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

Adam Brandt
Energy@Stanford & SLAC

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Lecture overview

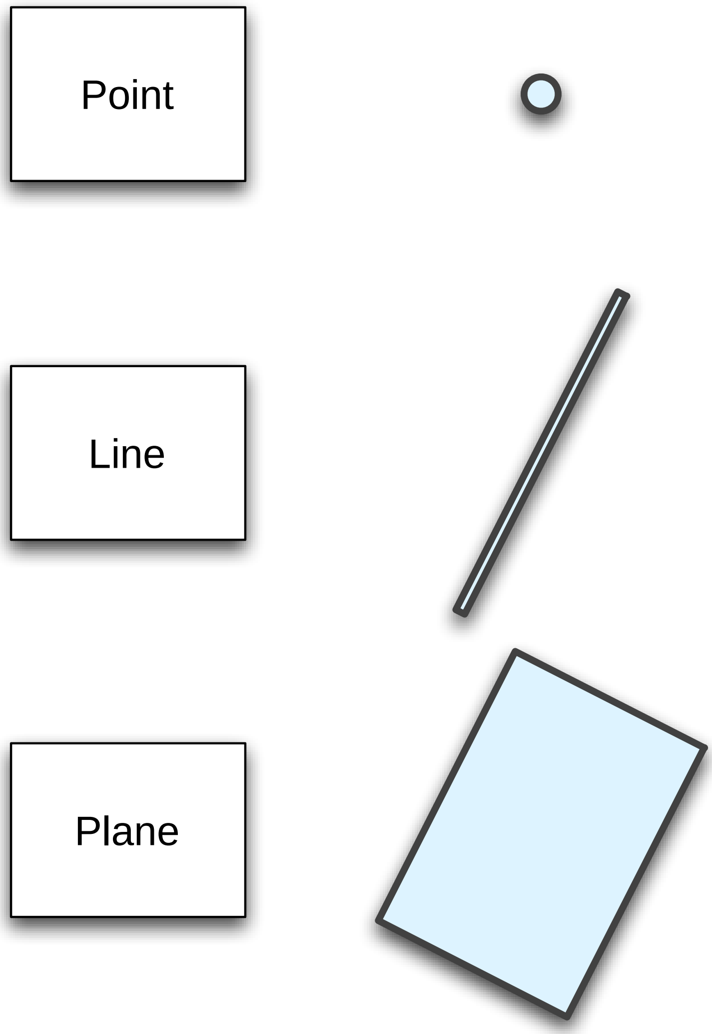
- Case study: reducing carbon emissions from transport fuels
- The challenge of scale and system boundaries
- LCA: from point impacts to distributed impacts
- Indirect impacts and complex interactions

Case study: Reducing CO_2 emissions from transport fuels

- Regulatory efforts to reduce CO_2 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

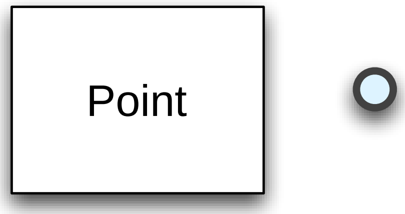


“Simple” engineering calculations

Complex interactions of multiple engineering systems

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

Point environmental assessment



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 CO_2

Fuel in

1 MJ

Gasoline

72.8 g CO_2

1 MJ

Maize ethanol

0 g CO_2

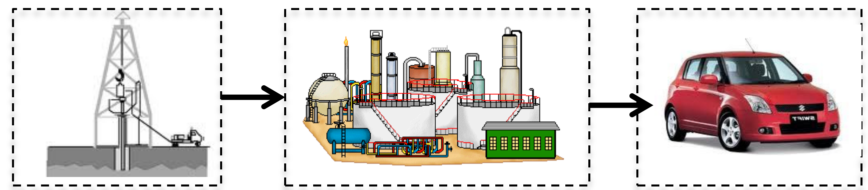
Fossil CO_2 emissions out?

