IOWA STATE UNIVERSITY

Biofuel Life Cycle Assessment (LCA) and Environmental Impact Analysis

Dr. Robert Anex
Agricultural & Biosystems Engineering
Iowa State University

Inquiring Minds Want to Know:

MORE THAN MEETS THE EYE

An occasional feature that digs deeper into things you've been wondering about

Paper or Plastic?

We hear the question almost every time we go grocery shopping. Some shoppers answer automatically: plastic — convinced that they are making a better choice for the environment. Others ask for paper, believing the very same thing. The reality is that both paper and plastic bags gobble up natural resources and cause significant pollution. When you weigh all the costs to the environment, **you might just choose to reuse:**

Source: Washington Post - Paper or Plastic?

CBiRC
Center for Biorenewable Chemicals

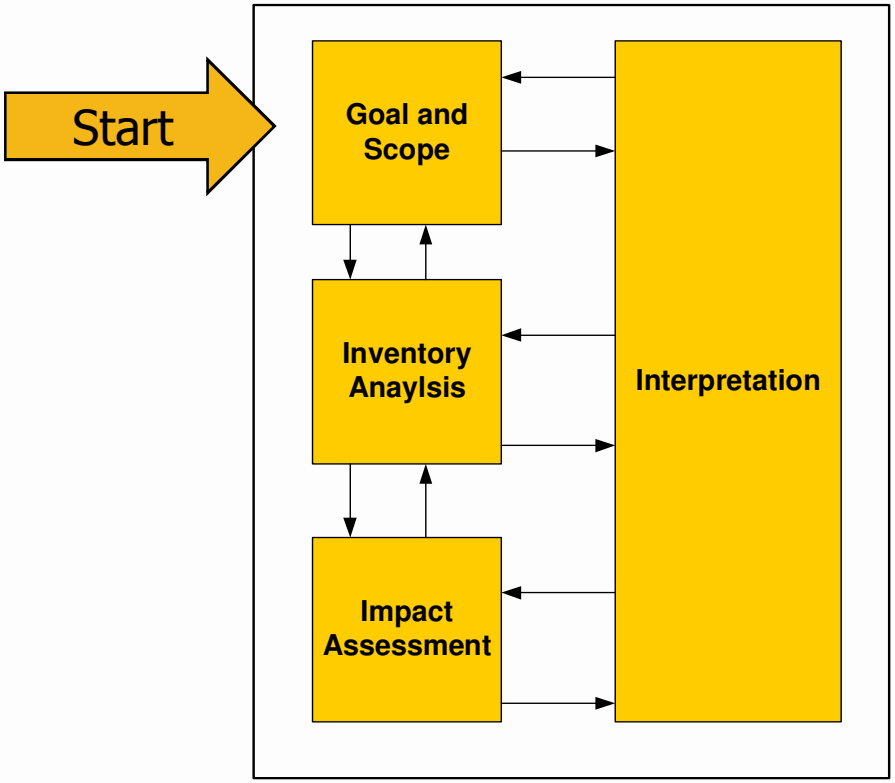
Lecture Outline

- **LCA procedure – Overview**
  - Goal & Scope
  - Functional unit
  - Inventory
  - Co-product allocation
  - Impact Assessment
- **Attributional vs Consequential LCA**
- **Other types of Biofuel analysis**

CBiRC
Center for Biorenewable Chemicals

Life Cycle Assessment Procedure

LCA is a **protocol** for assessing the environmental aspects and potential impacts associated with a product, process or activity.



Applications

- **Product development and improvement**
- **Strategic planning**
- **Public policy making**
- **Marketing**

From ISO14040-1997, *Environmental management-- Life cycle assessment-- Principles and framework*

CBiRC
Center for Biorenewable Chemicals

Goal of the study

- **The goal of an LCA shall unambiguously state:**
  - the intended application
  - the reasons for carrying out the study
    - comparing alternatives
    - identifying pollution prevention opportunities
    - identifying resource conservation opportunities
    - planning for recycling
  - the intended audience
    - inside company: managers, engineers, purchasing agents
    - outside company: suppliers, customers regulators

CBiRC
Center for Biorenewable Chemicals

Scope of the study

- **Identification of the function, functional unit, and reference flows**
- Identification of the initial system boundaries
- Identification of the criteria for inclusion of inputs and outputs
- Identification of the impact assessment methodology
- Identification of data quality requirements

CBiRC
Center for Biorenewable Chemicals

Different ways to provide the same function (i.e., "functional unit")

- **Carry home your groceries**
  - plastic bag, paper bag, cloth bag, net bag, basket, bicycle pannier, cardboard box, your coat pockets,…
    - capacity
    - strength
    - advertising potential (print quality)
    - handles?

CBiRC
Center for Biorenewable Chemicals

Specifying the Functional Unit

- Specification of the functional unit
  - the magnitude of service
  - the duration of service including the product's life span
  - the expected level of quality
- For example:
  - The magnitude and duration of service for a fuel tank might be 'MJ stored over 12 years'; the expected level of quality might include 'without leaking'

CBiRC
Center for Biorenewable Chemicals

Defining the Functional Unit by LCA type

- LCAs of a single material
  - Functions don't matter
  - Time does not matter
  - Reference flows reflect demand for some mass of material
- LCAs comparing materials
  - Functions will be based on material properties – providing equivalent strength, energy, protection, etc.
  - Time matters – if materials are less durable they will need to be replaced over some life time
  - Reference flows reflect a demand for some mass of material over time

CBiRC
Center for Biorenewable Chemicals

Example of a Functional Unit

- Ethanol (per kg, per MJ or per km?)
  - The ethanol-production oriented functional unit perspective reflects the fact that the ethanol supply (i.e., arable land or biomass supply) is constrained, while the traveling-distance oriented functional unit implies that ethanol fuel supply is unlimited.*
  - How about:
    - The magnitude and duration of service for the production of ethanol might be 'MJ produced over 25 years' the expected level of quality might specify the fuel standard (e.g., anhydrous, denatured) AND the LCA for 10 million gallons of per day should be different than for smaller production levels.

