Scraping the bottom of the barrel: CO₂ emissions consequences of a transition to low-quality and synthetic petroleum resources

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Alexander E. Farrell
Adam R. Brandt
Energy and Resources Group, UC Berkeley
aef@berkeley.edu
abrandt@berkeley.edu

Introduction
• Many GHG emissions scenarios imply a transition to alternatives to conventional petroleum
• We studied IPCC Special Report on Emissions Scenarios (SRES)
  - SRES is well known and detailed
  - Transition to alternatives is not explicit
  - In many SRES scenarios petroleum production forecasts require development of either:
    • Low-grade petroleum resources (extra heavy oil, tar sands, oil shale)
    • Synthetic liquid fuels to replace petroleum (gas-to-liquids, coal-to-liquids)
• Question: How is this transition modeled?
  - What emissions factors are used?
  - What resource endowments are assumed?
  - What uncertainties are associated with these assumptions?
Method

- Literature review
  - Estimation of fossil hydrocarbon endowment
    - Petroleum, conventional and unconventional
    - Gas
    - Coal
  - Evaluation of production technologies
    - Unconventional petroleum
    - Gas-To-Liquids
    - Coal-To-Liquids
- Review and simulation of some SRES forecasts
  - Scenarios
    - A1F
    - A1B
    - A2
  - Models
    - IMAGE
    - MESSAGE
    - MiniCAM

Estimates of conventional EUR

- Historically many analysts have projected Estimated Ultimate Recovery for conventional oil (EUR)
- This is the amount of oil estimated to be produced over all time

Definitional problems

- Reserves or EUR?
- What is petroleum?
- Resources or capacity?
- Stability of supply?

Rogner’s estimates (1997)

- All SRES modeling teams used Rogner (1997) for resource endowment
  - Rogner is “optimistic” - broad resource definition

![Graph showing oil resource categories: Conventional oil, Unconventional oil, Additional Occurrences, USGS mean]
SRES oil production

- We can compare this to the oil consumed in 3 SRES modeling efforts

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Cumulative Oil Production (Gbbl 2000-2100)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IMAGE</td>
</tr>
<tr>
<td>A2</td>
<td>3900</td>
</tr>
<tr>
<td>A1B</td>
<td>4500</td>
</tr>
<tr>
<td>A1F</td>
<td>5200</td>
</tr>
</tbody>
</table>

Rogner’s estimates (1997)

- All SRES modeling teams used Rogner (1997) for resource endowment
  - Rogner is “optimistic” - broad resource definition
Carbon implications

- These unconventional resources are more expensive and environmentally damaging
  - Supply curve with variable cost is included in Rogner, thus in SRES
  - However, Rogner does not describe excess emissions from substitutes

<table>
<thead>
<tr>
<th>Emissions (gCeq./MJ of refined product)</th>
<th>Gasoline</th>
<th>Tar sands and extra-heavy oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low emissions</td>
<td>5.6 (21%)</td>
<td>9.3 (31%)</td>
</tr>
<tr>
<td>High emissions</td>
<td>16 (44%)</td>
<td>20 (56%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Low emissions</th>
<th>High emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upstream</td>
<td>20 (78%)</td>
<td>20 (69%)</td>
</tr>
<tr>
<td>Combustion</td>
<td>20 (69%)</td>
<td>20 (56%)</td>
</tr>
<tr>
<td>Total</td>
<td>26</td>
<td>29</td>
</tr>
</tbody>
</table>

Normalized 1 1.14 1.39
Global supply curve for liquid hydrocarbons

3 types of uncertainty

- Using this supply curve, we can study 3 types of uncertainty in SRES modeling of transition

1. Upstream emissions factors for unconventional production
   - Unaccounted for in IMAGE and MESSAGE
   - Partially represented in miniCAM

2. Varying estimates of conventional EUR
   - Not included in any SRES model
   - Possibly implicit in different scenarios

3. Failing to include synfuels
   - Not included in any SRES model
Uncertainty 1) upstream emissions factors

Upstream emissions (gC/MJ)

IMAGE consumption in 3 scenarios

Baseline IMAGE emission factors

Low emission factors

Cumulative Production (Gbbl)

Low emission factors
Uncertainty 1) upstream emissions factors

Upstream emissions (gC/MJ)

- Mean emission factors
- Low emission factors
- Baseline IMAGE emission factors

Cumulative Production (Gbbl)

- Low emission factors
- Baseline IMAGE emission factors
- High emission factors
- Mean emission factors
Uncertainty 1) upstream emissions factors

- Using mean emission factors for unconventional oil, cumulative upstream emissions could be 20-130 GtC higher extra emissions relative to the baseline IMAGE results, depending on the scenario.

Uncertainty 2) varying estimates of conv. EUR

![Diagram showing cumulative production and upstream emissions with different estimates.]
Uncertainty 2) varying estimates of conv. EUR
Cumulative upstream emissions using MESSAGE (GtC 2000-2100)

<table>
<thead>
<tr>
<th></th>
<th>A2</th>
<th>A1B</th>
<th>A1F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rogner</td>
<td>93</td>
<td>180</td>
<td>358</td>
</tr>
<tr>
<td>USGS 5% Probability</td>
<td>93</td>
<td>195</td>
<td>373</td>
</tr>
<tr>
<td>USGS 50% Probability</td>
<td>152</td>
<td>273</td>
<td>451</td>
</tr>
<tr>
<td>USGS 95% Probability</td>
<td>224</td>
<td>344</td>
<td>522</td>
</tr>
</tbody>
</table>

Uncertainty 3) Synthetic petroleum

- Assume USGS 5% likelihood EUR value
  - Close to Rogner's conventional oil resource categories I-IV, which includes EOR

- Calculate “shortfall” between IMAGE implied production schedule and a forecast production schedule based on USGS 5% (Hallock et al. 2004)

- Estimate additional GHG emissions from filling the shortfall
  - GTL
  - CTL
Uncertainty 3) Synthetic petroleum

Calculate the shortfall

Uncertainty 3) Synthetic petroleum

Estimate additional GHG emissions
Conclusions and further work

• Scenarios that include persistent shortages or persistent, exceptionally high oil prices (>\$50/bbl) seem implausible.

• The potential for additional emissions in SRES scenarios is clear.

• Additional detail should be incorporated into future emissions models to ensure proper understanding of the potential emissions from oil substitutes.

• If liquid hydrocarbon production does not follow the least cost supply curve, these effects could be observed sooner and in greater degree.

• Simple model of global supply of liquid hydrocarbons (17 regions).

    But, don’t clap yet...

Acknowledgements

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