Source: EIA emissions factors

"Line" environmental assessment: LCA

Line

A "line" is made up of a series of "points"

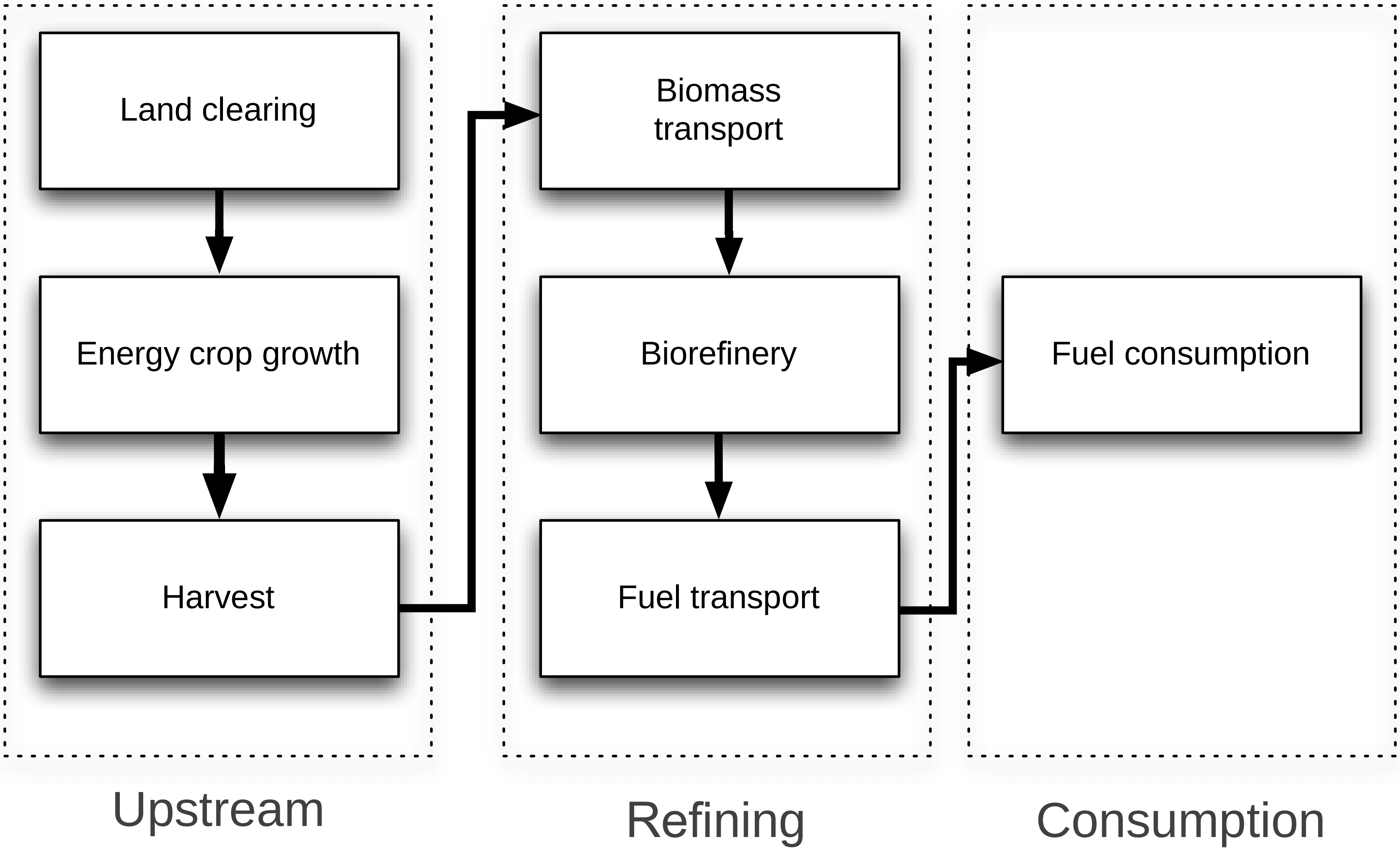


Methods: Modeling process pathways using data from multiple industries

