Oil shale as an energy resource in a CO_2 constrained world: Electricity production with in-situ carbon capture (EPICC)

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Outline

Description of problem
- Slow progress to commercialize oil shale
- Potential CO_2 constraint in future

Description of solution
- Schematic diagram
- Case descriptions

Results
- Temperature plot
- Mass balance plots
- Energy balance plots

Discussion
- Operation of a GFC
- Separation of gas and liquid components of the oil
- High pressure
- Leaving char behind

Conclusions
- Key ratios

The problem..

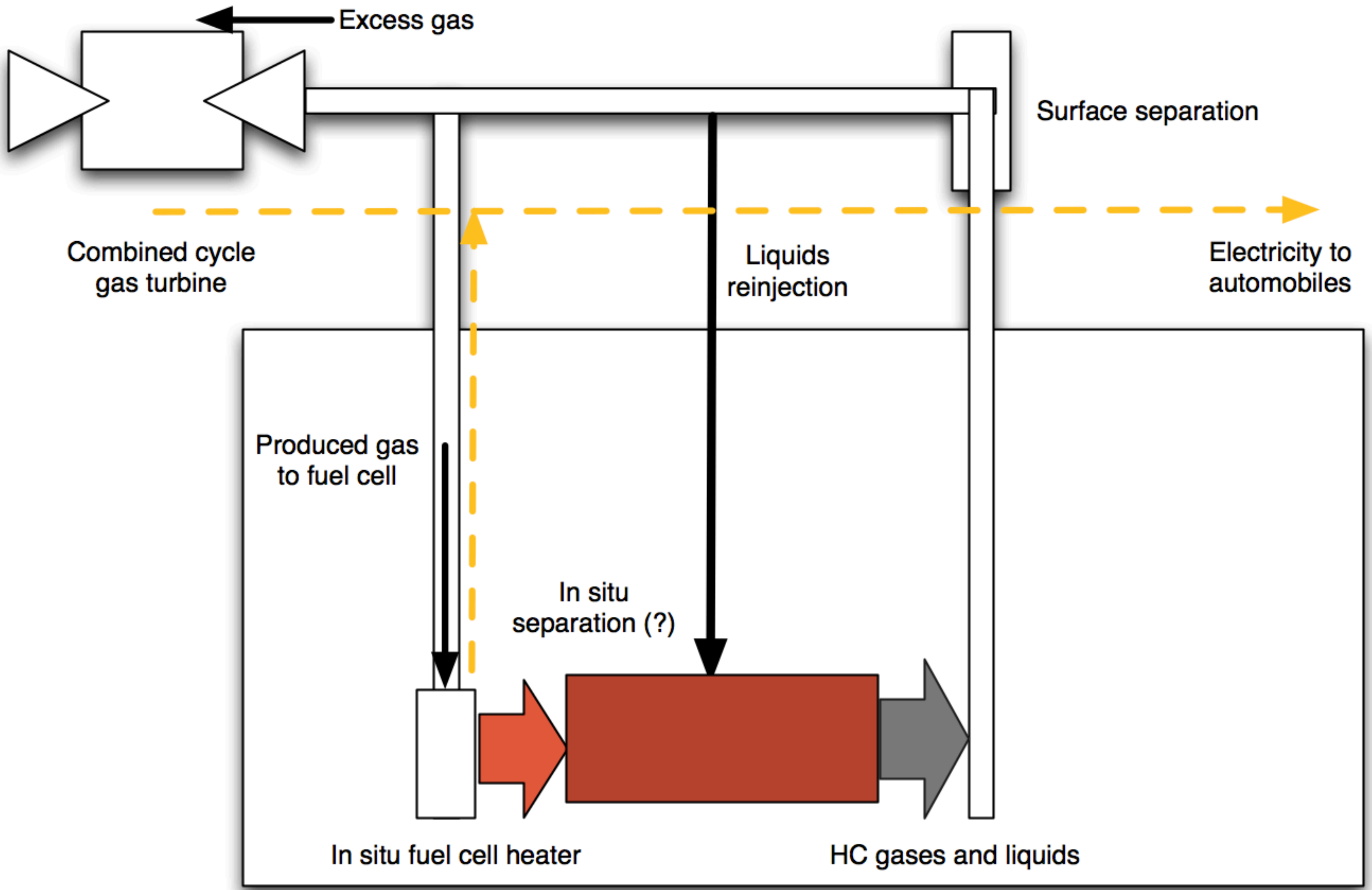
- Current rate of oil shale development slow
- In-situ oil shale development still at RD&D stage
- **New ideas needed to jolt industry (need to get noticed!)**
- Potential for CO_2 limitations in future very high