* Reference: Int J LCA 11(2): 117-121 (2006)

CBiRC
Center for Biorenewable Chemicals

Data Quality

- Data quality is judged on:
  - Time related coverage
  - Geographical coverage
  - Technology coverage
  - Precision and uncertainty of the data
  - Completeness and representativeness of the data

CBiRC
Center for Biorenewable Chemicals

Scope of the study

- Identification of the function, functional unit, and reference flows
- **Identification of the initial system boundaries**
- Identification of the criteria for inclusion of inputs and outputs
- Identification of the impact assessment methodology
- Identification of data quality requirements

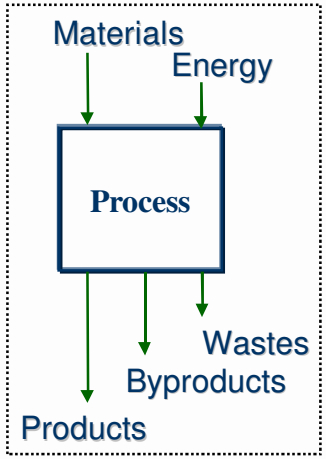
CBiRC
Center for Biorenewable Chemicals

System Boundaries

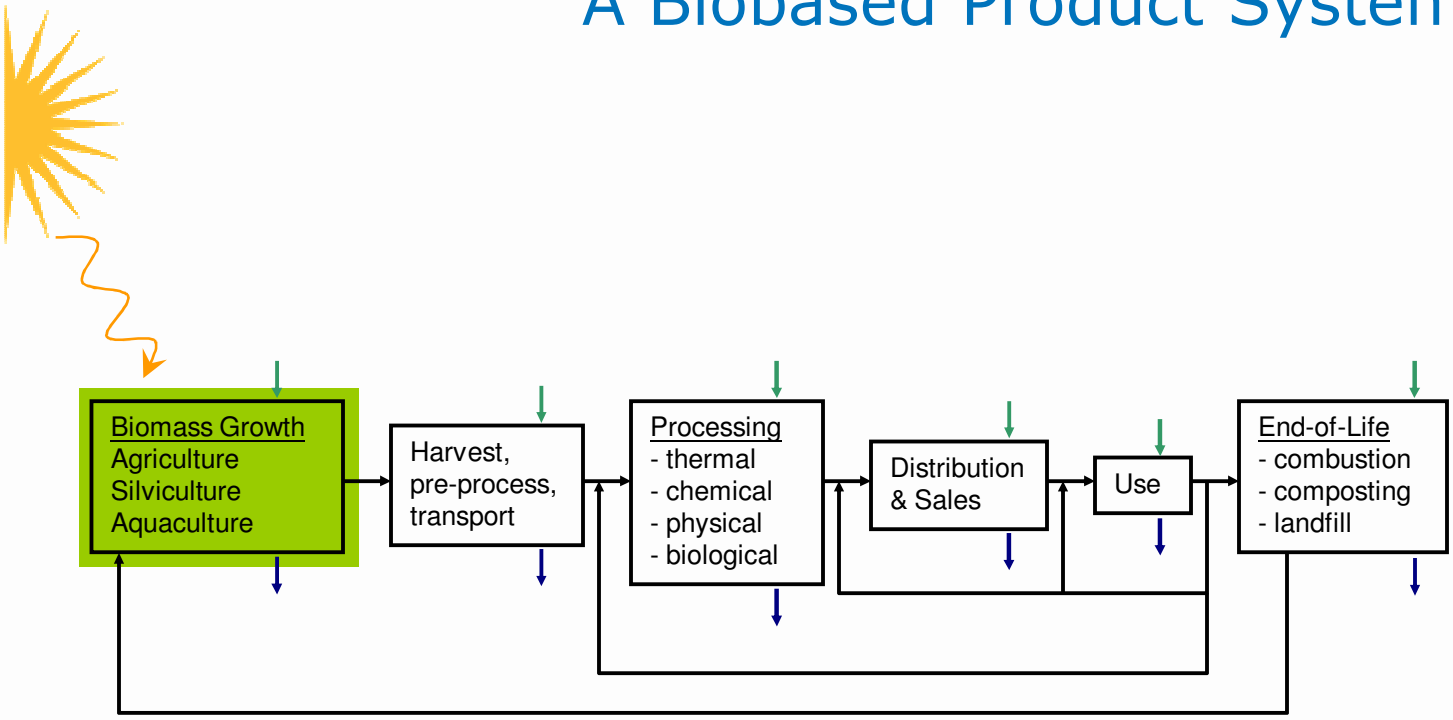
- ISO14040
  - selection of inputs and modeling of the system shall be consistent with the goal of the study
  - the system should be modeled in such a manner that inputs and outputs at the system boundaries are **elementary flows**.
- Reality
  - often by material weight (% of product is accounted for)
  - facilities, equipment, and infrastructure are often neglected but with today's data don't need to be

CBiRC
Center for Biorenewable Chemicals

Life Cycle Inventory (LCI)



A Biobased Product System



CBiRC
Center for Biorenewable Chemicals

Data Sources

- Measurements
- Electronic LCI databases: Boustead, US-LCI, SimaPro, GaBi, DEAM
- Literature data:
  - *Encyclopedia of Chemical Technology*
  - journal papers,
  - industry association conference papers,
  - LCA reports,
  - EPA sector notebooks
- Engineering Analysis

CBiRC
Center for Biorenewable Chemicals

General Inventory Issues

General issues related to quantifying inputs and outputs include:

