Attributional vs. Consequential Lifecycle Analysis: Applications and Limitations

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CRC Workshop on Lifecycle Analysis of Biofuels
Argonne National Laboratory ▪ 18 October 2011

NATURAL RESOURCES AND ENVIRONMENT
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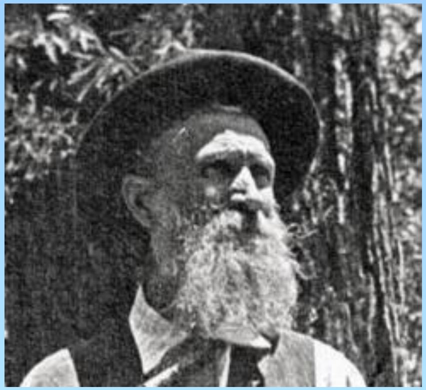
What are we trying to do?

- Three related tasks
  (in roughly historical order of pursuit):
  - Guide fuels technology R&D and investments
  - Understand the environmental impacts of different ***fuel product systems***
  - Regulate GHG emissions from fuels
- Lifecycle analysis (LCA) and related techniques have been used for all of these reasons
  - It use for earlier tasks seemed to lead naturally to its application for others
  - However, a given tool may not be right for all jobs
- Perhaps we should seek some guiding principles

Sources of guiding principles



John Muir
(1838 - 1914)

Alfred North
Whitehead
(1861 - 1947)

Reinhold Niebuhr
(1892 - 1971)

Ronald Reagan
(1911 - 2004)

How did we get here?

- Energy engineering systems analysis, representing process flows and efficiencies ("net energy," etc.)
- "Full fuel cycle" (FFC) analysis, as in late 1980s work by DeLuchi, Wang and others at UC Davis
  - Development of GREET and related tools, largely designed as attributional lifecycle analysis (ALCA) models
  - Similar to general environmental LCA tradition, as focused on various product systems and often addressing multiple impacts
- "Carbon footprint" entered the lexicon as a way to think about GHG emissions
- It seemed straightforward to adapt LCA concepts for policy when the time came
  (it also seemed analogous to fuels property standards)