One proposed solution - EPICC

- **EPICC = E**lectricity **P**roduction with **I**n-Situ **C**arbon **C**apture
- Rearranging chemical processes to optimize the system (turn it "inside out")
  - Question: *What is the best way to turn chemical energy from shale into rotational motion of vehicle wheels?*

	Resource	Heat source	Energy carrier	Conversion to work	Waste heat from conversion
Liquids production	Chemical energy in shale	Thermal or electrical energy from fuels	Liquid fuel	Automobile engine	To atmosphere
EPICC	Chemical energy in shale	Waste heat	Electricity	In situ fuel cell	To shale formation

EPICC system diagram



Key aspects of system

- In situ electricity generation converts chemical energy to work (electricity) where waste heat is useful
  - System could be similar to "geothermic fuel cells" proposed by Independent Energy Partners, Inc.
- Product gases are high value, low carbon stream
  - H_2, CH_4, CO, CO_2
  - Most carbon is left in ground as char
- Separation could occur in subsurface
  - In situ "bathtub ring" of condensation products could work in favor
  - If not, surface separation and reinjection of liquids until coked

STAN/DOS Modeling Method

- Three types of species – initial reactants, intermediate species and final products
- First order kinetic model based on literature
  - Burnham and Braun (1985)
  - Carbonate decomposition from Campbell (1978)
  - Mineral dehydration from Camp (1987)
- "Stock and flow" model
- Oil cracking included
- Oil boiling not accounted for (pressure effects not in model)