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

Manufacturing > Transport > Usage > Disposal

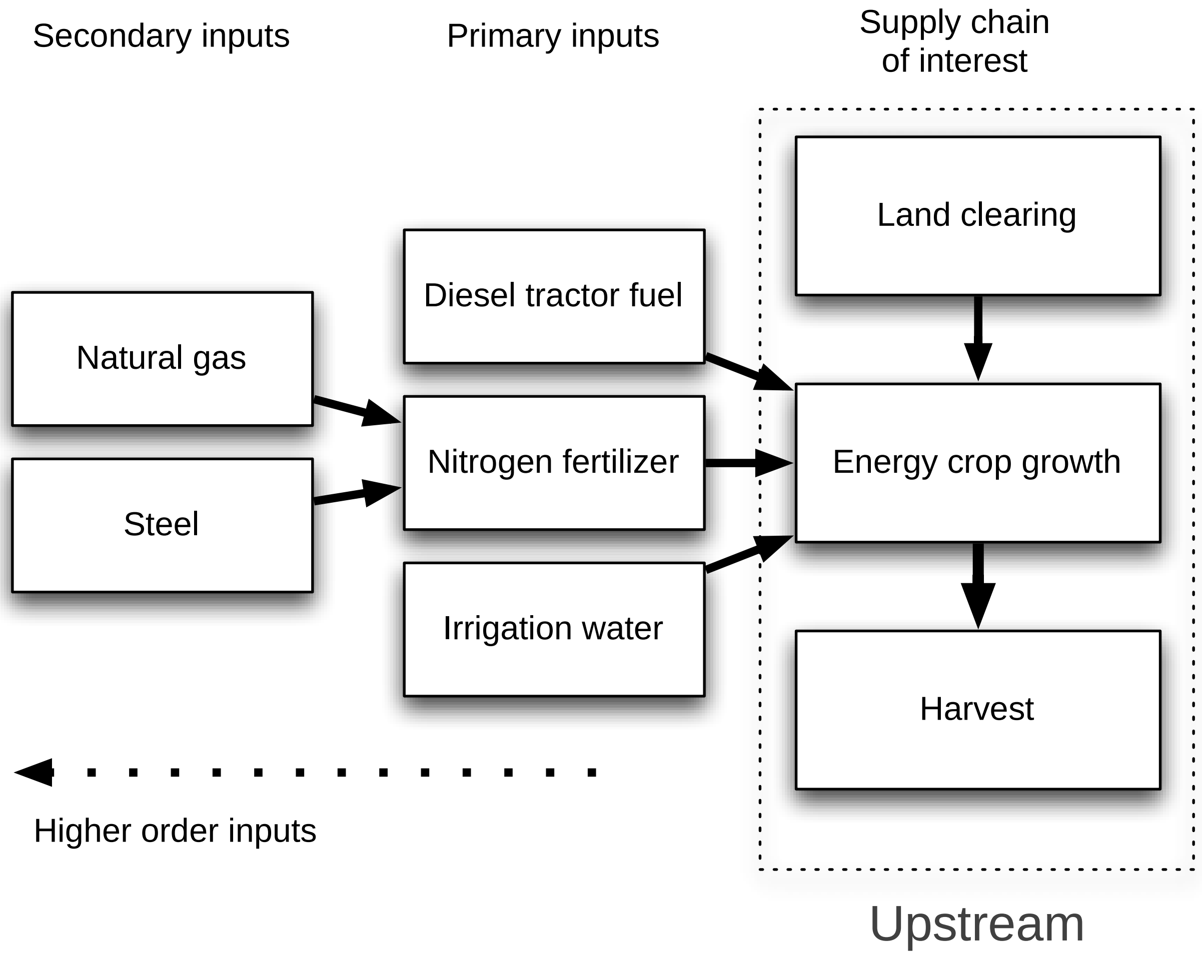
Full fuel cycle LCA - Ethanol



