Life Cycle Assessment of Oil Sands Technologies

Carbon Management Canada

May 24, 2012
What is LCA?

A decision making tool to identify environmental burdens and evaluate the environmental consequences of a product, process or service over its life cycle from cradle to grave.
Motivation for Research

Development of a LC tool for oil sands technologies can inform

- Oil sands operations and investment decisions
- Emerging technology evaluation
- R&D investment
- LCA-based polices

Policies such as California’s Low Carbon Fuel Standard

- First-of-kind to use LCA to enforce policy
- Requires more sophisticated tools and frameworks
LCA of Oil Sands

Recovery & Extraction → Processing → Refining → Use in Vehicle

Well-to-wheel

Transport & Distribution
SAGD RECOVERY & EXTRACTION
- steam injection
- bitumen prod.
+ flare & fugitive

Upgrading
- coker and/or hydrocracker
- hydrotreatment
+ flare & fugitive

Recovery & Extraction

Refining

End Use

Natural Gas

Power Grid

Diluent

Life cycle stage
- Greenhouse gas emissions accounted for in the model
H2 Hydrogen
Elec. Electricity
SCO Synthetic crude oil

Diluted Bitumen

SCO Synthetic crude oil

Process Gas

Upgrading

Steam

H2 unit

SCO

Surplus Electricity Sold to the Grid

Electricity

Transport

Make-Up Diluent

Recycled Diluent

Solution Gas

CO-GEN

Boiler

Recovery & Extraction
- steam injection
- bitumen prod.
+ flare & fugitive

Diluted Bitumen

Diluted Bitumen

GHOST Model

Greenhouse gas emissions accounted for in the model.

H2 Hydrogen
Elec. Electricity
SCO Synthetic crude oil

Natural Gas

Power Grid

Diluent

Other projects

1. GHOST model (extraction and upgrading)
2. Refining model
3. Pipeline model
4. Full WTW
5. Input Fuels/Coke markets/uncertainty
6. Cogeneration
7. Prediction of SOR
8. Emerging Technology Evaluation
Motivation for LCA of Emerging Technologies

• Important to guide the RD&D process
  – Avoid surprises
  – Ensure that the goals of innovation will be achieved

• Challenges
  – Proprietary data
  – Disproportionately high uncertainty
    • Comparison with mature technologies
  – Lab scale → commercialized technology
  – Potential for disappointment
Current Focus of Project

• Emerging technologies
  • Economic impacts
  • Environmental Impacts

• extraction/recovery/upgrading/transport/refining

• Expert elicitation to supplement model
  • Workshop One - January 2012
  • Two Step Expert Elicitation Surveys
REPLACING CONVENTIONAL FUELS:
CASE STUDY OF OIL SANDS COKE

Source: David Dodge, The Pembina Institute, oilsandswatch.org (modified)

Jennifer McKellar, University of Toronto; Joule Bergerson, Janne Kettunen, University of Calgary; Heather MacLean, University of Toronto
Using Oil Sands Coke

Why consider using coke?
- Stockpiled: >64 million t or 1.9 billion GJ (2009)
- 2009 Production: 7.8 million t or 230 million GJ
- Amounts to rise over time
- Off-set demand for conventional fuels
- Potential economic benefits

Why isn’t more coke used now?
- Could increase negative environmental impacts vs. conventional fuels
- Cost of shipping out of the oil sands
- Low demand for “dirty” fuels

Sources: ERCB (2010), Jacobs (2008)
Options for Utilizing Coke

Decision-Support Framework

Pathway Identification ➔ 1st Stage LCA/LCC Analyses ➔ Feasibility Screening ➔ 2nd Stage LCA/LCC Analyses ➔ Preference Analysis

Most Promising Pathways

Hydrogen Production
- On-site
- Sell-to-Market
  • With & Without CCS
  • Natural Gas Price $5/GJ
  • Net electricity for CO₂ capture

Electricity Generation
- China
- IGCC
  • With & Without CCS
  • 3 Coal Price Options $3.3, $4.1, $6.6/GJ
  • 20% efficiency penalty for CCS

CCS: Carbon capture & storage; IGCC: Integrated gasification combined cycle; Includes current AB carbon regulations
Second Stage LCA/LCC Results

![Graph showing Second Stage LCA/LCC Results]

- **Amortized Project Value [$/t coke]**
  - Y-axis ranging from -50 to 200

- **Incremental GHG Emissions [t CO₂E/t coke]**
  - X-axis ranging from -2.5 to 1.5