Reactions included

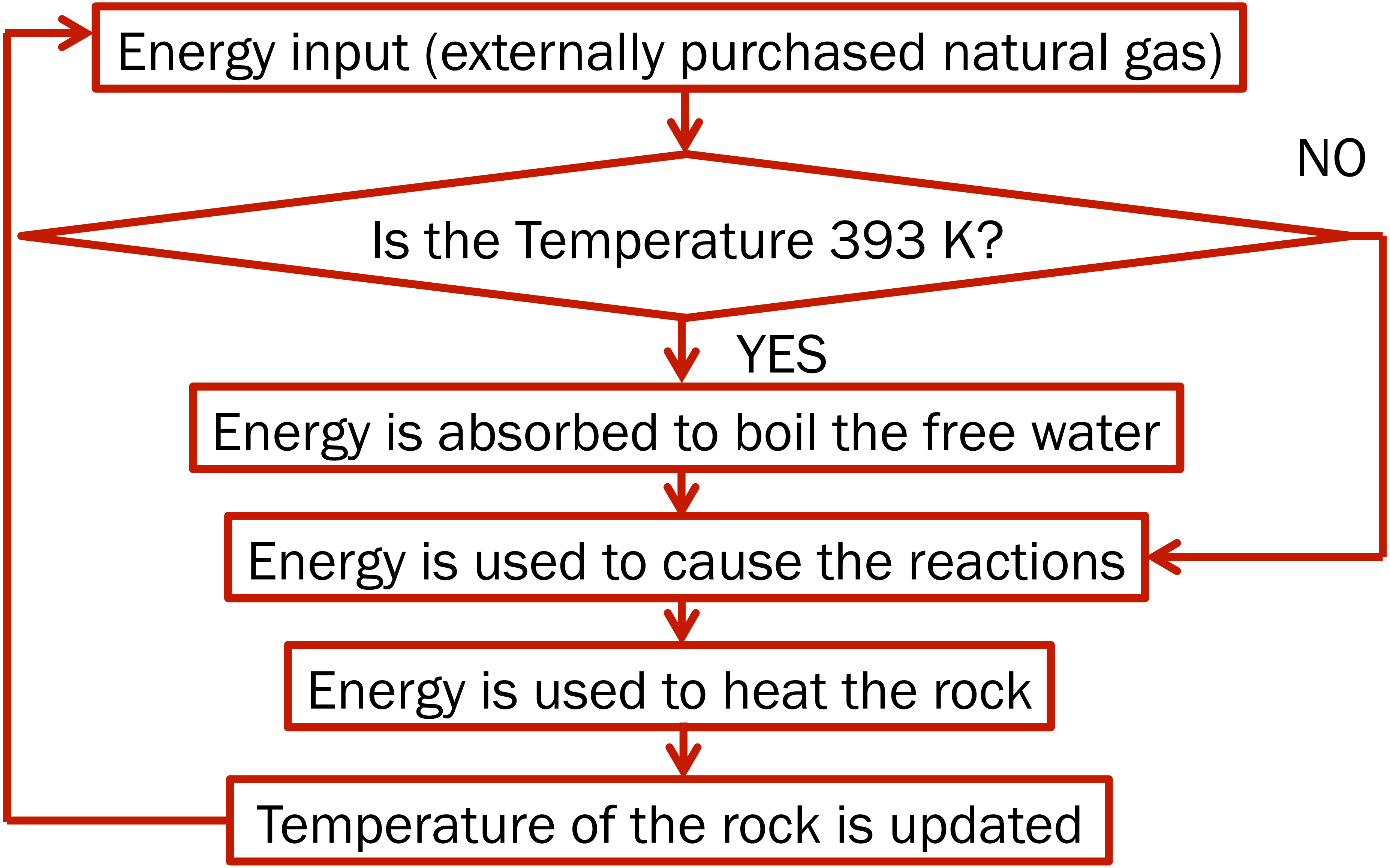
Primary decomposition reactions

Species	Reaction
Nahcolite	$2NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$
Calcite	$CaCO_3 \rightarrow CaO + CO_2$
Dolomite	$CaMg(CO_3)_2 \rightarrow MgO + CaCO_3 + CO_2$
Bitumen/ Kerogen	$100\ CH_{1.50}N_{0.025}O_{0.05} \rightarrow 5.3\ CH_{1.56}N_{0.021}O_{0.01} + 74.2\ CH_{1.56}N_{0.021}O_{0.021} + 14.7\ CH_{0.63}N_{0.056}O_{0.02} + 0.3\ CO + 1.0\ H_2 + 4.2\ CH_4 + 1.0\ H_2 + 1.3\ CO_2$

Secondary reactions

Species	Reaction
Primary char	$100\ CH_{0.63}N_{0.05}O_{0.02} \rightarrow 94.5\ CH_{0.23}N_{0.03}O_{0.02} + 5.5\ CH_4 + 6.4\ H_2 + 2.2\ NH_3$
Secondary char	$100\ CH_{0.23}N_{0.03}O_{0.02} \rightarrow 100\ CH_{0.1}N_{0.03}O_{0.02} + 8.0\ H_2$
Oil cracking	$Oil_i \rightarrow Oil_{j<i}$ + Primary char + $CH_4 + CO + H_2$