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

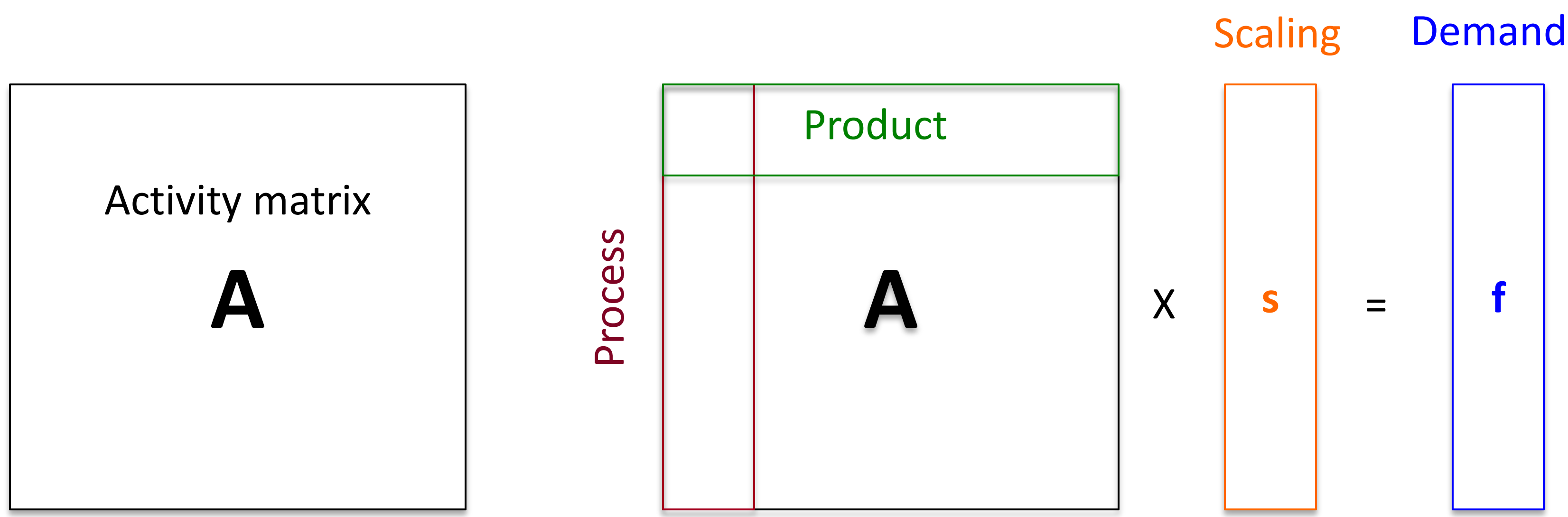
Higher-order inputs



"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)*

- Matrix formulation solves for infinite interactions



