Energy Tutorial:
Energy & Earth Systems 101

GCEP RESEARCH SYMPOSIUM 2012 | STANFORD, CA

Pamela Matson

Dean - School of Earth Sciences
Senior Fellow - Woods Institute for Environment

Ian Monroe

Visiting scholar
Stanford University

GLOBAL CHALLENGES – GLOBAL SOLUTIONS – GLOBAL OPPORTUNITIES

Today's workshop….

- Because energy is strongly connected to many other human needs and to our life support systems, making good energy choices (with more co-benefits and fewer unintended consequences) is key to a transition to sustainability

- What knowledge, tools and approaches are available to help, and what more is needed?

- Several detailed examples…

***Sustainability: the most critical challenge of the 21st Century*:**

Meeting the needs of people today and in the future

Sustaining the life support systems of the planet

NRC. 1999. Our Common Journey

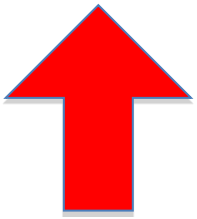
Social needs are not being met

1 – 2 billion persons are…

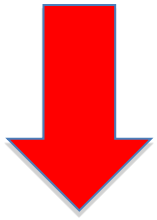
- illiterate adults
- without adequate shelter
- without access to safe water or sanitation
- without access to electricity
- undernourished

Life support systems are degraded

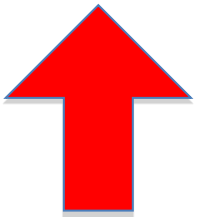
- Air Pollution and Climate change
- Acidification of the oceans
- ~50% land surface has been converted
- Biodiversity loss 100+ times faster
- 60% of ecosystem services in decline
- Water and soil resources limitations
- Nitrogen over-enrichment
- Mineral resource limitations



Meeting the needs of people



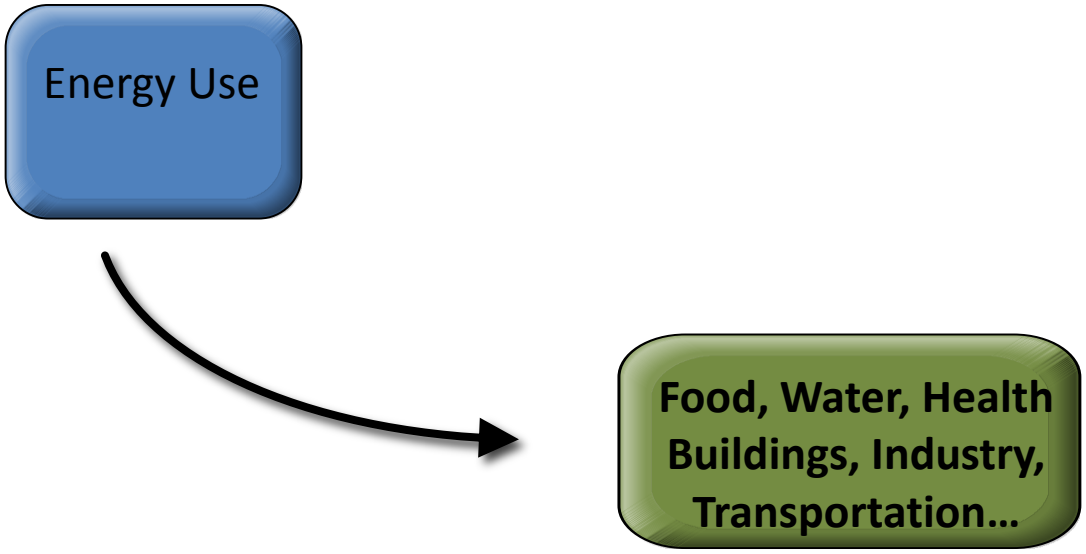
Sustaining atmosphere, water, climate and ecosystems

