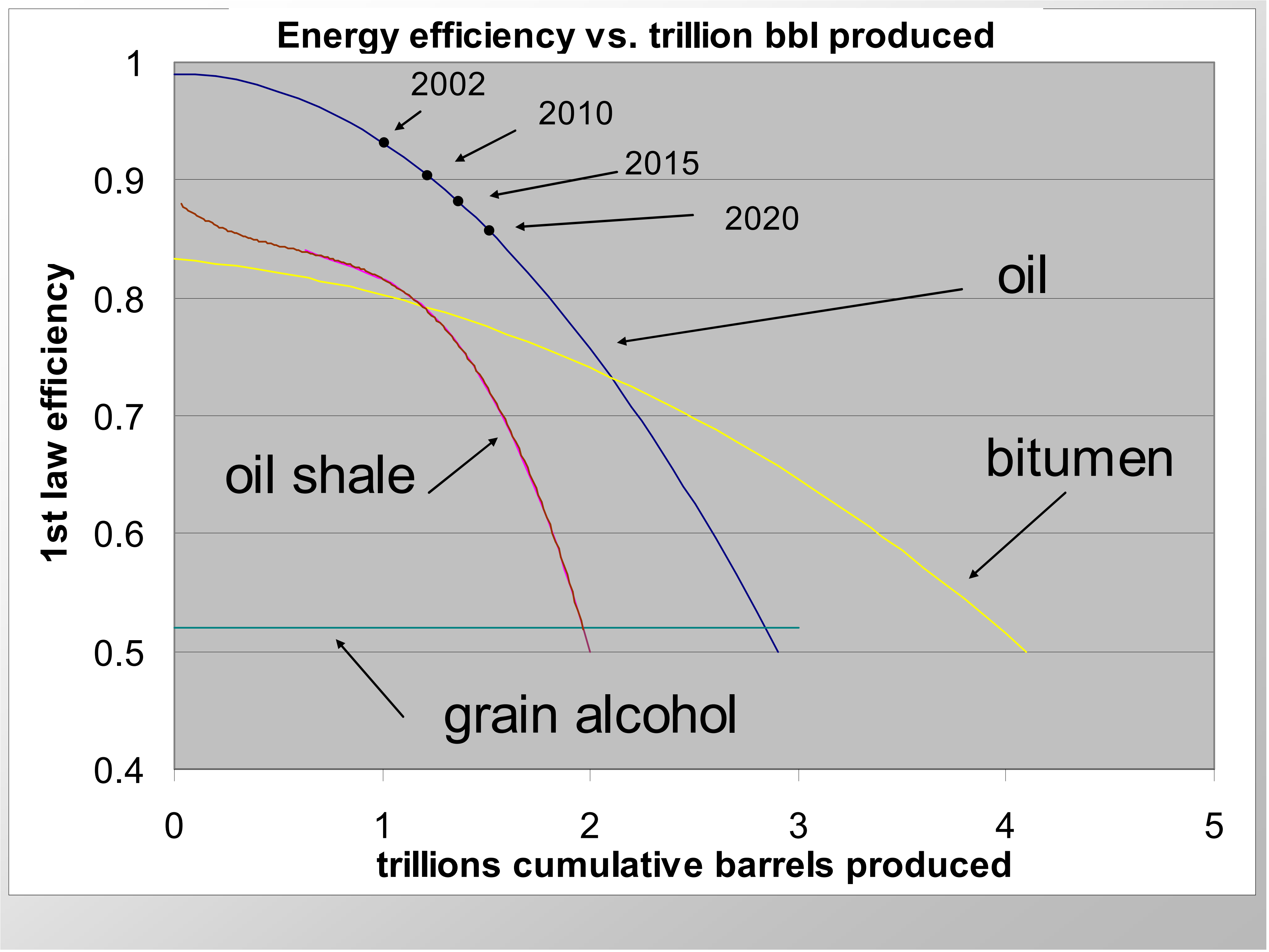
C is calculated from experience-based information:

$C = Ae^{Be}$ where A and B are derived from the data

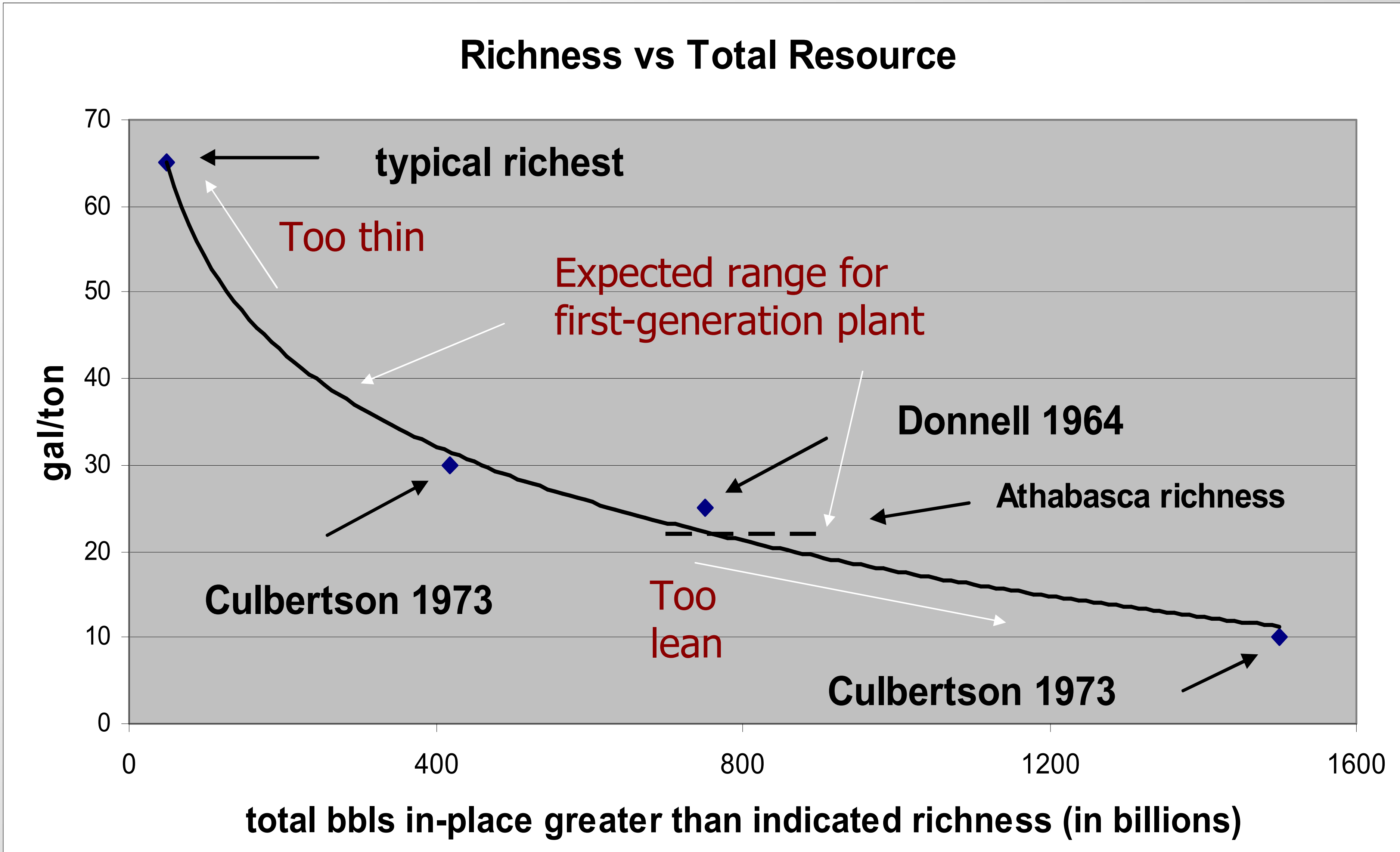
P = \$35/bbl when E = 0.93 (typical petroleum) and,

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


Estimated Minimum price vs. First Law Production Efficiency (E)
600
500
400
300
200
100
0
$/bbl
minimum price
feasible production
June, 2009 price
not feasible
material, labor,
OH costs
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
E


Energy efficiency vs. trillion bbl produced
1st law efficiency
1
0.9
0.8
0.7
0.6
0.5
0.4
0
1
2
3
4
5
trillions cumulative barrels produced
2002
2010
2015
2020
oil
oil shale
bitumen
grain alcohol

Green River Formation Oil Shale



Conclusions

- 1st 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.