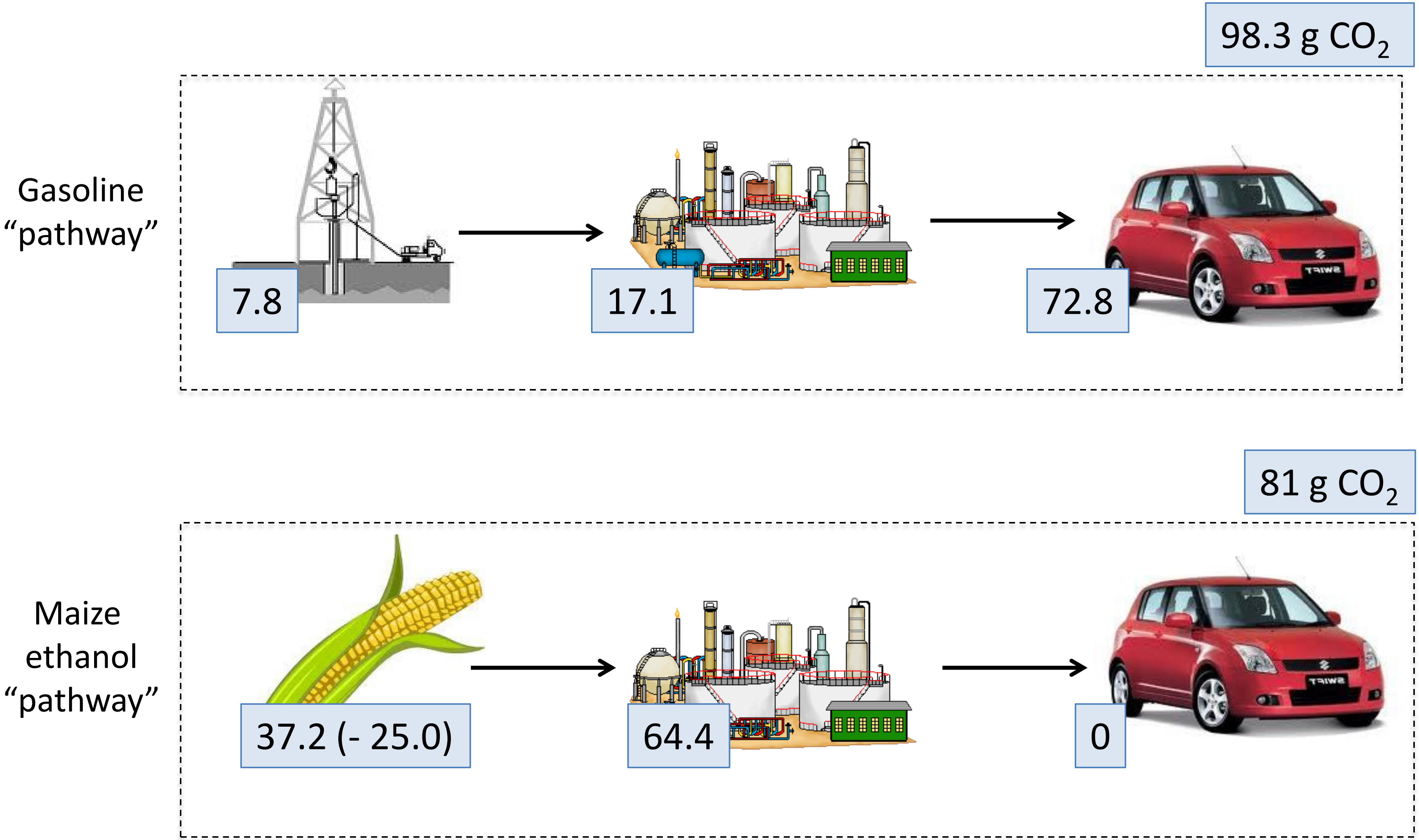
Rows have consistent units

Flow direction relies on sign convention

As = f

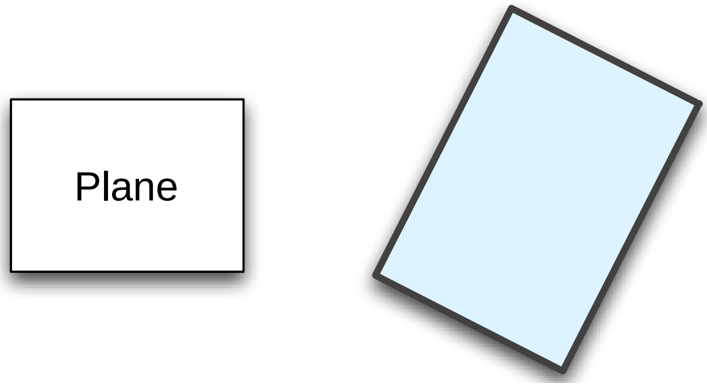
$\mathbf{s} = \mathbf{A}^{-1}\mathbf{f}$