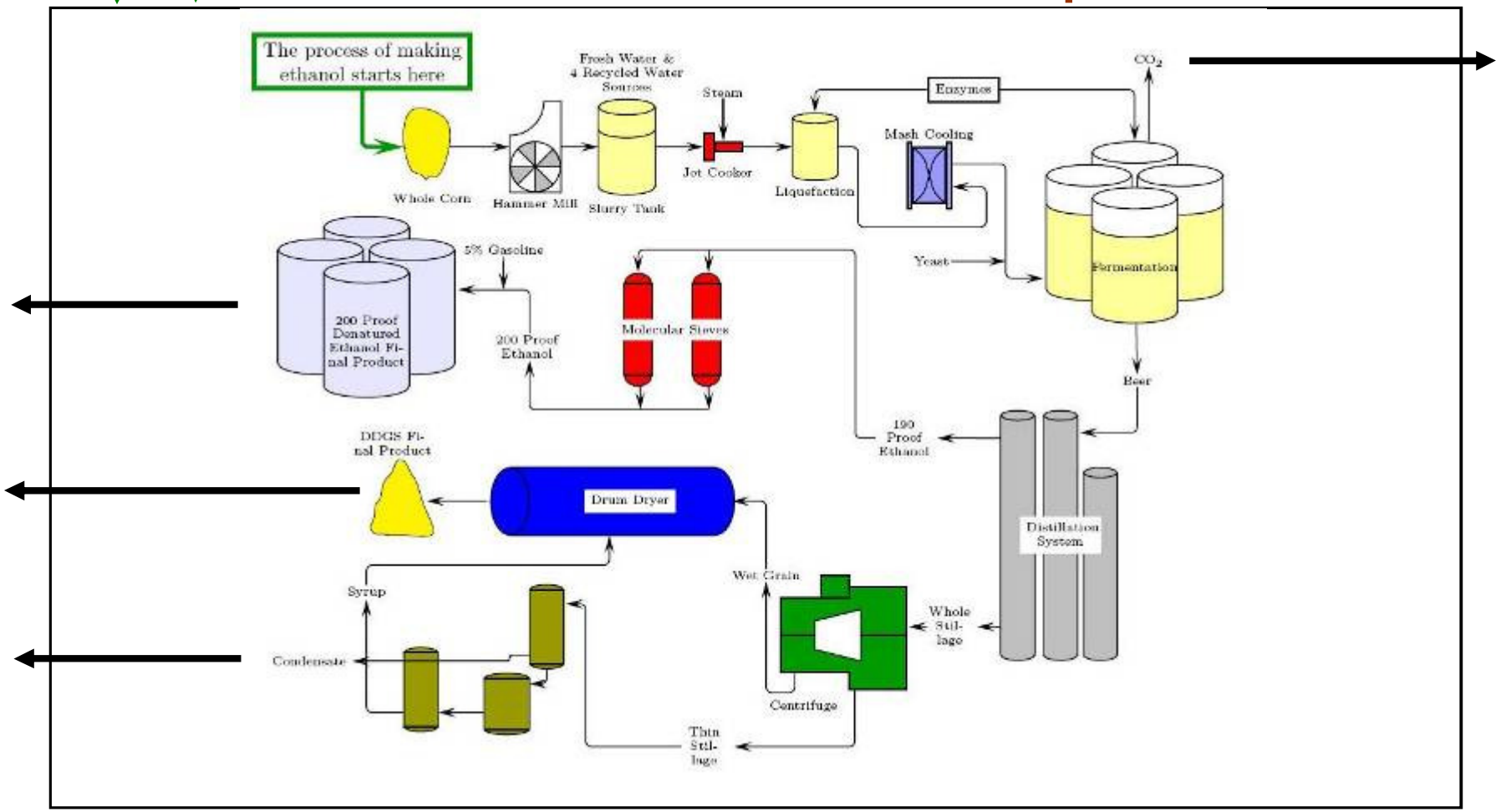
- energy sources
- transportation
- level of aggregation
- **multifunctional processes**
  - **co-product allocation**
  - **substitution / system expansion**

Co-Products in Corn Dry Milling

Energy: natural gas (or coal), electricity, gasoline

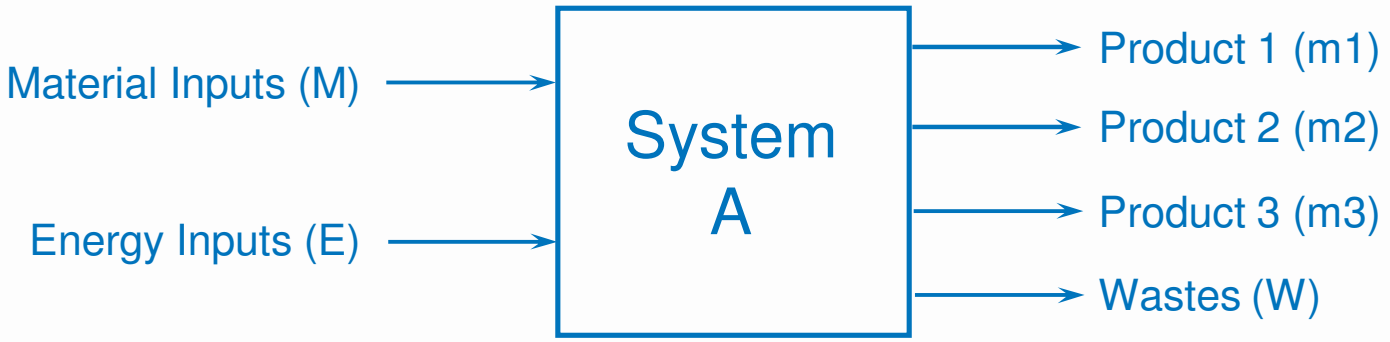
Materials: corn, NaOH, H_2SO_4, enzymes, yeast