STAN/DOS Modeling scheme

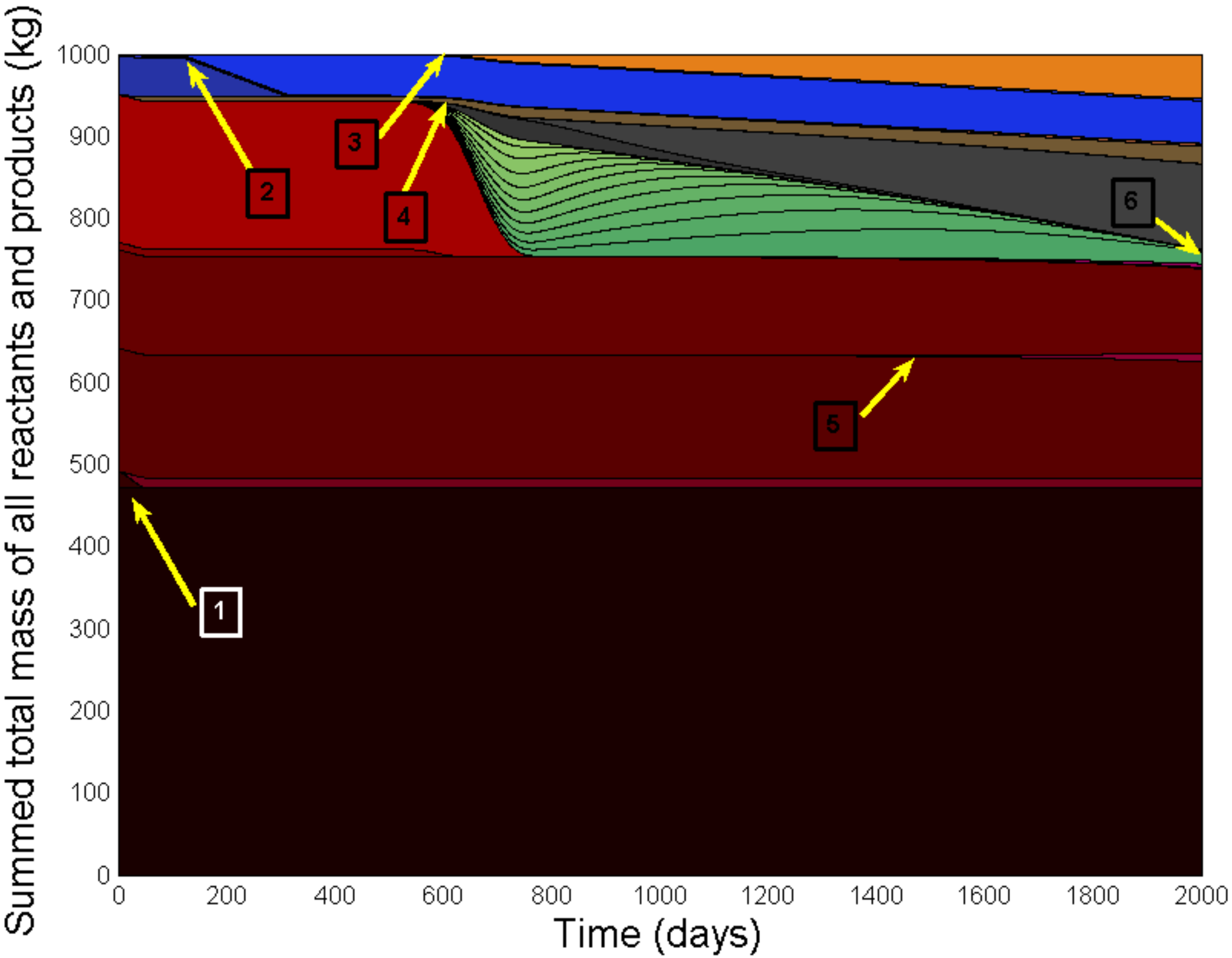


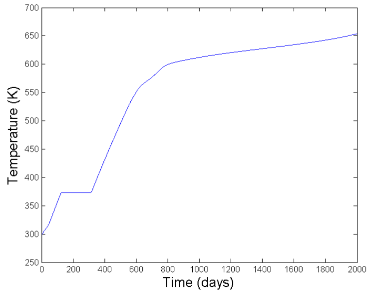
STAN/DOS details

- 1000 kg of shale
- Base case:
  - Uniform temperature (no heat transfer limitation)