Life cycle ("line") comparison of vehicle GHGs

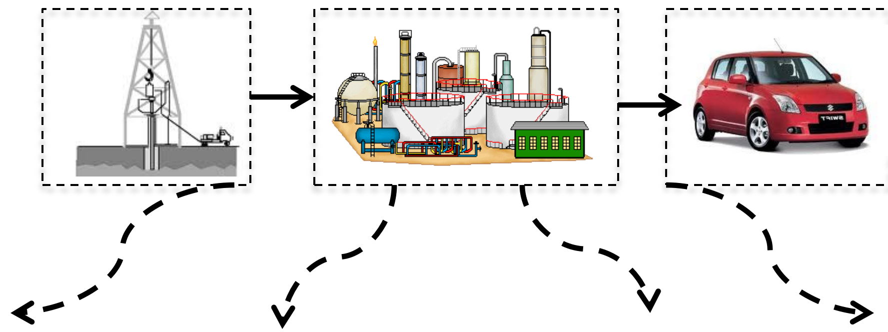


Source: EIA emissions factors, GREET model and Farrell et al. (2006) for ethanol pathways.
Totals also include transport emissions (not shown). Graphics from michellehenry.fr and other sources

"Plane" assessment: Non-static supply chain analysis



Direct impacts are only part of the story



Methods: LCA + modeling of indirect interactions

Examples:

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

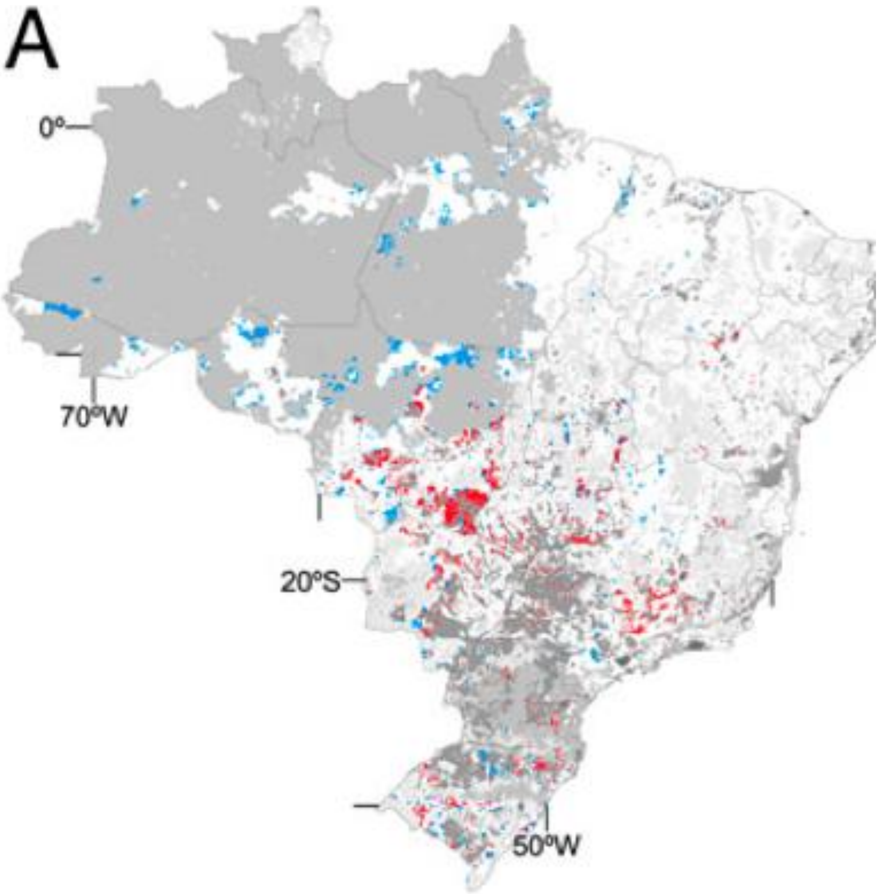
What impacts might occur that are difficult to predict, mediated by policies and human actions?

“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 biodeisel target?