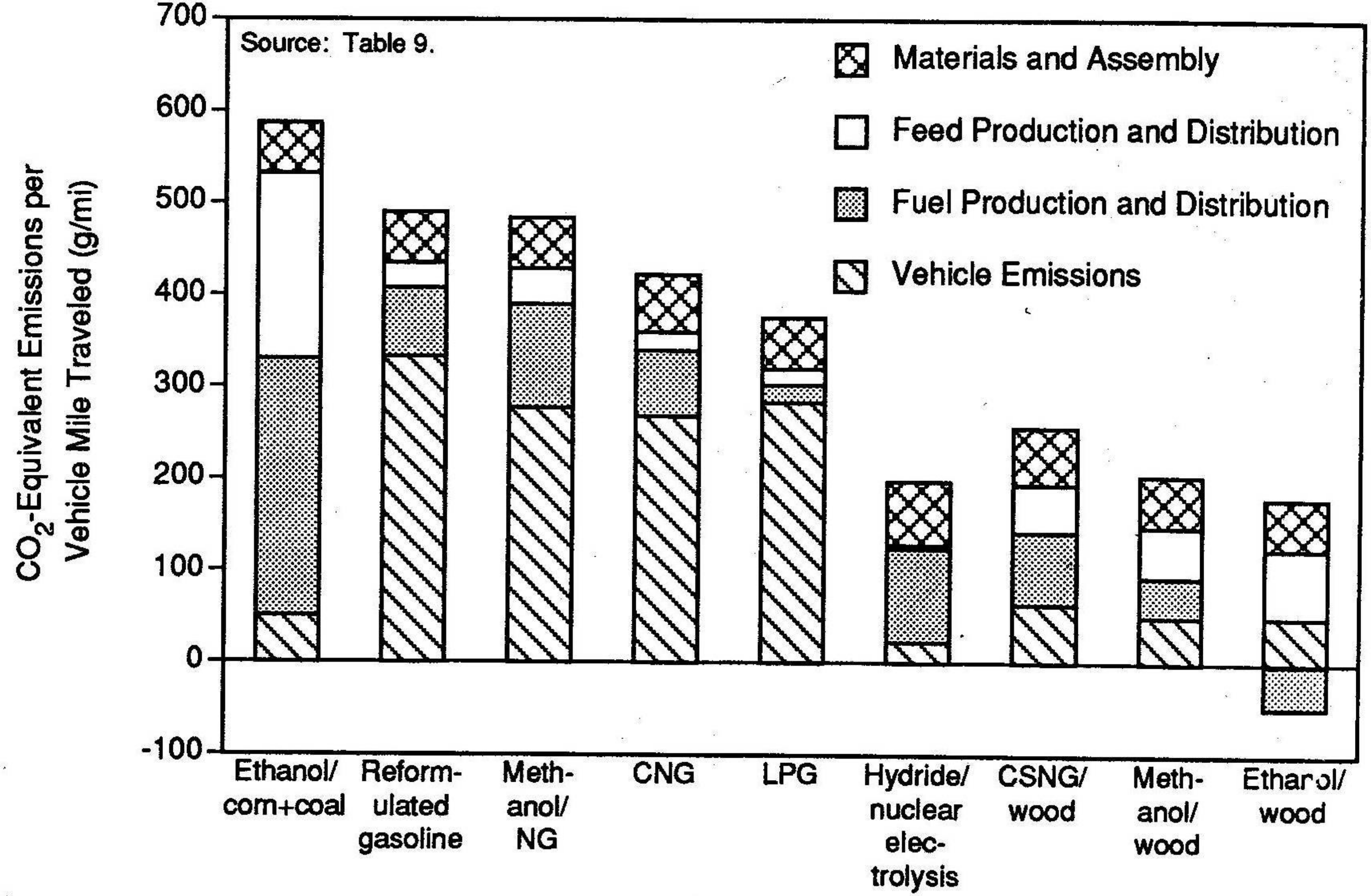


FIGURE 2 **Total Fuel-Cycle, CO_2-Equivalent Emissions for Light-Duty Vehicles**

Source: DeLuchi, M.A. 1991. Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity. Report ANL/ESD/TM-22. Argonne, IL: Argonne National Laboratory, Center for Transportation Research. November.

Early recommendations …

- Largely influenced by FFC modeling results, the "Car Talk" *Majority Report* (1995) recommended:
  "production incentives … in proportion to full-cycle greenhouse gas emissions based on a facility-by-facility audit"
- DeCicco & Lynd (1997) recommended:
  "Full fuel cycle (FFC) GHG standards or a FFC GHG cap for motor fuels"
- … had little direct connection
  to development of current policies, except that LCA thinking had now become commonplace

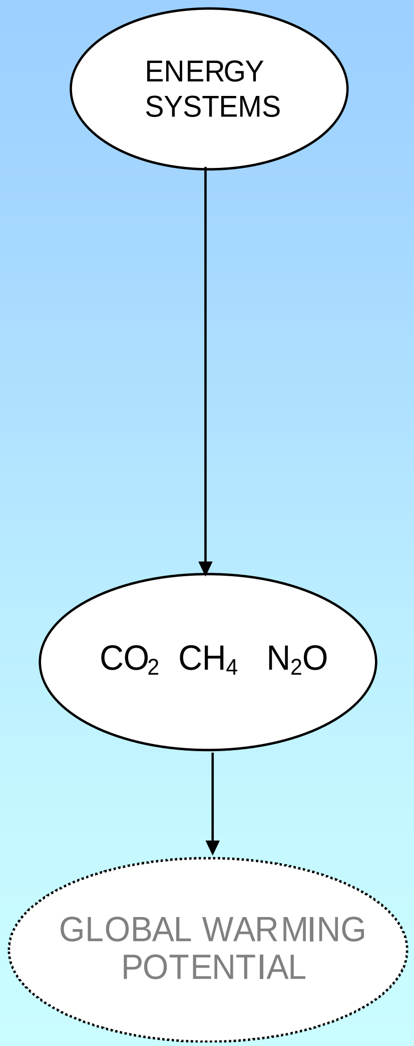
But, unprecedented in public policy

- From EPA RFS2 NPRM:

  "To EPA's knowledge, the GHG reduction thresholds presented in EISA are the first lifecycle GHG performance requirements included in federal law."