	Inert mineral (%)	Nahcolite (%)	Calcite (%)	Dolomite (%)	Bitumen (%)	Kerogen (%)	Bound water (%)	Free water (%)	Total (%)
Standard case	47.1	2	12	15	0.9	18	0.25	4.75	100
High kerogen content	39.75	2	12	15	1.25	**25**	0.25	4.75	100
Low kerogen content	55.5	2	12	15	0.5	**10**	0.25	4.75	100
High water content	42.1	2	12	15	0.9	18	**0.5**	9.5	100
Low water content	49.6	2	12	15	0.9	18	**0.125**	2.375	100

Results – non-bounding case





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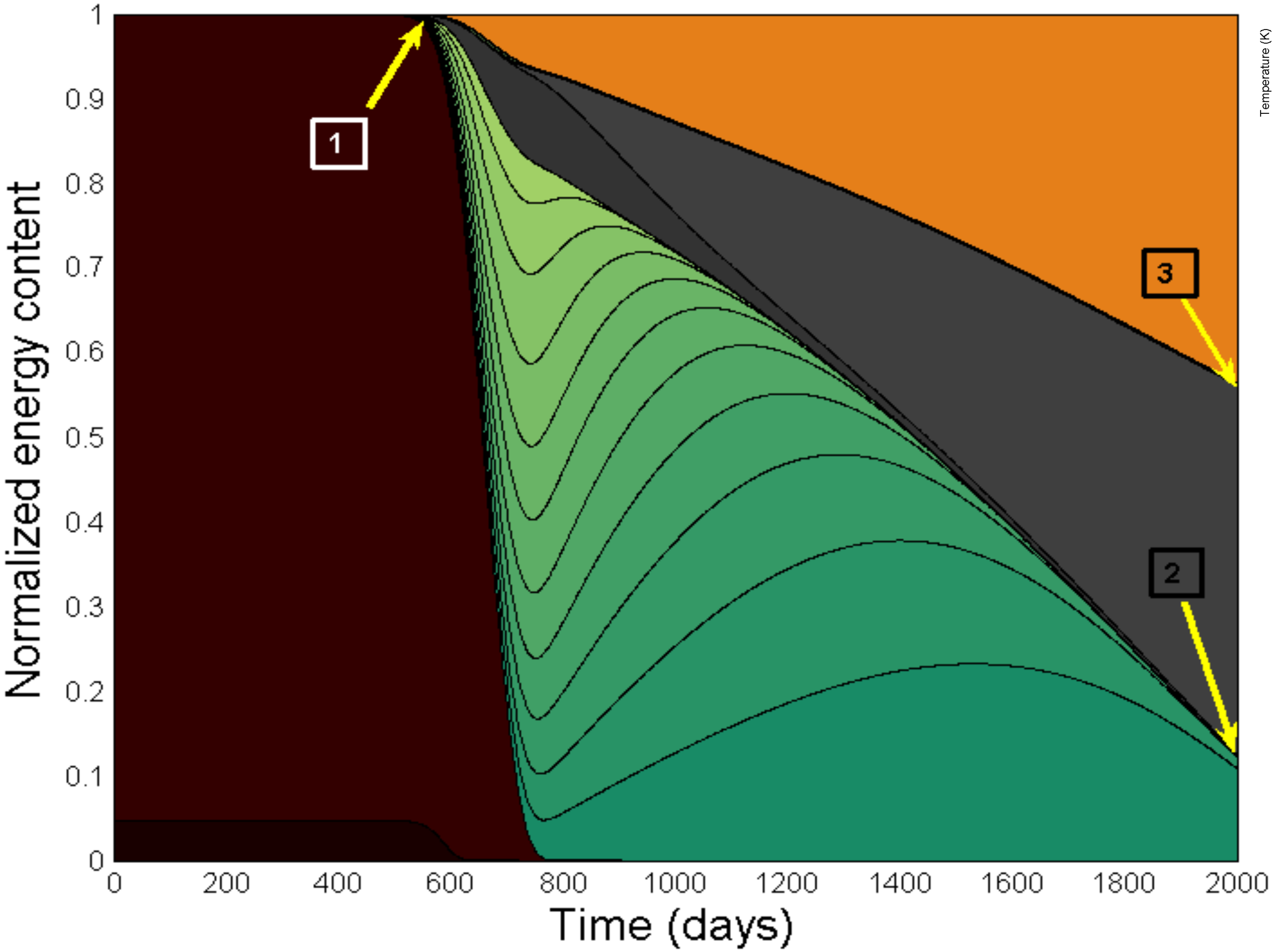
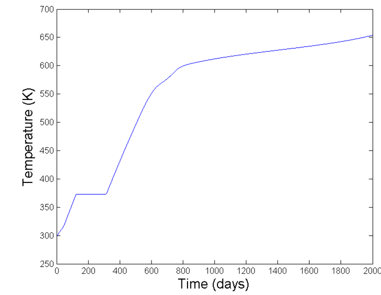
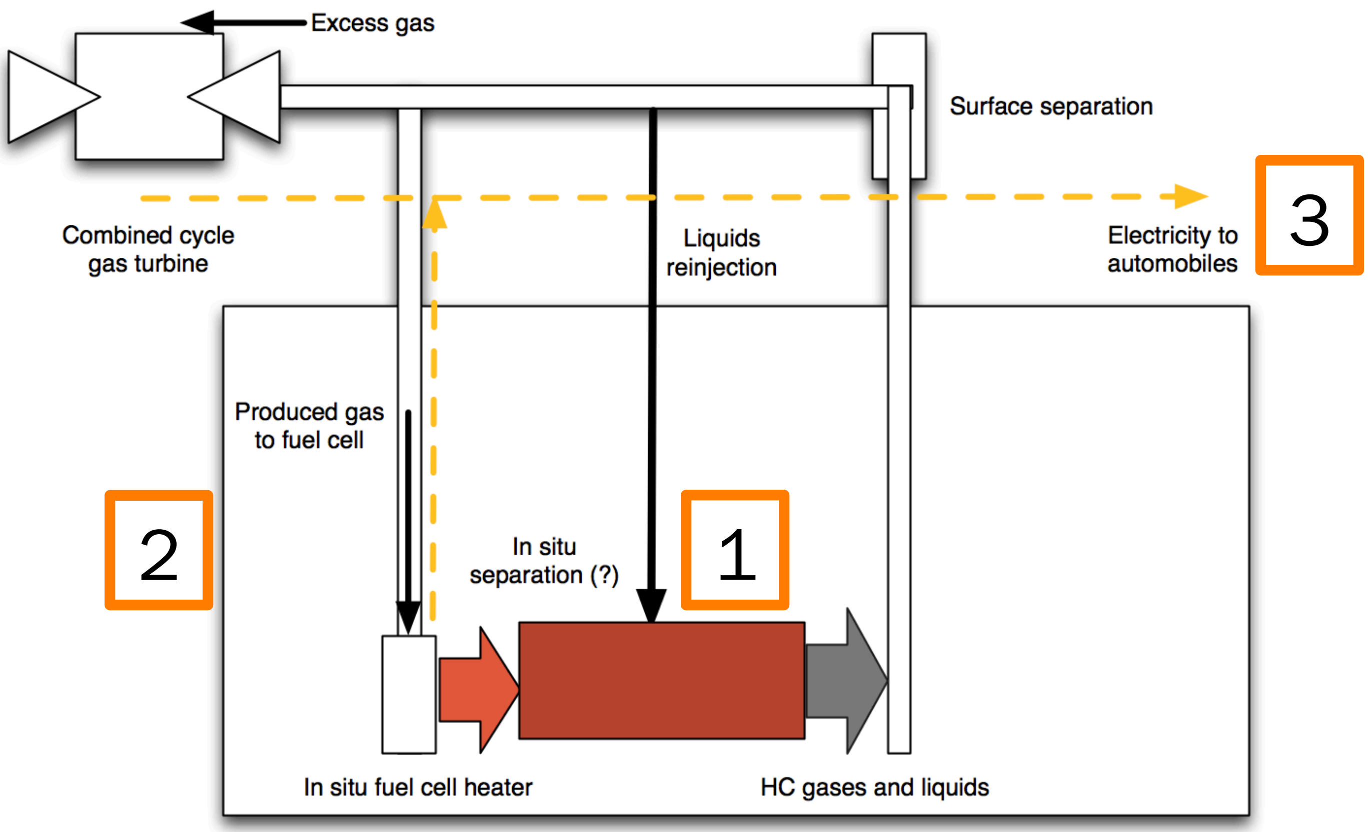