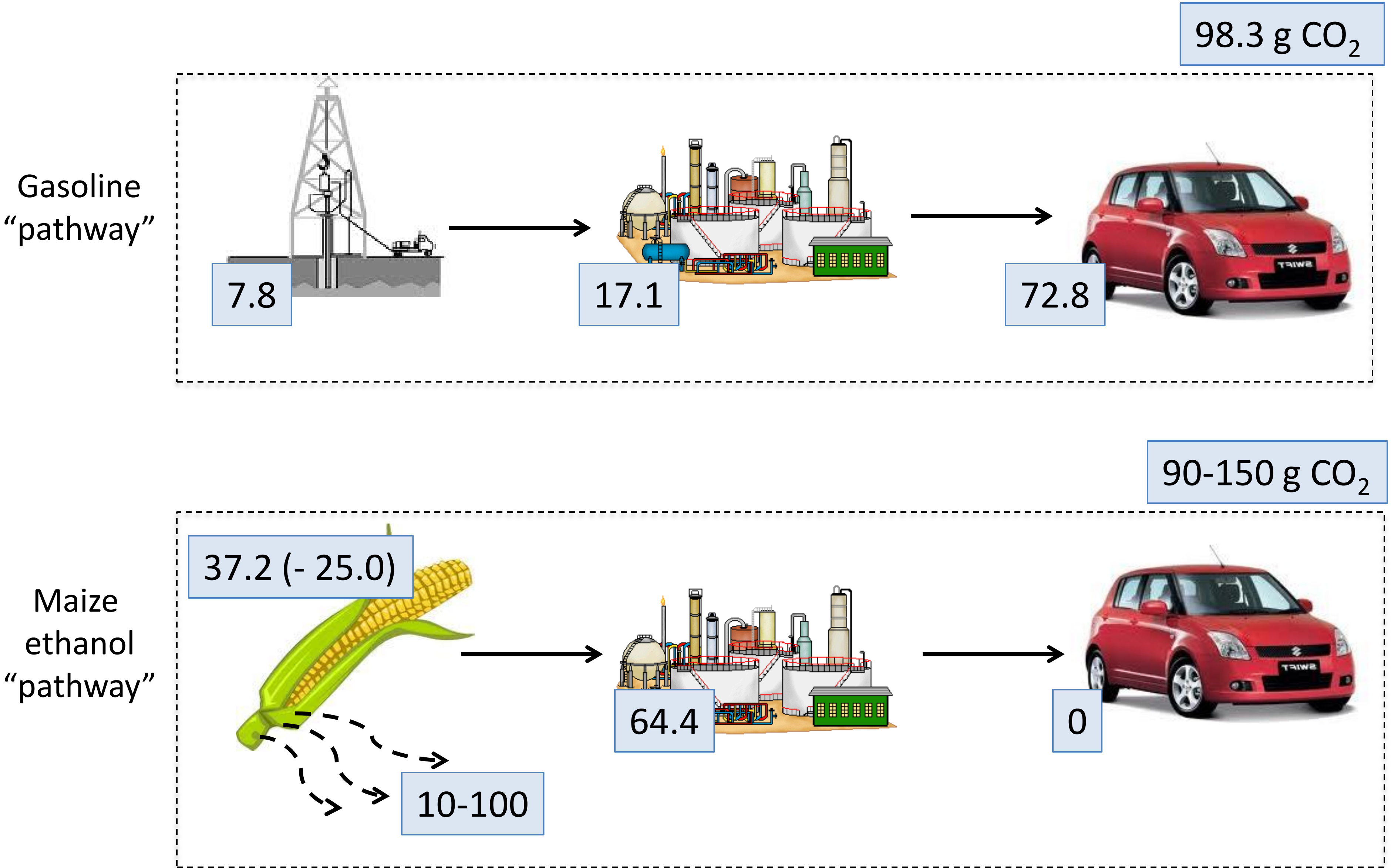


Red = direct land use change
Blue = indirect land use change

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



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