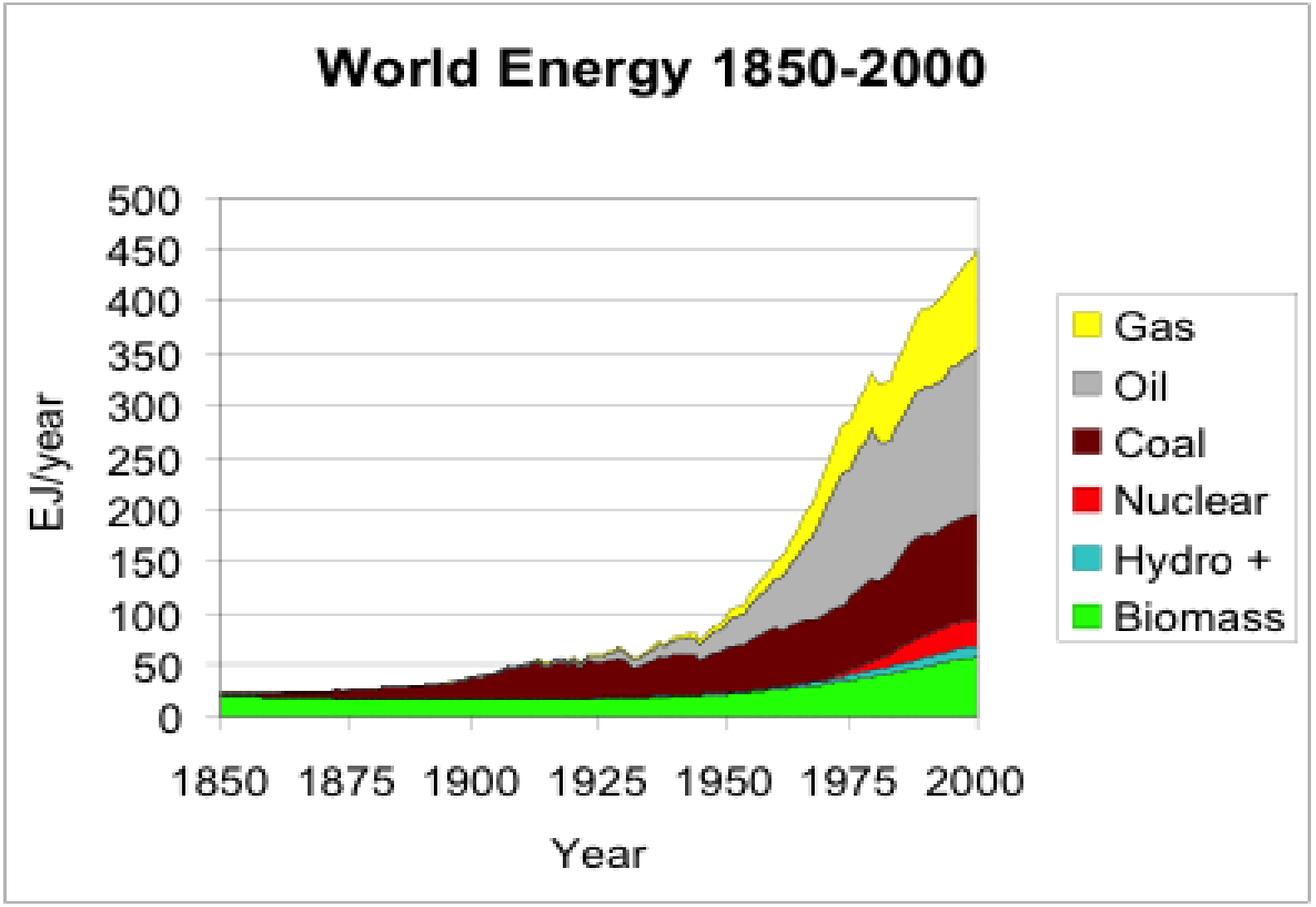


Meeting the needs of people

Sustaining atmosphere, water, climate and ecosystems

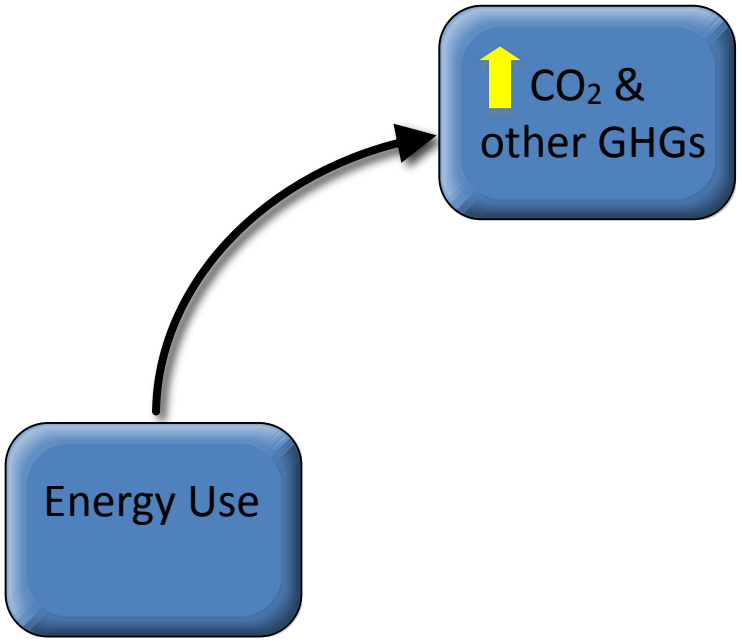
Energy is key to just about everything we do, and provision of energy is a *sustainability* challenge



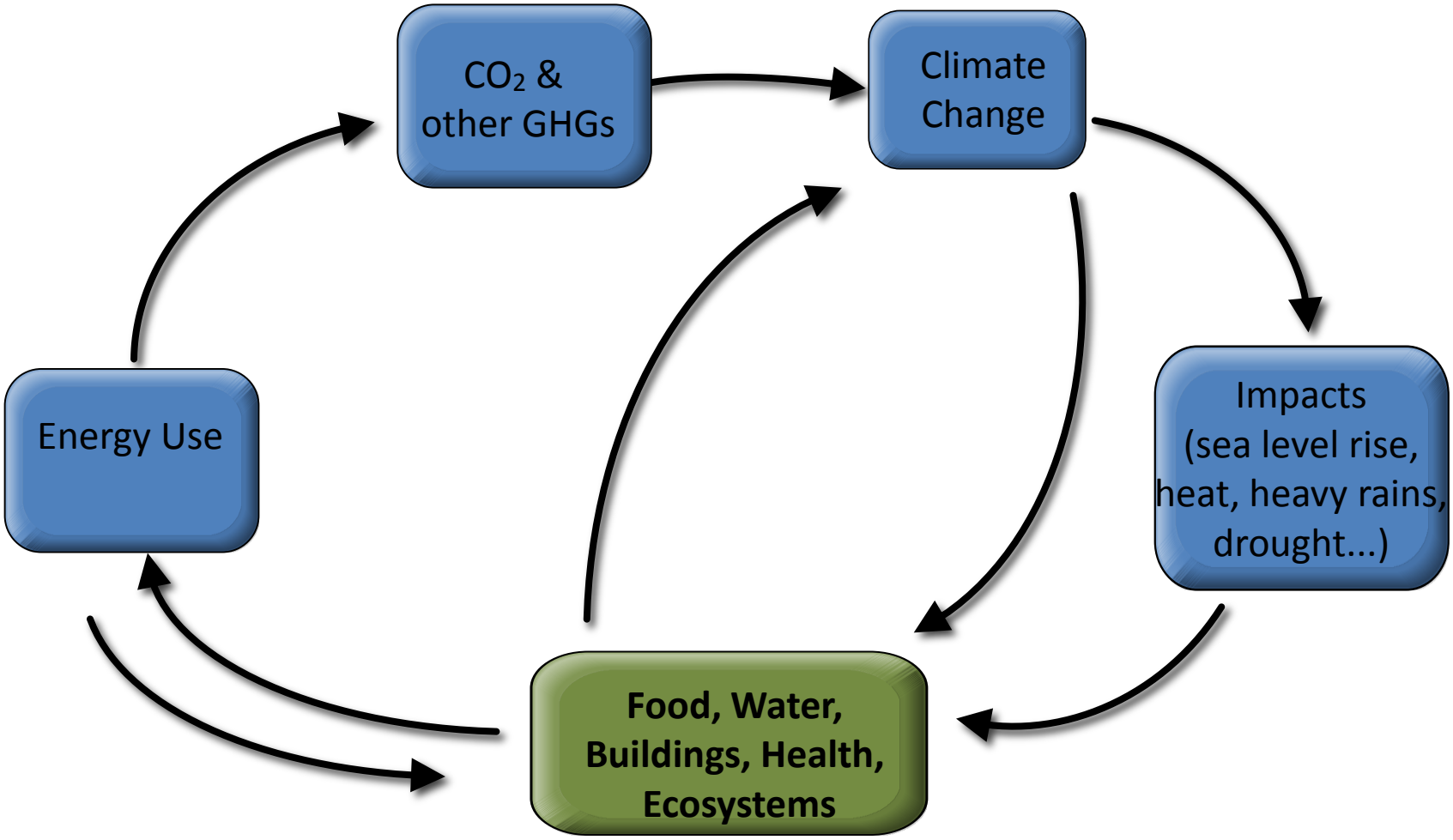

World Energy 1850-2000
500
450
400
350
300
250
200
150
100
50
0
EJ/year
1850
1875
1900
1925
1950
1975
2000
Year
Gas
Oil
Coal
Nuclear
Hydro +
Biomass

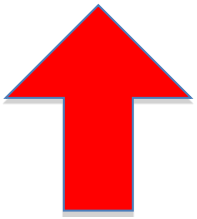
But energy use has a cascade of unintended consequences:

A major source of air, water, soil and ocean pollution, and of greenhouse gases

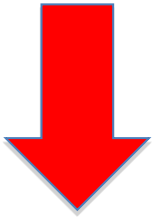


The energy-climate-food-water nexus is a *sustainability* challenge

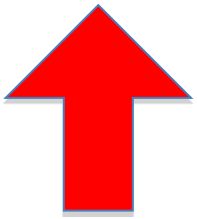




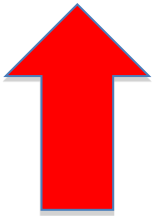
Meeting the needs of people for energy



Sustaining atmosphere, food, water, climate and ecosystems



Meeting the needs of people for energy



Sustaining atmosphere, food, water, climate and ecosystems

A *Transition* to Sustainability?

