Life cycle assessment:
A “systems” perspective on environmental impacts

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September 12th, 2012
Lecture overview

- Case study: reducing carbon emissions from transport fuels
- The challenge of scale and system boundaries
- LCA: from point impacts to distributed impacts
- Indirect impacts and complex interactions
Case study: Reducing CO₂ emissions from transport fuels

• Regulatory efforts to reduce CO₂ emissions from transportation fuels
  – CA: Low Carbon Fuel Standard (LCFS)
  – EU: Fuel Quality Directive (FQD)

• A challenge to track fuel carbon emissions
  – Fuels produced in complex supply chains
  – Emissions come from multiple industries
  – Emissions are often difficult to measure
Changing the scale of environmental assessment

“Simple” engineering calculations

Complex interactions of multiple engineering systems

Very complex, indeterminate, political/economic human factors and significant uncertainties

Source: This framework is due to Richard Plevin, UC Berkeley
Methods: Process modeling of a single facility or technology

Examples:

Combustion modeling of boiler to understand soot formation, NOx formation, flue gas clean-up technologies

How much $CO_2$ is released from an automobile tailpipe per km traveled?
“Point” assessment of fuel CO₂

1 MJ → 72.8 g CO₂

Fuel in
Gasoline

1 MJ → 0 g CO₂

Maize ethanol

Fossil CO₂ emissions out?

Source: EIA emissions factors
“Line” environmental assessment: LCA

Methods: Modeling process pathways using data from multiple industries

Example:
What are total impacts from all stages of product “life cycle”?

Manufacturing > Transport > Usage > Disposal
Full fuel cycle LCA - Ethanol

Upstream
- Land clearing
  - Energy crop growth
    - Harvest

Refining
- Biomass transport
  - Biorefinery
    - Fuel transport

Consumption
- Fuel consumption
The problem of system boundaries

• Question: *Where does a production process begin and end?*
  
  – Fuel used to drive tractors on farms?
    • Building tractors for farming?
      – Feeding workers who build tractors?
        » Natural gas consumed to make fertilizer used to grow food to feed workers to build tractors?

• The “truncation” problem
  
  – Selecting boundaries requires balancing effort and accuracy
"When we try to pick out anything by itself, we find it hitched to everything else in the Universe."

John Muir – *My First Summer in the Sierra* (1911)
Mathematical modeling of systems of interacting processes

- Matrix formulation solves for infinite interactions

Activity matrix $A$

Rows have consistent units
Flow direction relies on sign convention

Scaling

$As = f$
$s = A^{-1}f$

Demand

Source: Heijungs and Suh – The Computational Structure of Life Cycle Assessment
Life cycle ("line") comparison of vehicle GHGs

Source: EIA emissions factors, GREET model and Farrell et al. (2006) for ethanol pathways.
Totals also include transport emissions (not shown). Graphics from michellehenry.fr and other sources.
"Plane" assessment: Non-static supply chain analysis

Methods: LCA + modeling of indirect interactions

Examples:
What are indirect impacts from changes to main pathway ("line")?

What impacts might occur that are difficult to predict, mediated by policies and human actions?
“Consequential” LCA of biofuels

- Biofuels are produced on a planet with 7 billion people, who all need to eat
- Expanding biofuels production with food crops affects people everywhere
  - High crop prices induce more global land clearing for food products
  - Causes “indirect land use change” (iLUC)
  - iLUC is only partly a physical or engineering problem
Indirect land use change

Where will land conversion happen to meet a Brazilian biodiesel target?

Just because soybeans themselves are grown on rangeland does not mean that rainforests are not affected!

Source: Lapola et al. (2010) results for soy biodiesel
Consequential LCA ("plane") comparison of vehicle GHGs

**Gasoline "pathway"**
- 7.8
- 17.1
- 72.8

**Maize ethanol "pathway"**
- 37.2 (-25.0)
- 64.4
- 0

Source: EIA emissions factors, GREET model and Farrell et al. (2006) for ethanol pathways. Totals also include transport emissions (not shown). Graphics from michellehenry.fr and other sources.
Key insights from LCA

1. The scale and boundaries applied in your analysis can strongly affect your results!
2. Products can have large impacts “upstream”
3. Difficult to calculate exact emissions from any complex set of processes
4. Complex indirect interactions should not be ignored

Learn more:
ENERGY 295 - Quantitative environmental assessment of energy systems
Spring quarter 2013