  Federal Register 74(99): 25021, May 26, 2009

Conventional LCA model



- Evaluates impacts of replacing one defined engineering system with another (e.g., oil-gasoline pathway vs. corn-ethanol pathway, each specified by engineering parameters)
- Scope is supply chain, e.g., as circumscribed by ISO convention
- Static material and energy flow relationships (perhaps calibrated using I/O tables, but otherwise not economically responsive)
- Climate impacts simply represented through emissions factors and GWPs.

(Diagram by Mark Delucchi)

Some key assumptions

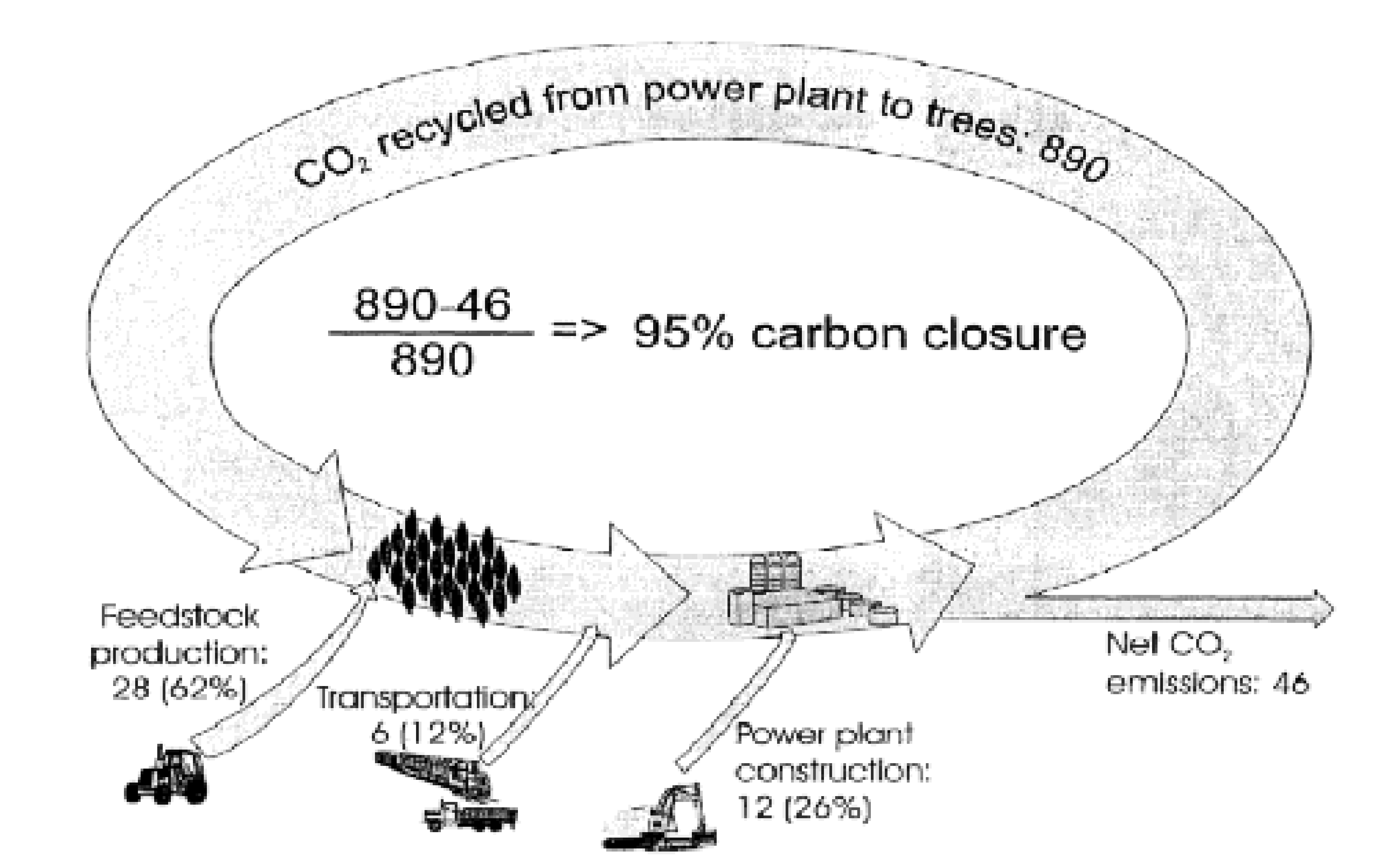
as used in conventional ALCA for fuels

- **Closed Fuel Cycles**
  "This analysis is 'closed.' In other words, the fuel cycles modeled … are, for the most part, complete (i.e., closed)." [p. 32]