Energy Ratios



NER	(3)/(1+2)
EER	(3)/(2)

Results – Energy contents

Case	Initial energy content (MJ)	Extracted energy (MJ)	Energy left behind (MJ)	Extraction efficiency (%)
Standard	7806	3109	4697	39.8
High kerogen	10841	3353	7488	30.9
Low kerogen	4337	1922	2415	44.3
High water	7806	2723	5080	34.9
Low water	7806	3274	4532	41.9

Extraction efficiency ≈ 40 % in standard case

Results – Energy ratios

Case	EER	NER	CO_2 intensity (g CO_2/MJ electricity)
Standard	1.12	0.49	52.4
High kerogen	1.17	0.49	49.1
Low kerogen	0.87	0.48	89.8
High water	1.04	0.49	54.9
Low water	1.15	0.49	52.0

CO_2 intensity of electricity ≈ ½ CCGT in standard case

Potential difficulties

- Unclear if model (Burnham and Braun) can be extended to this regime
- Reliable operation of a GFC unknown
- Effective separation of liquids and gases in sub-surface un-tested
- Fracturing of rock possible due to pressure buildup (pressure not modeled)
- Opportunity cost of leaving char underground

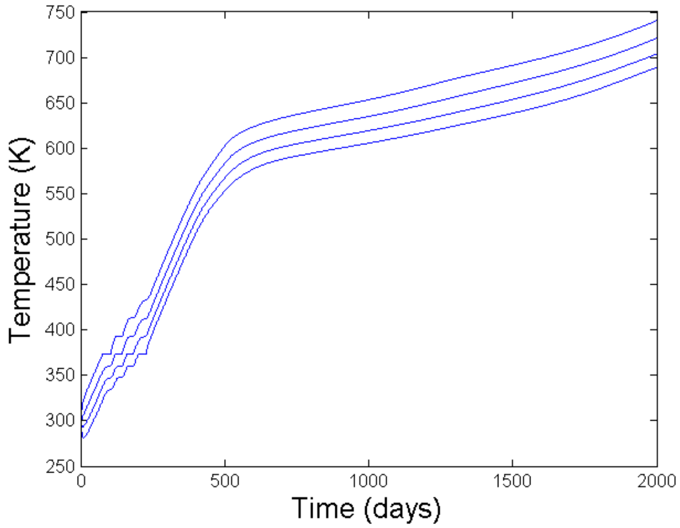
Conclusions

- Shown proof-of-concept for EPICC through STAN/DOS
- Can yield extraction efficiency of 31 – 45 %
- Can yield NER's between 0.44 – 0.88
- Can yield EER's between 0.8 – 1.37
- Can reduce CO_2-intensity from ~ 120 g CO_2/MJ e (gas turbine) to between 52-90 g CO_2/MJ e (EPICC)
- Concept is worthy of additional modeling (heat transfer and fluid flow)

Thanks:

- Attendees of 30th Oil Shale Symposium
- Co-author: Adam Brandt
- Sponsor: Jerry Boak