- **Key Points**:
  - **Elec/China IGCC (high, med, low) (vs. coal)**
  - **Elec/China IGCC + CCS (high, med, low) (vs. coal)**
  - **H₂/Edmonton + CCS**
  - **H₂/On-site + CCS (vs. NG)**
  - **H₂/Edmonton (vs. NG)**
  - **H₂/On-site (vs. NG)**
  - **Stockpiling**

- The graph compares various processes in terms of their economic and environmental impacts.
Implications of Uncertainty

• Elec/China IGCC is financially preferred under many variations in key parameters

• If natural gas price rises to over $6.0/GJ and coal prices are low: H2/Edmonton preferred

• If a carbon tax is implemented at >$23/t CO$_2$E and coal prices are low H2/On-site preferred
Combined LCA/Real Options Analyses

Real options modifies traditional NPV analysis by incorporating the value of flexibility (e.g., wait and invest later) under uncertainty

Situation: Upgrader with “waste” coke – can store it, use it, or sell it under 2-year off-take agreements

– Natural Gas: mean-reverting, mean varies over time
– Cap & Trade: jump, then Geometric Brownian Motion
– Carbon Tax: jump, with potential for later jumps
Real Options Analysis

Determine optimal sequences of decisions based on the following question:

Should we invest in an on-site pathway today (and receive only those cash flows from now on) or pursue another pathway today and reconsider the on-site investment at another time?
Pathway Preferences under Uncertainty in Natural Gas Price & Carbon Tax

Expected Value of NPV: $1.1 billion (+22% vs Elec/China IGCC)

Expected Value of Incremental GHG Emissions: -9.0 million t CO\(_2\)E (-3.1% vs Elec/China IGCC)
Sensitivity Analysis

Carbon tax implemented at $30/t CO₂E (vs. $20/t CO₂E)
- 4.4% increase in expected value of NPV
- 11% increase in expected value of GHG emissions

Faster natural gas price growth (to expected value of $14/GJ at end vs. $5.3/GJ)
- Elec/China IGCC preference to zero after year 4
- 130% increase in expected value of NPV
- 130% increase in expected value of GHG emissions
Key Findings

There are opportunities available for coke utilisation

– Elec/China IGCC financially preferred under LCC analysis

A real options analysis provides greater insights into the financial & environmental implications of uncertainty

– Over time, preference shifts to hydrogen production

Decision-support framework and combined LCA/real options analyses are valuable tools for analysing financial, environmental and feasibility aspects of fuel replacement decisions and energy systems generally
Acknowledgements

Toronto: Dr. Heather MacLean
  Dr. Jennifer McKellar
  Diana Pacheco
  Sylvia Sleep

Calgary: Dr. Joule Bergerson
  Dr. David Keith
  Dr. Jared Carbone
  Jessica Abella
  Dr. Ganesh Doluweera
  Graeme Marshman
  Jessica Chan
Acknowledgements

- Natural Resources Canada
- Alberta Innovates: Energy and Environment Solutions
- Carbon Management Canada NCE
- AUTO21 Network Centre of Excellence
- Natural Sciences and Engineering Research Council of Canada
- Ontario Graduate Scholarship
- Oil Sands Industry Consortium
Decision-Support Framework

1. Pathway Identification
   • Technical Specifications, Life Cycle Activities

2. First Stage Life Cycle Assessment (LCA) & Life Cycle Costing (LCC)
   • Simplifying Assumptions, Reasonable Quality Data

3. Feasibility Screening
   • Regulatory Compliance, Pathway Experience & Drivers, Sensitivity Analysis

4. Second Stage LCA & LCC for Most Promising Pathways
   • Revisit Assumptions, Improve Accuracy

5. Stakeholder Preference Analysis
   • How Might Stakeholders Try to Influence Decisions?
Life Cycle Assessment & Costing

- Comparative LCAs:
  - Coke vs. conventional fuel pathway
  - Between coke pathways (incremental metric)
- Metrics: GHGs, select criteria air pollutants
- NPVs based on cost of conventional fuel pathways
- Horizon 15 y
- Discount rate 15%
- Coke of one project 2.5 million t/y
Prices Under Uncertainty

Expected Value of Natural Gas Price [U.S. $/GJ]

Time [y]

Expected Value of Carbon Price [U.S. $/t CO2E]

Cap & Trade

Carbon Tax

Natural Gas