- **Fate of All Carbon**
  "The model accounts for the fate of all carbon, in detail." [p. 37]

Source: DeLuchi (1991)

Lifecycle CO_2 flows in a bioenergy system



Basis of the "renewability short" (automatic crediting of biogenic CO_2)

Impacts of changing stocks and flows

- ALCA focuses only on flows
  - Emphasizes circular (recycling) flow of biomass carbon
  - But it takes land (a finite resource) to recycle carbon; ACLA does not fully treat terrestrial stock changes
- Actual climate impact (as driven by CO_2 buildup) depends on both stocks and flows
  - Issue is **net carbon balance** of biosphere/geosphere with respect to the atmosphere
  - Land use is mediated by markets and property "law"
    - Carbon stock effects may be negligible or large depending on feedstock and management practices
    - Highly aggregate estimation and modeling foster neither confidence nor sound management

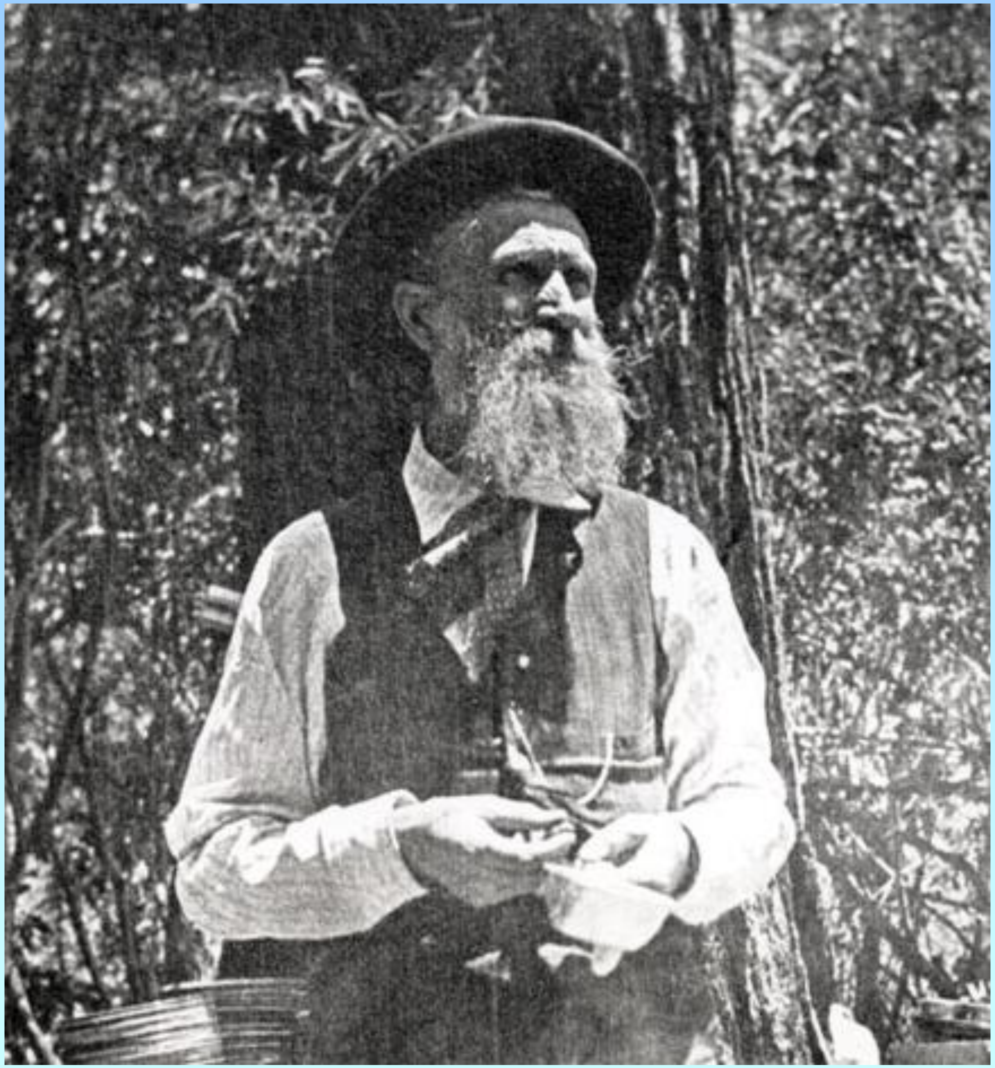
Consequential effects

- ALCA limitations for addressing carbon balance
  - economic (behavioral) effects enter the picture in addition to physical effects
  - lead to use of consequential LCA (CLCA)
  - note also that some "ALCA" treatments of co-products are based on economic relationships
- Many agricultural product market effects
  - Substitution effects
  - Livestock emissions effects
  - As well as other interlinked market effects, including in other sectors → ILUC
- Resulting effects on other environmental cycles
  - E.g., nitrogen, water (hydrology), albedo …

John Muir

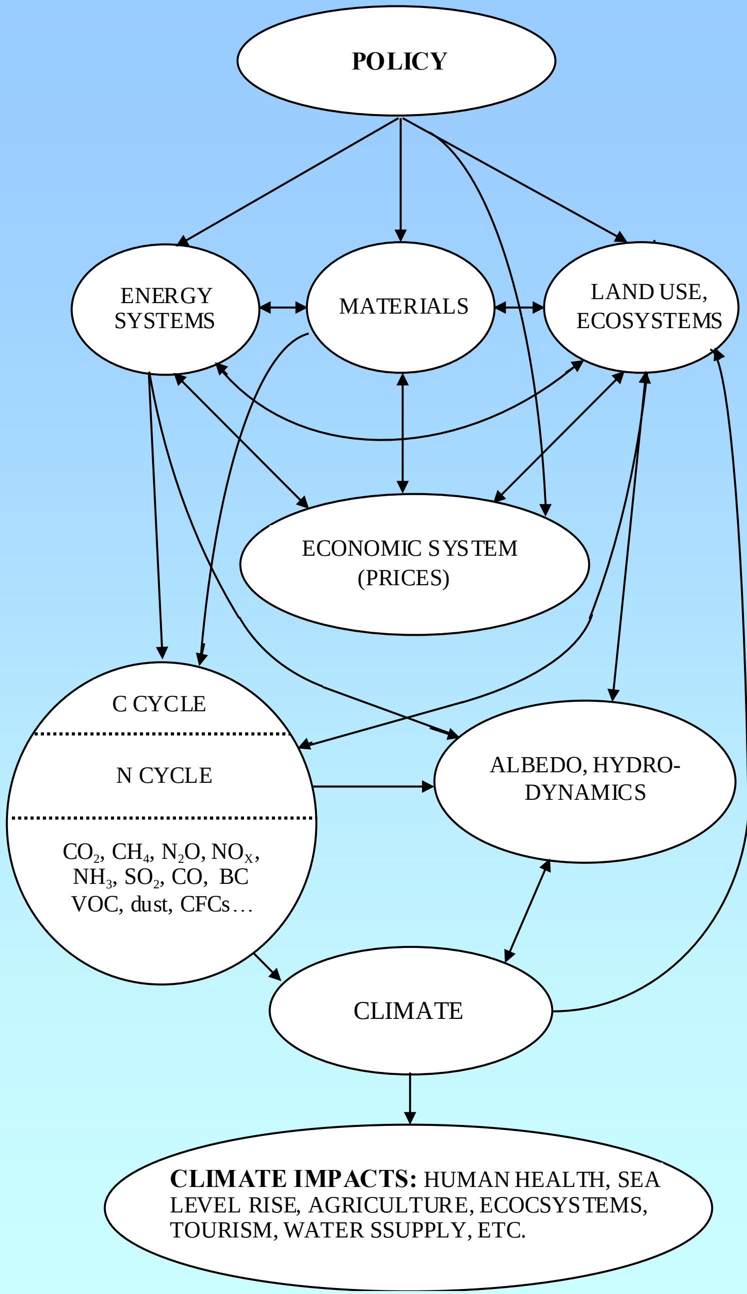
(1838 - 1914)

"When we try to pick out anything by itself, we find it hitched to everything else in the Universe."