What will it take?

What will it take for a transition to sustainability?

- new knowledge, tools and approaches
- linking knowledge to action
- educating leaders and the public
- hope, inspiration, and motivation
- the will to change
-leadership by corporations, citizens, governments, non-profits, universities
- *and a stable human population….*

What will it take for a transition to sustainability?

- new knowledge, tools and approaches
- linking knowledge to action
- educating leaders and the public
- hope, inspiration, and motivation
- the will to change
-leadership by corporations, citizens, governments, non-profits, universities
- *and a stable human population…*

Development of new energy technologies

Solar
Wind
Water
Ocean sources
Nuclear
Geothermal
Biofuels

Fuel switching (to natural gas)
Carbon capture and storage
Energy storage

Need to understand tradeoffs and co-benefits…

Solar
Wind
Water
Ocean sources
Nuclear
Geothermal
Biofuels
…..

Technology

Implementation Barriers

Unintended consequences
for Biodiversity
Ecosystem services
Water resources
Atmosphere
Climate

Trade and security

Health and Equity

How do we make choices that reduce unintended consequences?

What tools and approaches do we have to evaluate the trade-offs and co-benefits among different options and across different areas of concern?

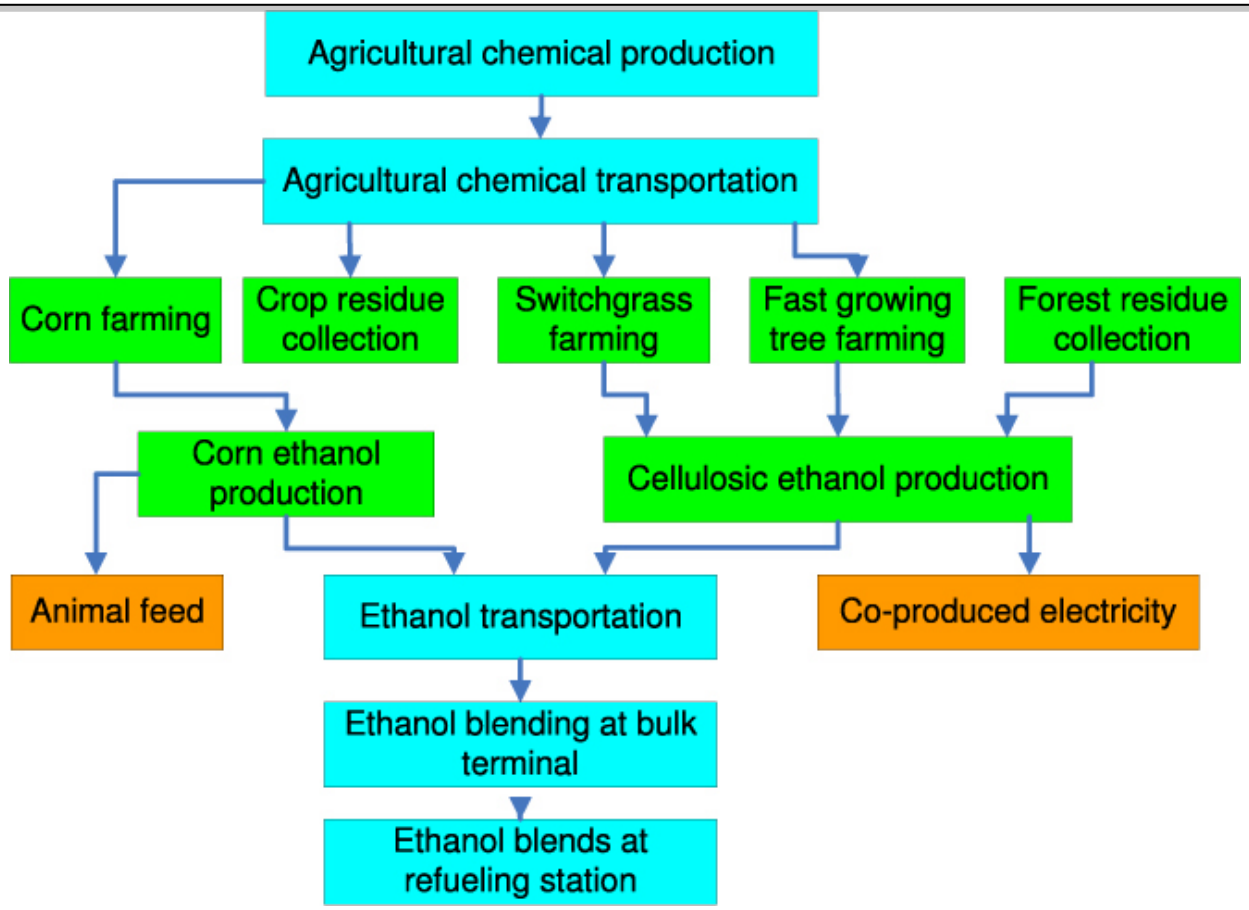
Tools and Approaches for Measuring and Evaluating Tradeoffs, Co-Benefits, and Unintended Consequences

- Life Cycle Assessment Models
- Econometric Models
- Ecosystem Process Models
- Ecosystems Services Models
- Vulnerability Analyses
- Integrated Assessment Models
- Multi-criteria spatial analysis, including ground-based measurements and remotely sensed data
- Metrics and Indicator Systems
- Certification systems
- Stakeholder engagement and decision support systems

Life Cycle Assessment: a tool to assess the resource and environmental impacts throughout a product's lifetime

basic "attributional" Life Cycle Assessment (LCA) of biofuels – to understand the energy yield and GHG emissions of energy choices