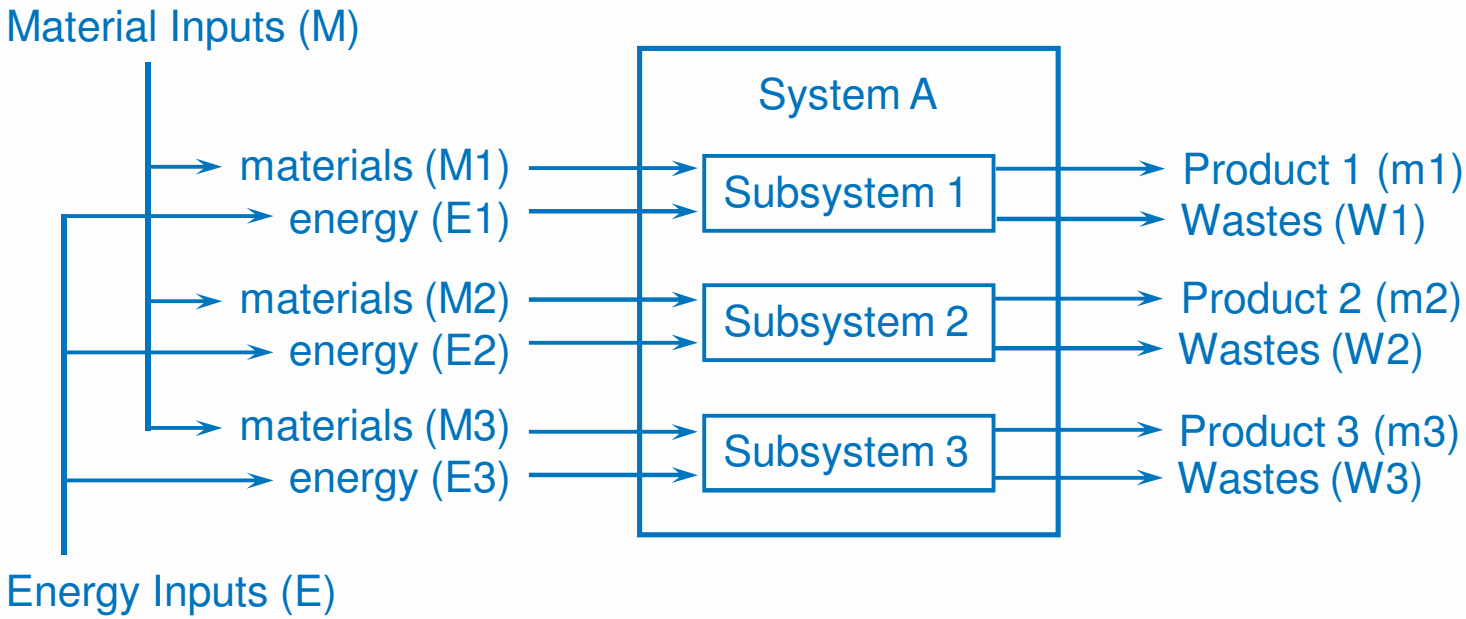
Wastes: water, sludge, VOCs



CBiRC
Center for Biorenewable Chemicals

Co-Product Allocation or 'partitioning'





CBiRC
Center for Biorenewable Chemicals

Substitution / system expansion

- In the substitution/ system expansion method, a separate, mono-functional “avoided” process for the production of the co-product is added to the system.
- Problems with the substitution method include
  - which process do you use as the "avoided process"
  - avoided processes might be multifunctional (needs another process added- sort of a snowball effect)
  - assumptions about the quality of products (e.g., is the feed protein of the same quality?)
- System expansion makes the LCA “consequential” in that the impacts are those that result from a marginal increase in production of the primary good.