Evolution of modeling

- Engineering process / energy analysis models
- "Classic" full fuel cycle analysis: basically a form of ALCA derived from process models
- Degrees of consequential analysis (CLCA)
  - Market and other "ripple" effects incorporated in a largely *ad hoc* manner based on judgments about the impacts deemed most important to consider
  - EISA requirement and CARB approach call for "LCA"
  - Many other considerations are arising, as analysts are pointing out (including full CLCA of fossil fuels)
- But where does this all lead, as more and more consequential impacts are deemed significant enough to affect compliance and CI values?



(Diagram by Mark Delucchi)

Ideal Model

- Policy effects modeled for all relevant systems (not just technology change)
- Scope covers all related production and consumption activities globally
- Economic relationships are explicitly represented, including those across sectors (price effects modeled)
- Emissions effects are modeled in context of major climate influences (C- and N- cycles, H_2O, albedo, etc.)
- Climate impacts represented in terms of their affects on human and global systems of concern

See Delucchi (2011), "Beyond LCA: Developing a Better Tool for Simulating Policy Impacts"

And what does this yield?

- ALCA $\rightarrow$ CLCA $\rightarrow$ IAM ("Integrated Assessment Model")
  - Full system behavioral representation
  - Both physical and economic relationships
  - Very broad spatial and temporal boundaries
- So, can IAM compute a CI (carbon intensity)?
- CI ("carbon footprint," e.g., gCO_2e/MJ) is
  - an emergent characteristic of a complex, dynamic system ($\therefore$ spatio-temporal boundary dependent)
  - yet only one dimension of policy concern
  - a fuel property -- NOT!
- Uncertainties go well beyond the scientific

Alfred North Whitehead

(1861 - 1947)

"… the intolerant use of abstractions is the major vice of the intellect."

Fallacy of misplaced concreteness:
"the error of mistaking the abstract for the concrete."

Reinhold Niebuhr

(1892 - 1971)

"God grant me the serenity to accept the things I cannot change; the courage to change the things I can; and the wisdom to know the difference."

Should we remind ourselves of why we are doing this?

- Climate concern is only one motive for biofuels
  - Rural economic development
  - Petroleum displacement for energy security
- Core climate problem
  - Excess anthropogenic CO_2 emissions
  - Now ~90% from fossil carbon, ~10% from deforestation

"It's the carbon, stupid!"

  - Yes, of course other gases and other effects should be considered when addressing this core concern

Facility-level carbon balances are in fact well defined

- ALCA can be verified empirically through facility (i.e., location) specific carbon balances
  - "Facility" as expansively defined, to include feedstock (farm, forest) sources as well as fuel refining
  - Basis of scientific management, similar to longstanding practice for other aspects of productivity
  - A key issue is burden of proof (automatic crediting): **Location of Emissions ≠ Location of (Net) Uptake**
- As for consequential effects:
  - All indirect land-use change is direct land-use change somewhere else
  - How do we handle (or, ideally, manage) that?

Ronald Reagan

(1911 - 2004)

"Trust, but verify."

Perhaps we need a two-track approach

LCA

Single tool for all jobs

Build (if not indeed rebuild) into better representations of complex dynamic systems

IAM

"CLCA+" to inform policy

Break down into facility-level and source-specific GHG measurement and management protocols

TBD*

Verifiable framework to specify policy

IAM = Integrated Assessment Model; **TBD** = to be determined

*see DeCicco (2011) "Biofuels and Carbon Management"

Conclusions

- Using LCA to evaluate fuels for purposes of GHG regulation leaves one between a rock and a hard place:
  - ALCA is too incomplete to give a sound answer
  - CLCA is overwhelmed by unresolvable uncertainties
- The "renewability shortcut" (automatic credit for biogenic CO_2) is an ALCA concept that is a root of major problems
- Consider objectives of different forms of policy and then select right tools for the job, which may not be the same:
  - ALCA -- with sufficient measurement-based verification -- can be adapted to audit GHG impacts in feedstock and fuel supply chains
  - CLCA is not useful for regulation because functionally indeterminate
  - *Reconstruct* LCA into Integrated Assessment Models to *inform* policy
  - *Deconstruct* LCA into verifiable mechanisms to *specify* policy
- The LCA (and LCA+) community has its work cut out for itself, but let's not turn modeling hubris into a regulatory headache!

Thank you!

- For further information, contact:

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