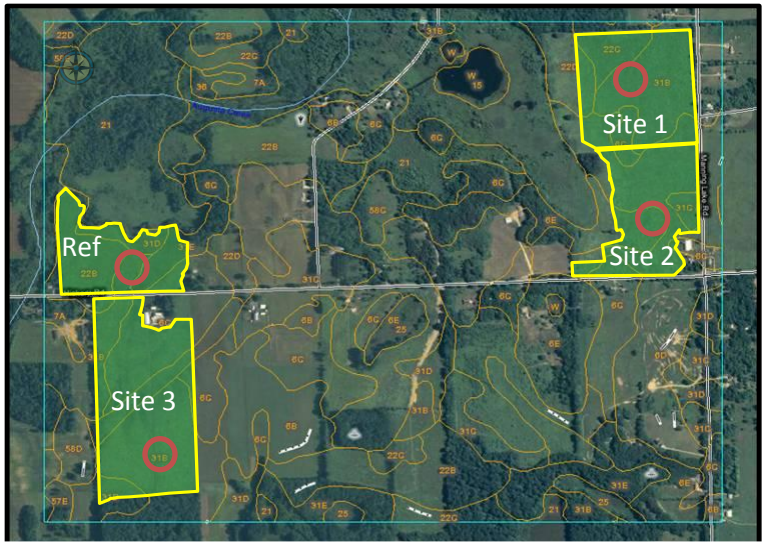
Biofuels Life Cycle Assessment

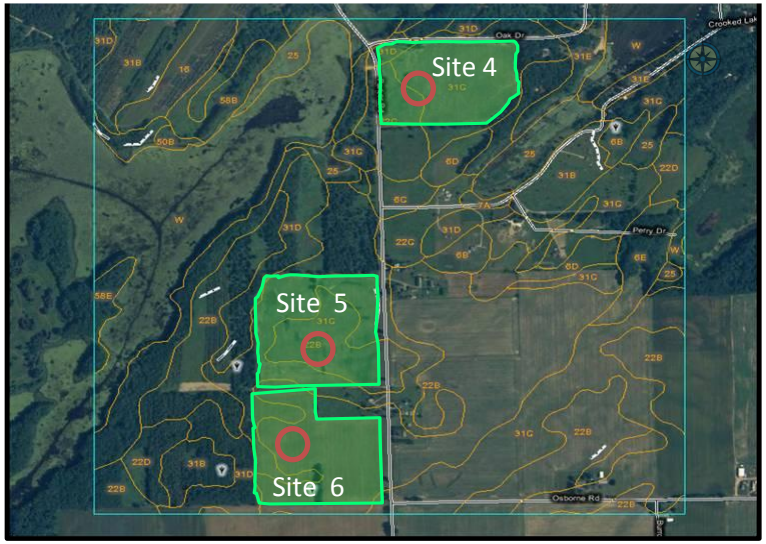


LCA shows that crops, yields, fuel production processes, vehicles all matter…

Wang et al 2007: DOE GREET model

Measurements for in-field GHG LCA:



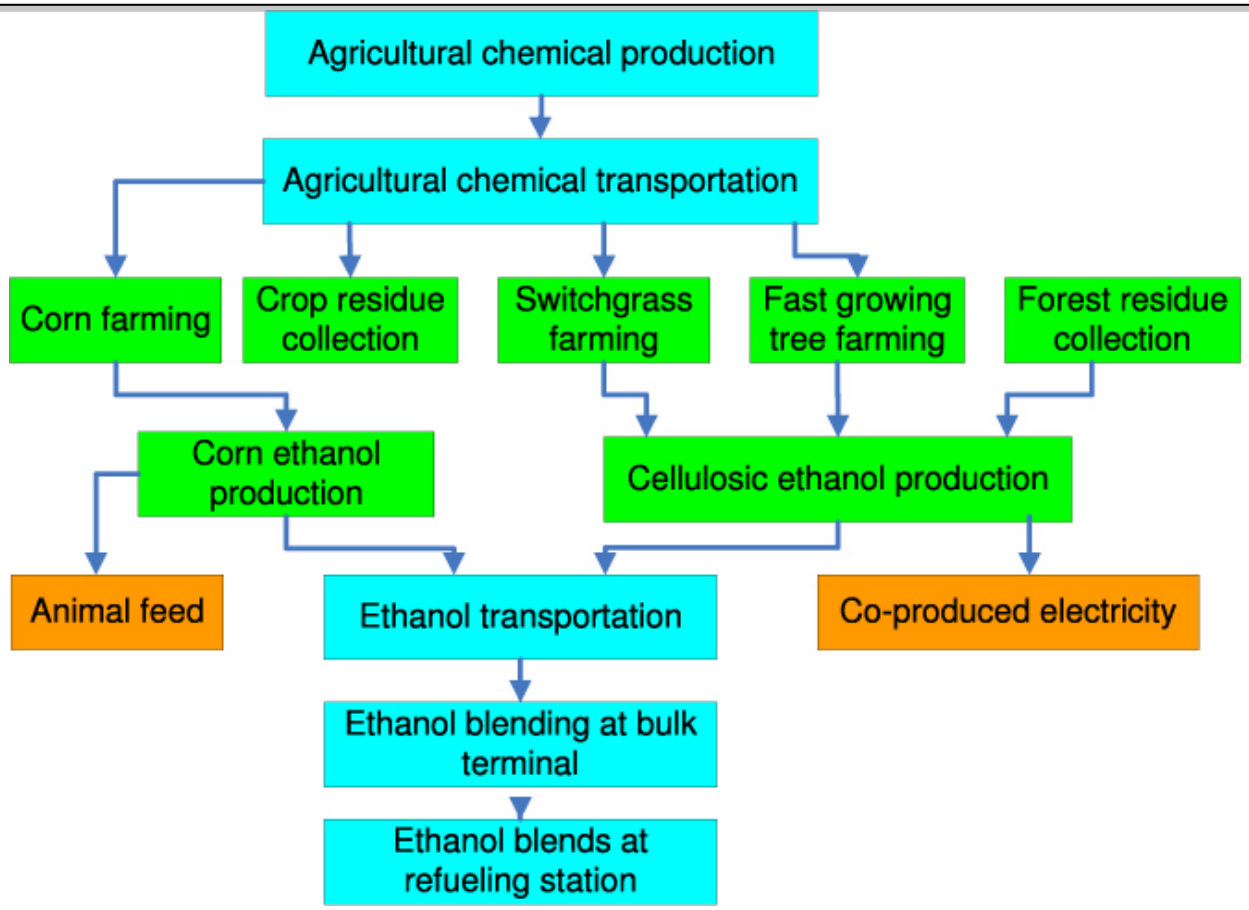


ecosystem C change with CO_2 eddy covariance

chamber based fluxes of other GHG

- ***Gelfand, Robertson, et al. in review***

Biofuels Life Cycle Assessment



LCA shows that crops, yields, fuel production processes, vehicles all matter…

Wang et al 2007: DOE GREET model

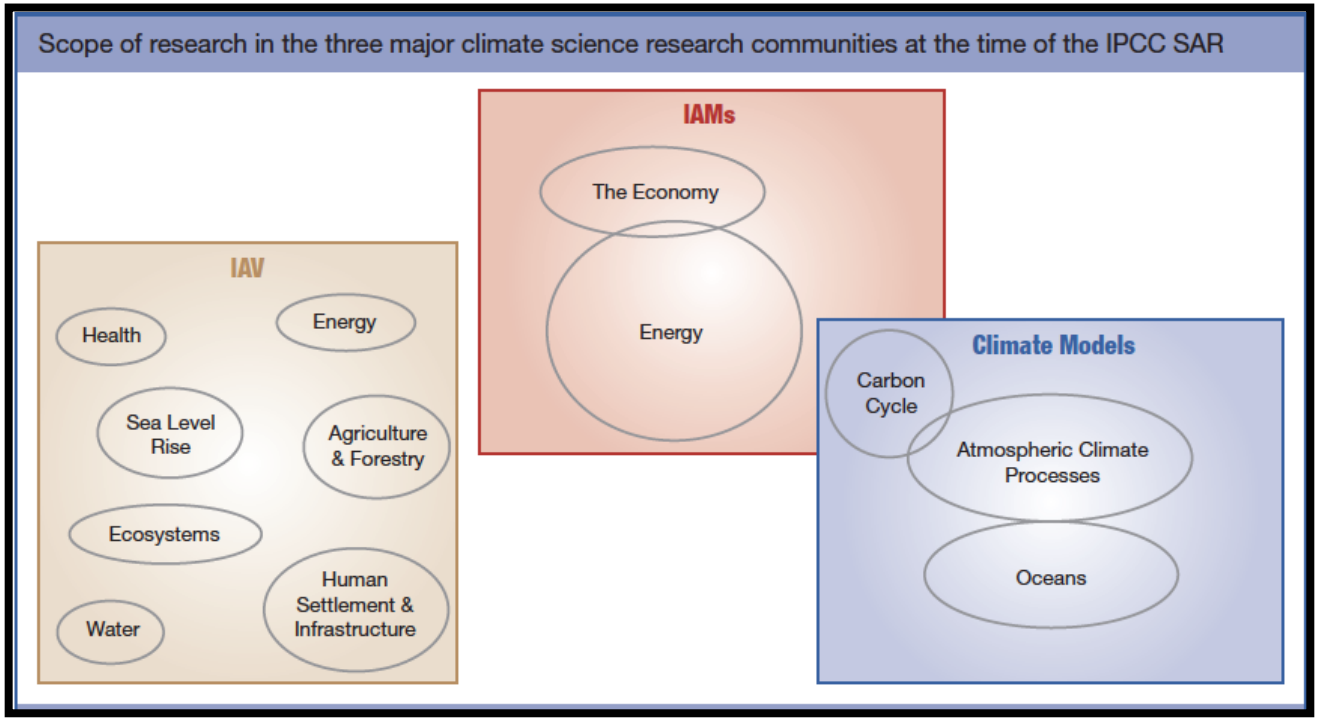
direct effects are included in LCA, but what about indirect effects?

If land that was previously used for food production is used for biofuel production, other lands may be converted to agriculture to meet food demands – and that leads to GHG emissions (and higher food prices)

Everyone agrees this happens, but how important it is is questioned – scenarios, assumptions, models and methods are all debated

“Consequential” LCA

Integrated Assessment Models
Global Change Research Communities



Economy, Energy and Climate

IGSM	MESSAGE
MiniCAM	MERGE
IMAGE	and others

Janetos et al 2009

But what about sustainability concerns that go beyond greenhouse gas emissions and energy yield?

Freshwater
Food
Pollution
Health
Biodiversity
Other ecosystem services
Equity
…

Freshwater Accounting Approaches

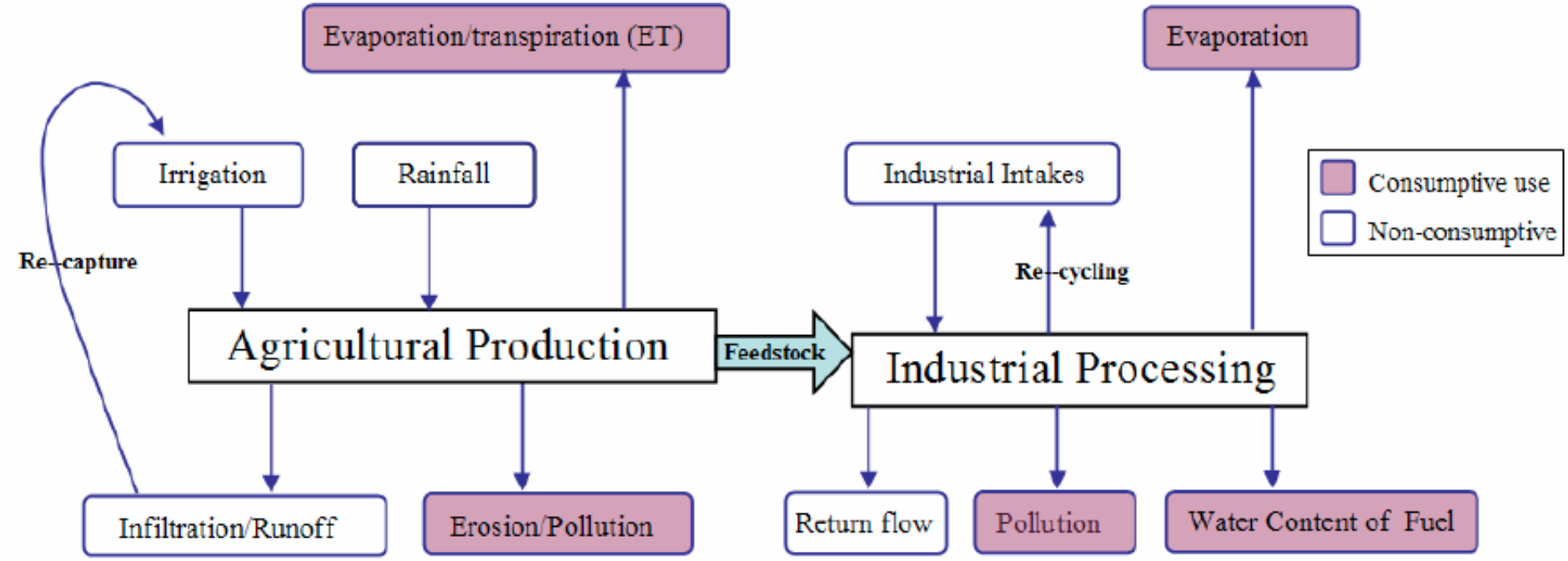


Figure 5: Schematic of water uses in biofuel production

Fingerman et al 2008

(Must be considered in context of overall resource at appropriate scales)

Freshwater
Food
Pollution
Health
Biodiversity
Other ecosystem services
Equity
…

Food vs. Fuel

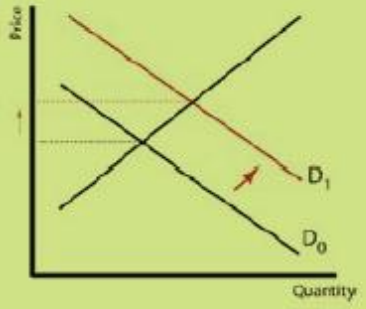
direct & indirect impacts

More demand for crop land for biofuels should lead to higher agricultural product prices (general equilibrium models agree…)

Naylor et al 2007

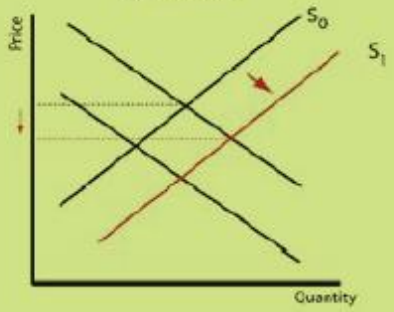
Dynamics of a biofuels-induced increase in demand for maize, wheat, and soybeans in the United States

(1) Maize



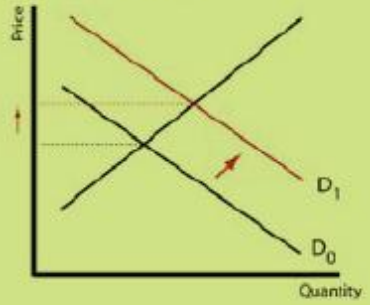
Rising demand for maize leads to growth in supply along the curve that includes production a higher marginal costs.