CBiRC
Center for Biorenewable Chemicals

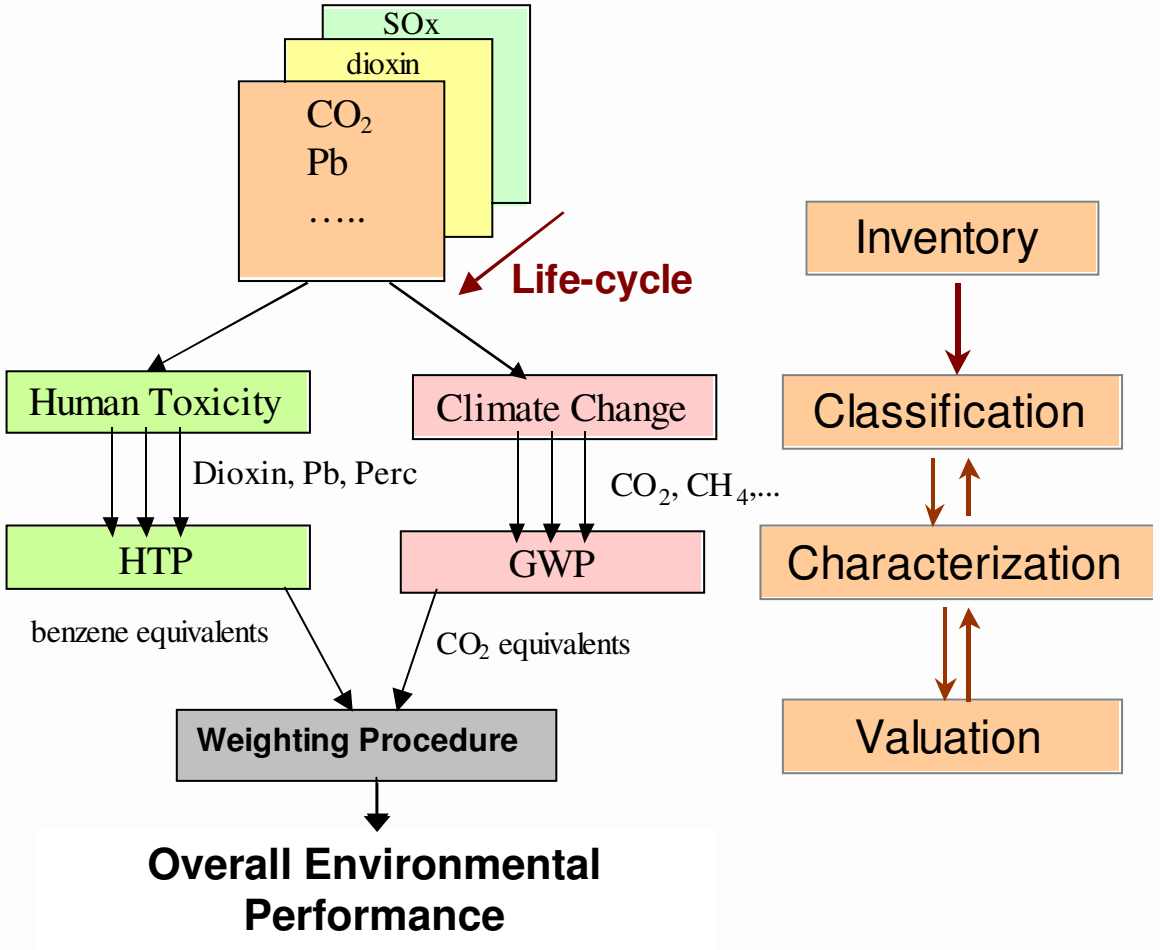
Impact Assessment

- **Aimed at evaluating the significance of potential environmental impacts using the results of the inventory analysis.**
- **In general, the process involves associating inventory data with specific environmental impacts and attempting to understand those impacts.**

From ISO14040-1997, *Environmental management-- Life cycle assessment-- Principles and framework*

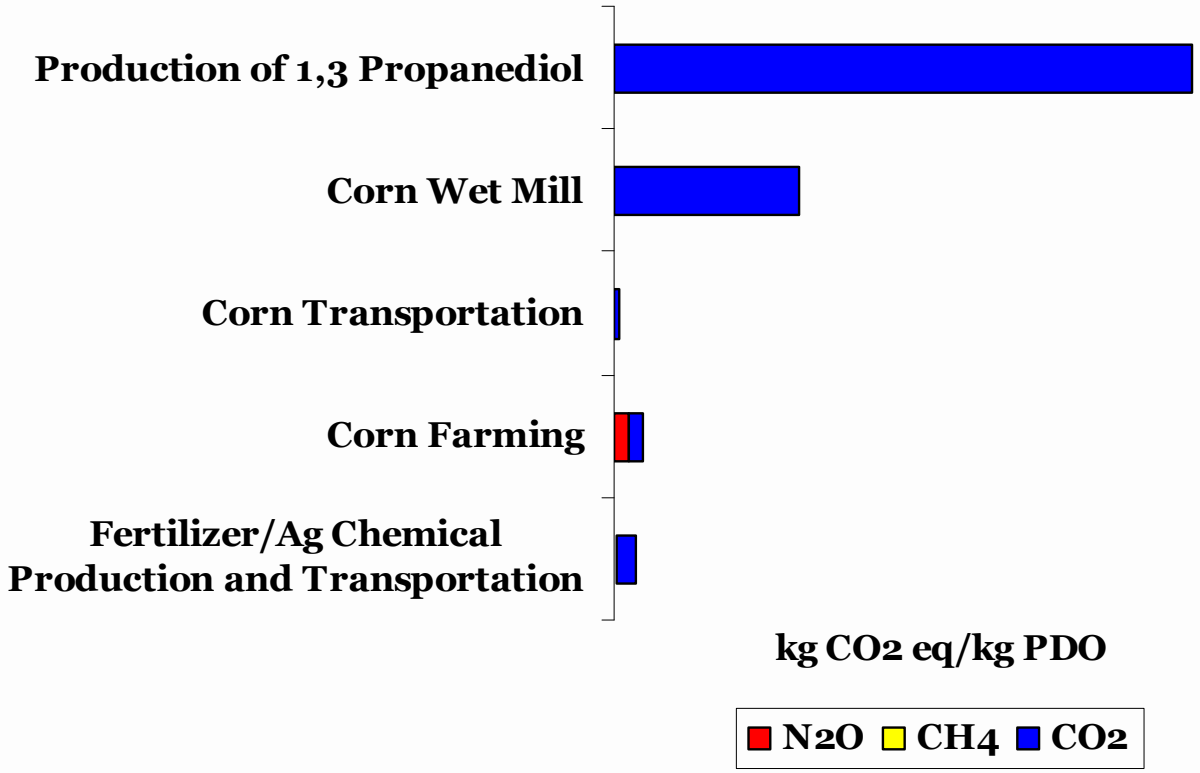
CBiRC
Center for Biorenewable Chemicals

Impact Assessment



CBiRC
Center for Biorenewable Chemicals

Typical Output: Climate Change Potential



Impact of climate change on agricultural productivity?

CBiRC
Center for Biorenewable Chemicals

Summary Results

	Plastic	Paper	Plastic	Paper	Plastic	Paper	Plastic	Paper
	luxury		ordinary 1		ordinary 2		small	
Non-renewable energy in MJ/bag	5,3	- 58 %	6,5	- 70 %	3,3	- 50 %	1,5	- 48 %
Consumption of water in l/bag	3,6	+ 66 %	1,1	+ 490 %	0,7	+ 759 %	0,3	+ 630 %
Greenhouse effect g CO_2 eq/bag	284	- 54 %	280	- 61 %	137	- 28 %	63	- 32 %
Acidification g H+ eq/bag	0,037	- 18 %	0,034	- 15 %	0,018	+ 39 %	0,009	+ 29 %
Photochemical oxidants g C_2H_4 eq/bag	0,23	- 28 %	0,25	- 39 %	0,17	- 26 %	0,07	- 9 %
Eutrophication g PO_4 eq/bag	0,062	+ 62 %	0,032	+ 174 %	0,008	+ 628 %	0,007	+ 485 %
Non-hazardous end waste kg/bag	0,092	- 50 %	0,097	- 60 %	0,050	- 31 %	0,022	- 38 %
Risk to the environment due to discarding	medium	low	medium	low	medium	low	medium	low

difference considered as not significant — result favourable to paper — result unfavourable to paper

CBiRC
Center for Biorenewable Chemicals

Attributional vs. Consequential LCA

- Recognizing that life cycles are industrial systems that are part of larger economic systems, has led to the use of LCA to search for the consequences of technology dissemination….
  - e.g., if you use corn to make fuel, the price of corn goes up, the price of pork goes up, and less pork is grown (everything else held constant).