Results - bounding case



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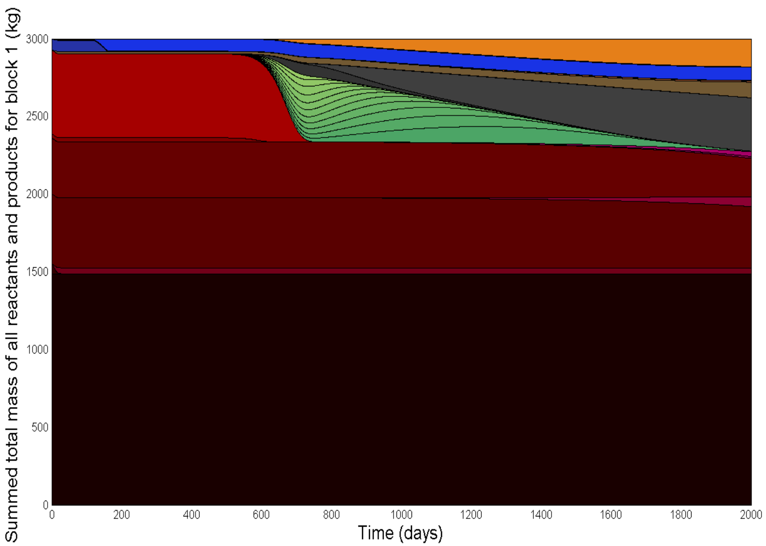

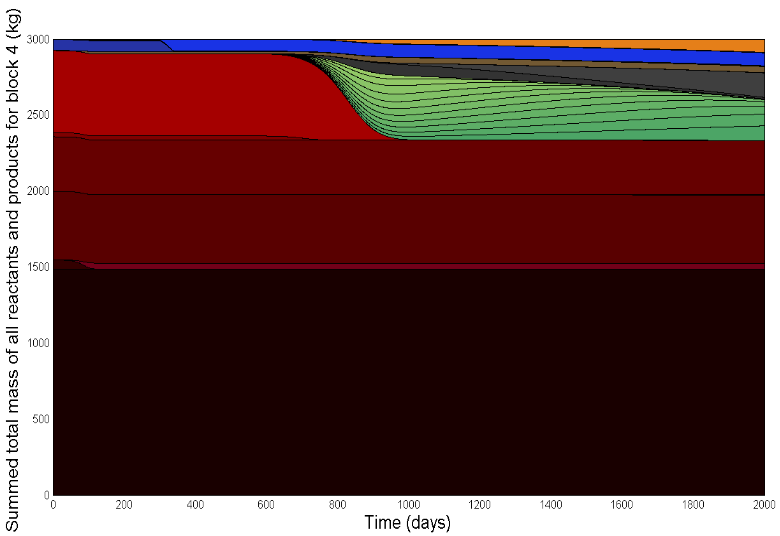

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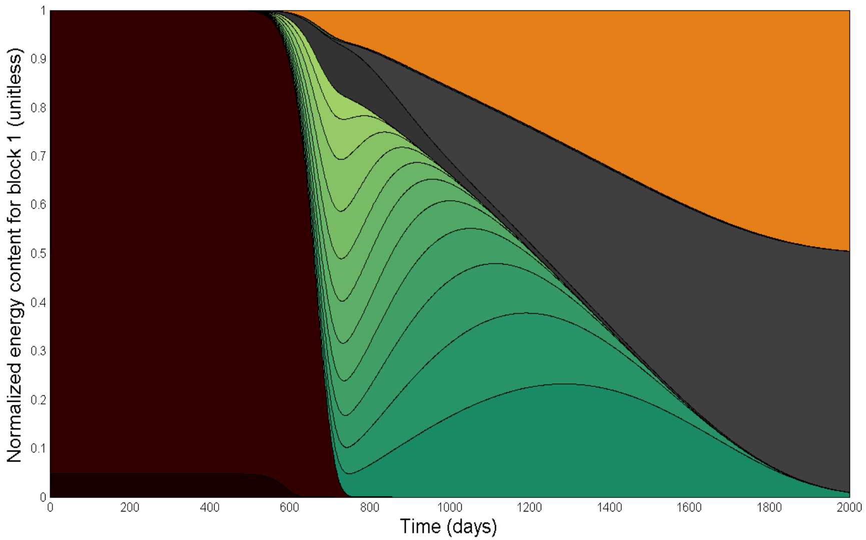
Results – bounding case (cont.)



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