(2) Maize



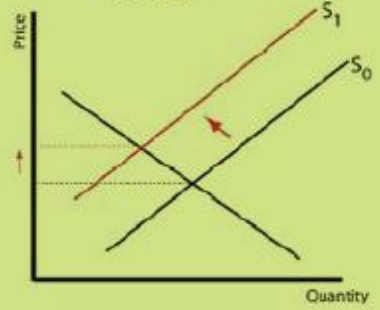
Longer-run shift in supply due to technical change induced by higher prices.

(3) Wheat



Higher maize prices increase demand for wheat in livestock markets, causing wheat prices to rise.

(4) Soy



Greater area sown to maize reduces area planted to soy, causing soy prices to rise.

Freshwater
Food
Pollution
Health
Biodiversity
Other ecosystem services
Equity
…

Assessments can include
indicators
of a range of
social and environmental impacts
along with
assessments of
energy yield and greenhouse gases
emissions…

Environmental Assessment of Biofuels (comparison of unblended biofuel technologies)

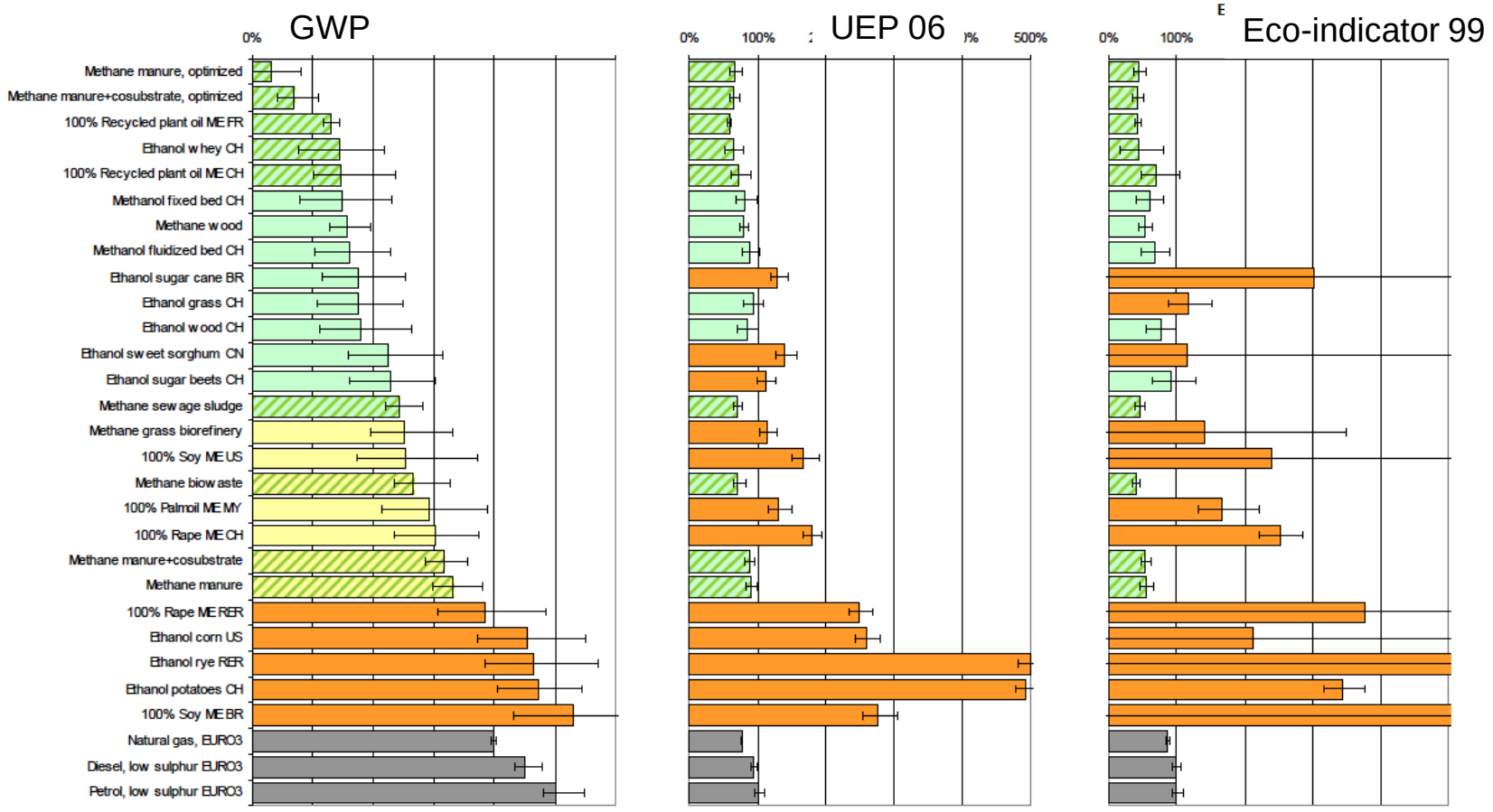


Figure 5 **Overall environmental Life Cycle Assessment of all unblended biofuels studied in comparison to fossil reference. GHG emissions reductions of more than 30% are yellow, GHG emissions reductions of less than 30% are red. In other diagrams green = better than reference; red = worse than reference. Cross-hatched fields = production paths from waste materials or residue. Error bar = 2.5 % / 97.5 % percentiles calculated using Monte Carlo simulation.**