CBiRC
Center for Biorenewable Chemicals

Attributional LCA

- Attributional methodology for life cycle inventory analysis (LCI) aims at describing environmentally relevant physical flows to and from a life cycle and its subsystems.
- Ideally, it should include **average data** on each unit process within the life cycle.
  - grid electricity is a average mix of coal, natural gas, hydro produced power ….
- The attributional LCI model does not include unit processes other than those of the life cycle investigated, although this is not necessarily good practice
- Most previous LCAs resemble attributional LCA.

CBiRC
Center for Biorenewable Chemicals

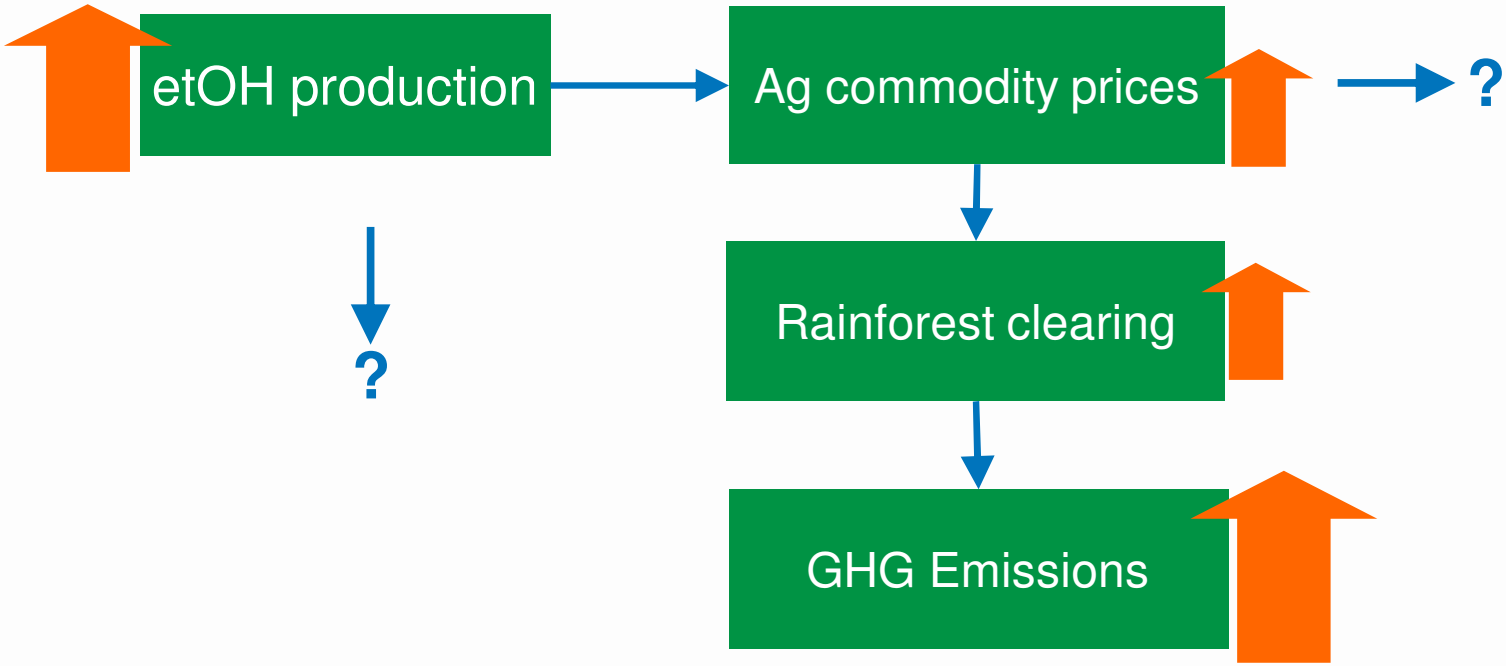
Consequential LCA

- Consequential LCI methodology aims at describing how the environmentally relevant physical flows to and from the technosphere will **change in response to possible changes made within the life cycle.** A consequential LCI model includes unit processes that are significantly affected irrespective of whether they are within or outside the life cycle.
- Ideally, it should include **marginal data** on bulk production processes in the background system.
- In a consequential LCI, **allocation is usually avoided by means of system expansion**.
- A consequential LCI model will often use economic partial equilibrium models and other tools designed to quantify specific causal relationships

CBiRC
Center for Biorenewable Chemicals

Example (but not a "good" example)

- **Searchinger et al. (2008)* - used results from a partial equilibrium economic model and lots of assumptions about land clearing and forest burning**



* "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases through emissions from Land Use Change" Science, February, 2008.