Zah et al 2007

Comparison of unblended biofuel technologies

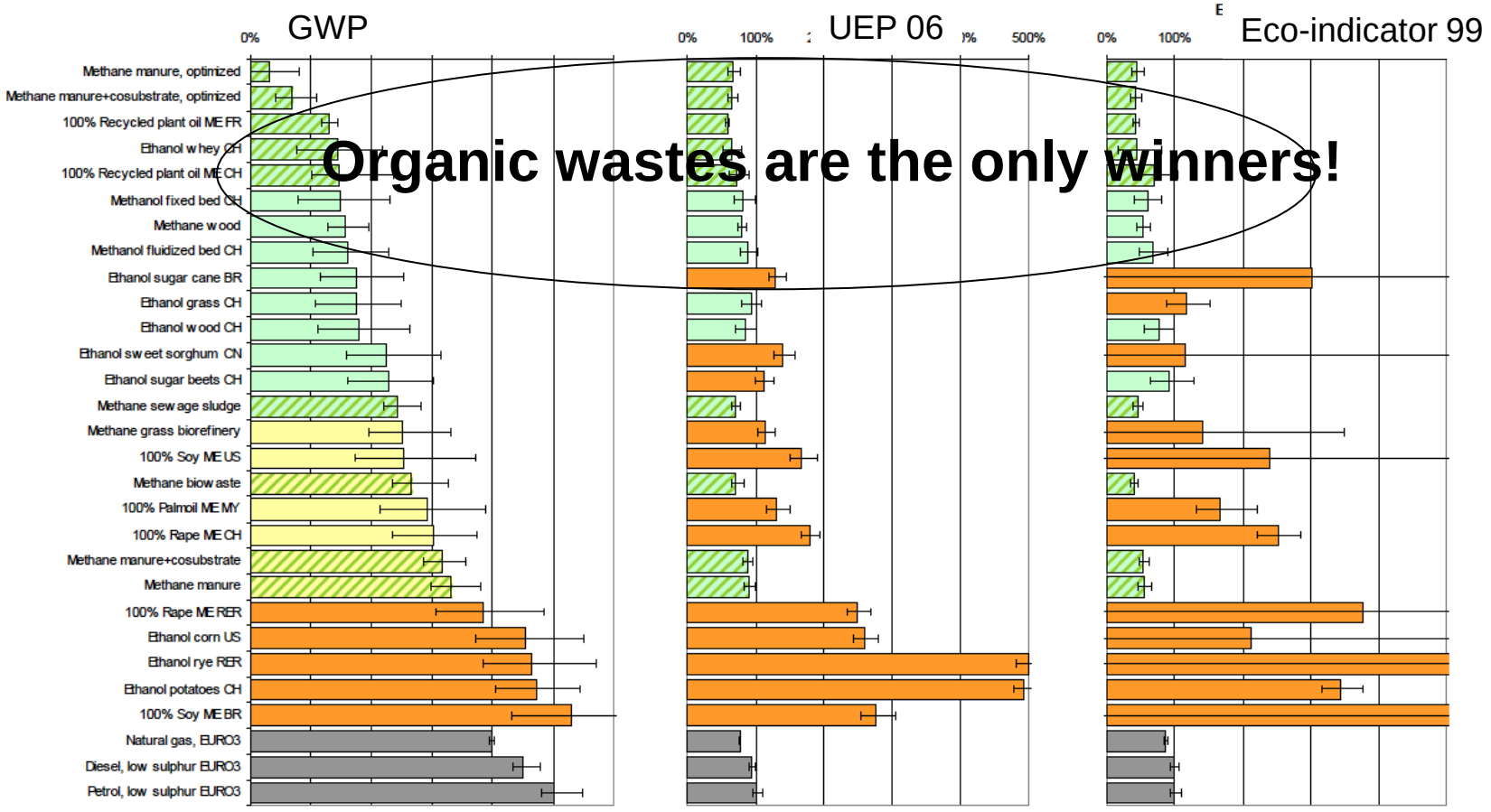
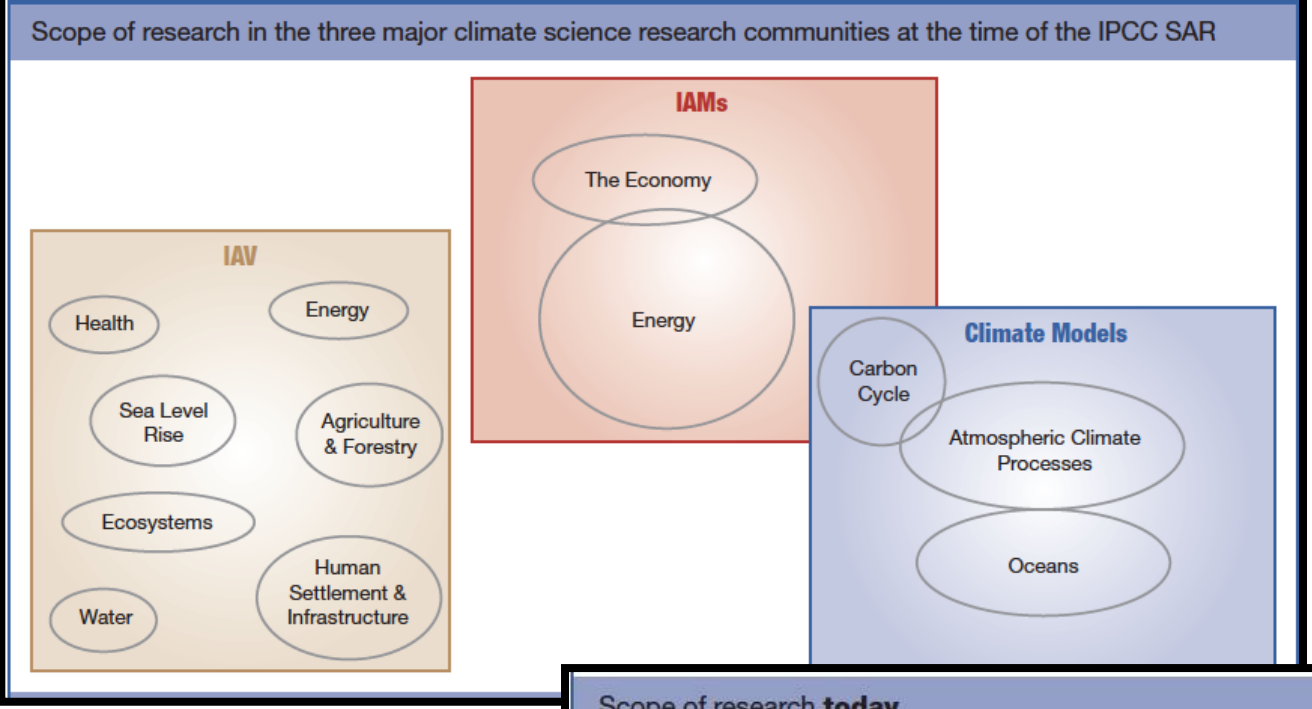
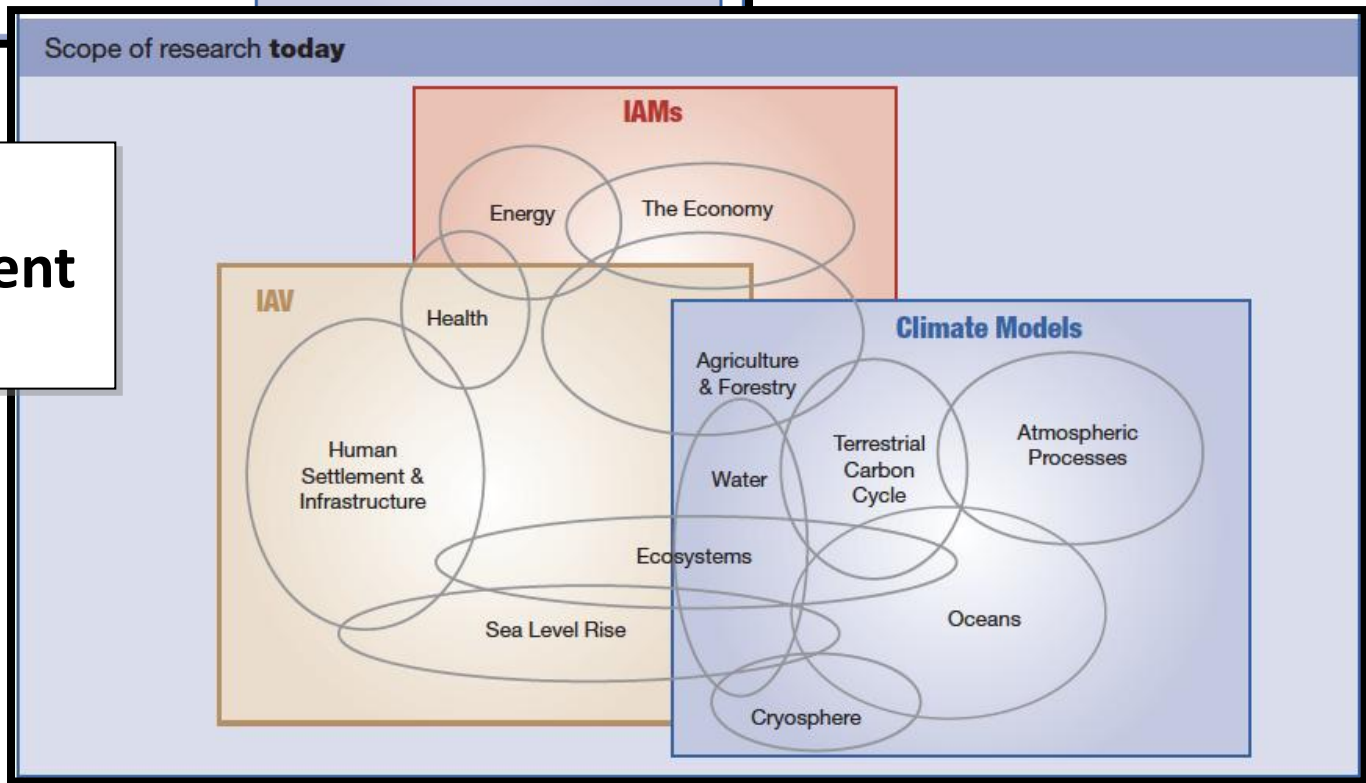