CBiRC
Center for Biorenewable Chemicals

Use Caution

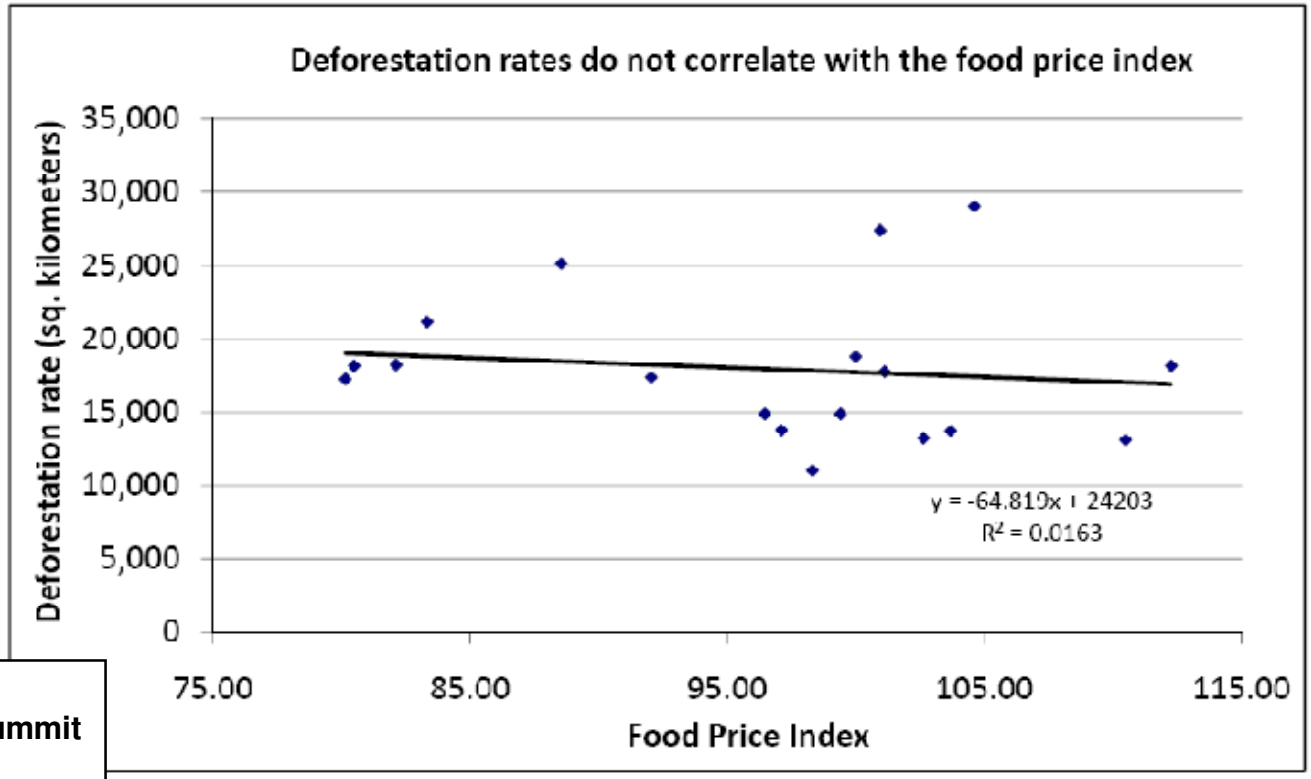
- **Single citation*: study not designed to identify causal factors of land clearing**
  - **focused on land classification after deforestation**
  - **focused on large-scale changes only**
  - **problem with "pasture" – adjusted data to fit conclusion**
- **Correlation does not mean causation**
- **Forest clearing driven by interactions among cultural, technological, biophysical, political, economic, and demographic forces**

* "Cropland expansion changes deforestation dynamics in the southern Brazilian Amazon" (D.Morton et al.) PNAS 2006.

CBiRC
Center for Biorenewable Chemicals

Use Caution

Lack of correlation doesn't prove lack of a positive causal relationship either

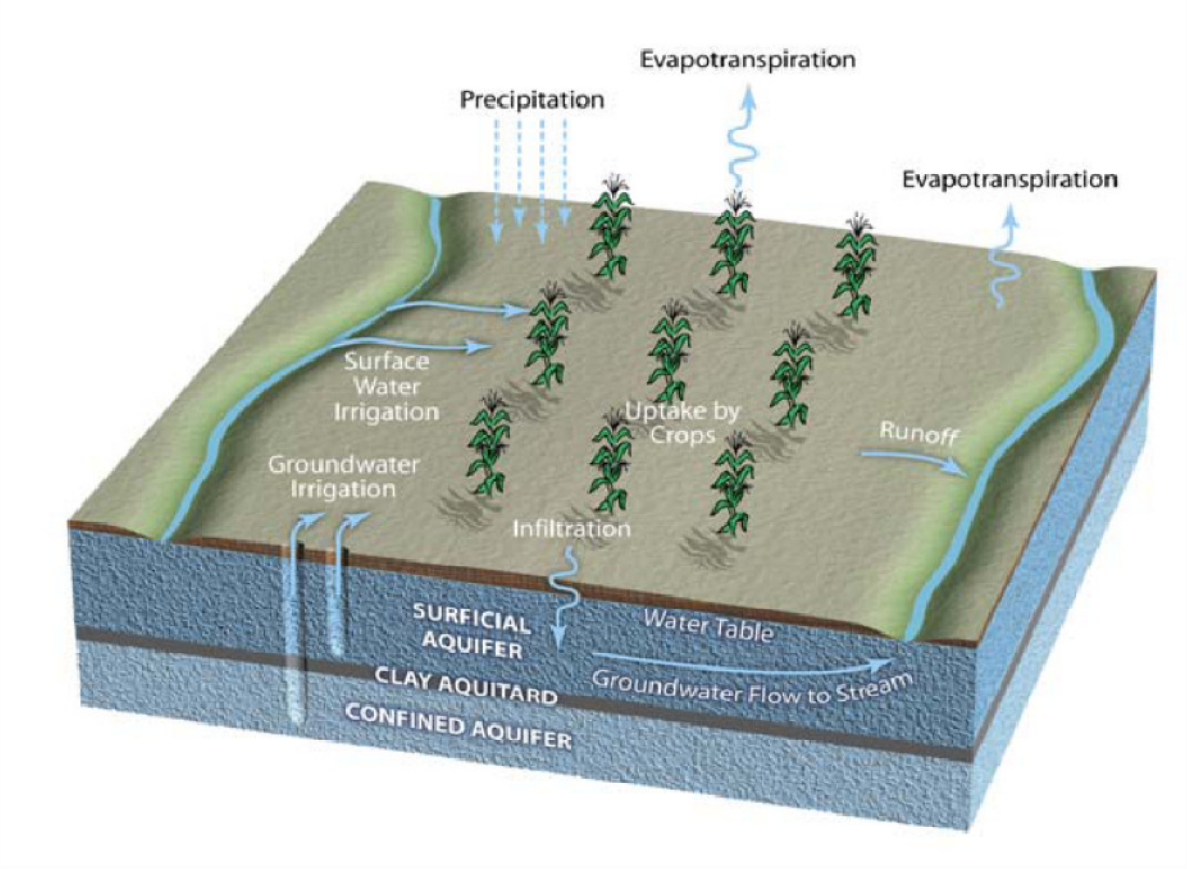


Source: Robert C. Brown
Iowa Renewable Fuels Summit
January 27, 2009

Sources: Deforestation data from FAO and INPE-Brazil; Commodity prices from Index Mundi.

CBiRC
Center for Biorenewable Chemicals

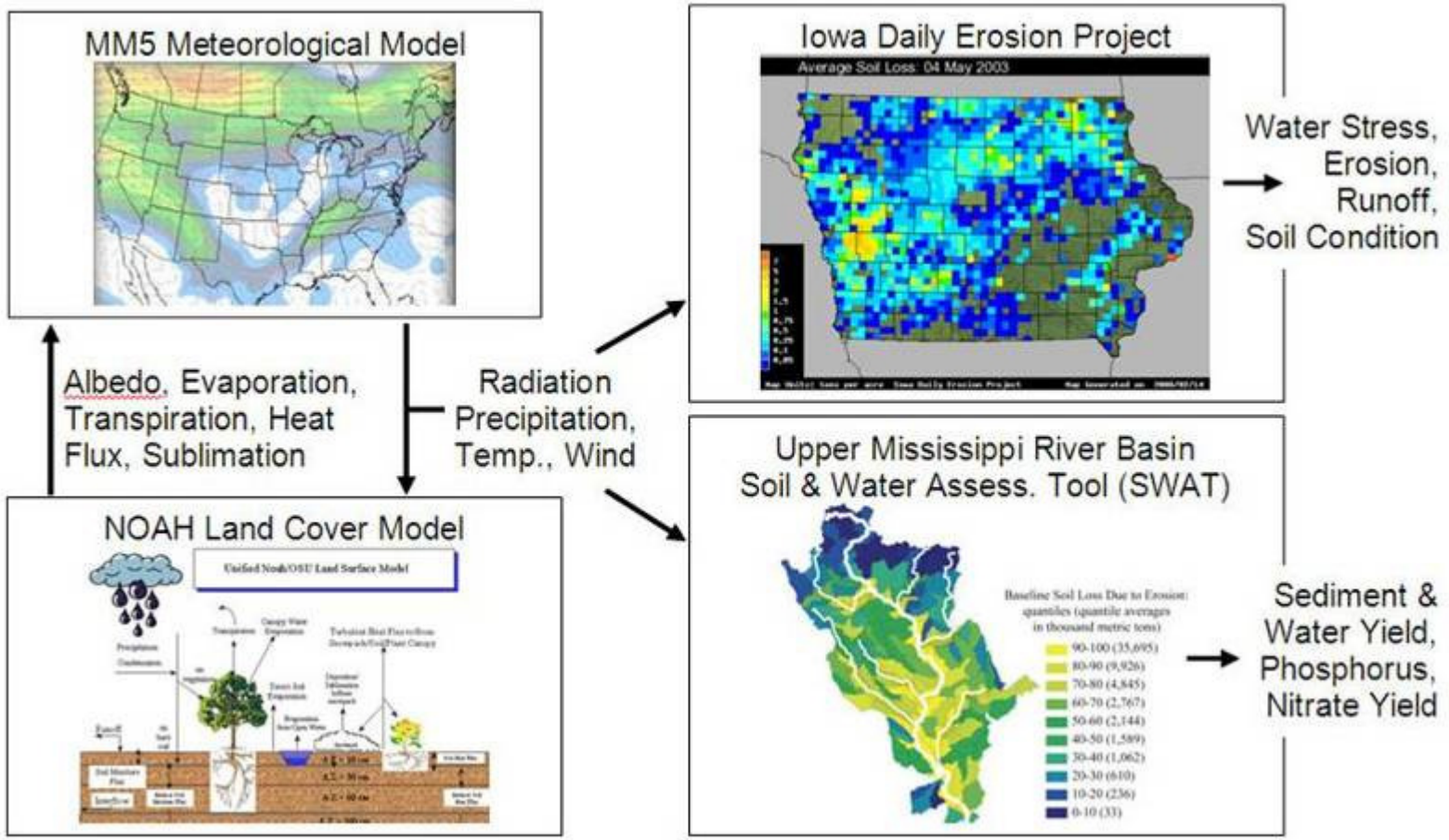
Other biofuel impact analyses



Biofuel feedstock impact on the Water Cycle

CBiRC
Center for Biorenewable Chemicals

Integrated Modeling: Biofuels and the Hydrologic Cycle



CBiRC
Center for Biorenewable Chemicals

Imperfect information is still valuable

"We are looking neither for universal agreement nor for perfect analysis that reflects the minute details of environmental processes, but for an improvement of the current decision-making process that often does not include environmental considerations."

- Hertwich, et al. 2003

CBiRC
Center for Biorenewable Chemicals

Questions?