Figure 5 Overall environmental Life Cycle Assessment of all unblended biofuels studied in comparison to fossil reference. GHG emissions reductions of more than 30% are yellow, GHG emissions reductions of less than 30% are red. In other diagrams green = better than reference; red = worse than reference. Cross-hatched fields = production paths from waste materials or residue. Error bar = 2.5 % / 97.5 % percentiles calculated using Monte Carlo simulation.

Zah et al 2007





More integrated integrated assessment models

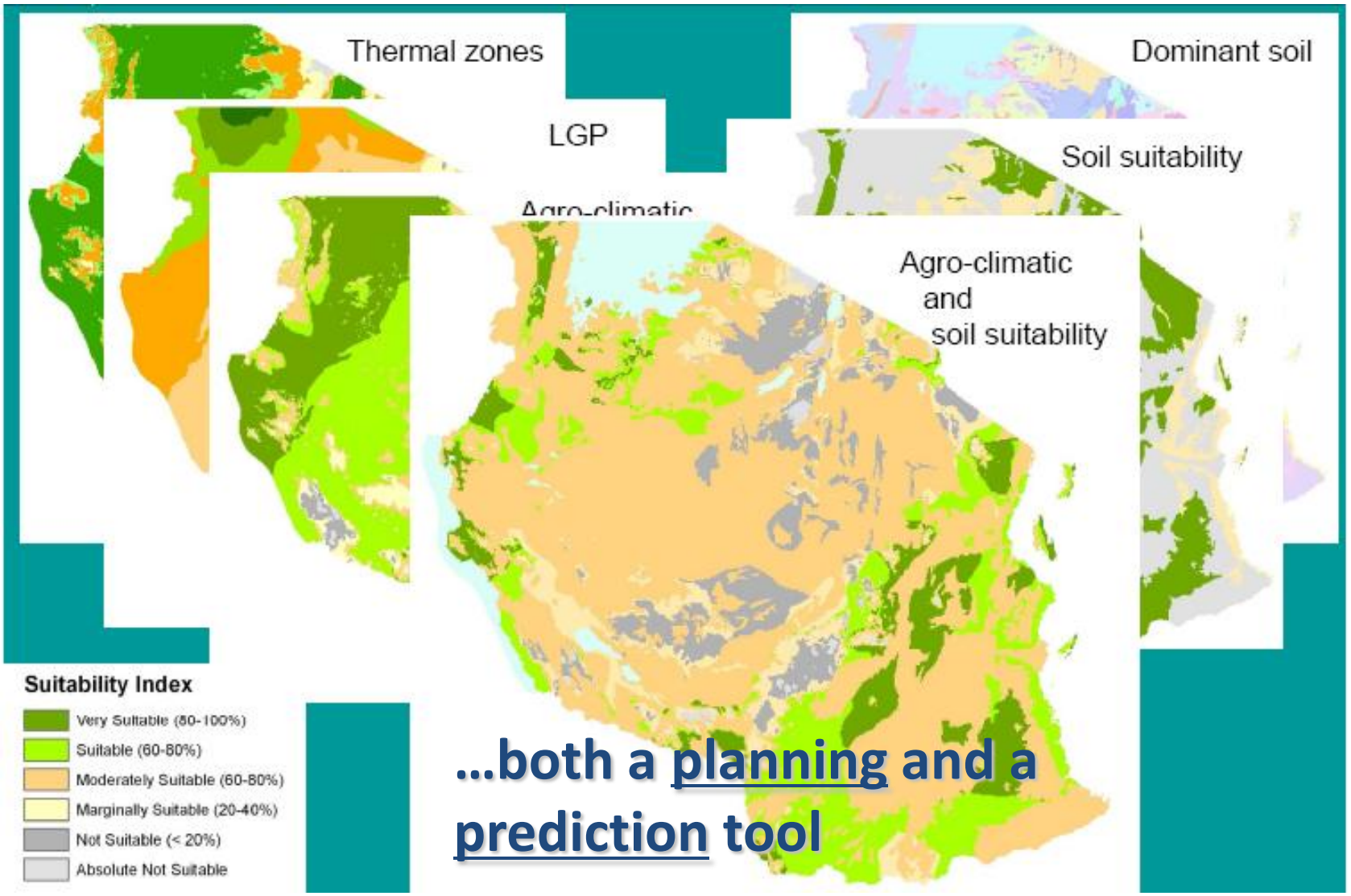
Janetos et al 2009

Multi-criteria analysis
Getting Ahead of the Game

Identifying sites for renewable energy that minimize negative, unintended consequences

Maximizing Food, Fuel, Biodiversity and other Ecosystem Values

Simultaneously evaluating multiple variables in GIS



…both a planning and a prediction tool

Schram [FAO Tanzania] (2008) "The Bioenergy and Food Security Project"

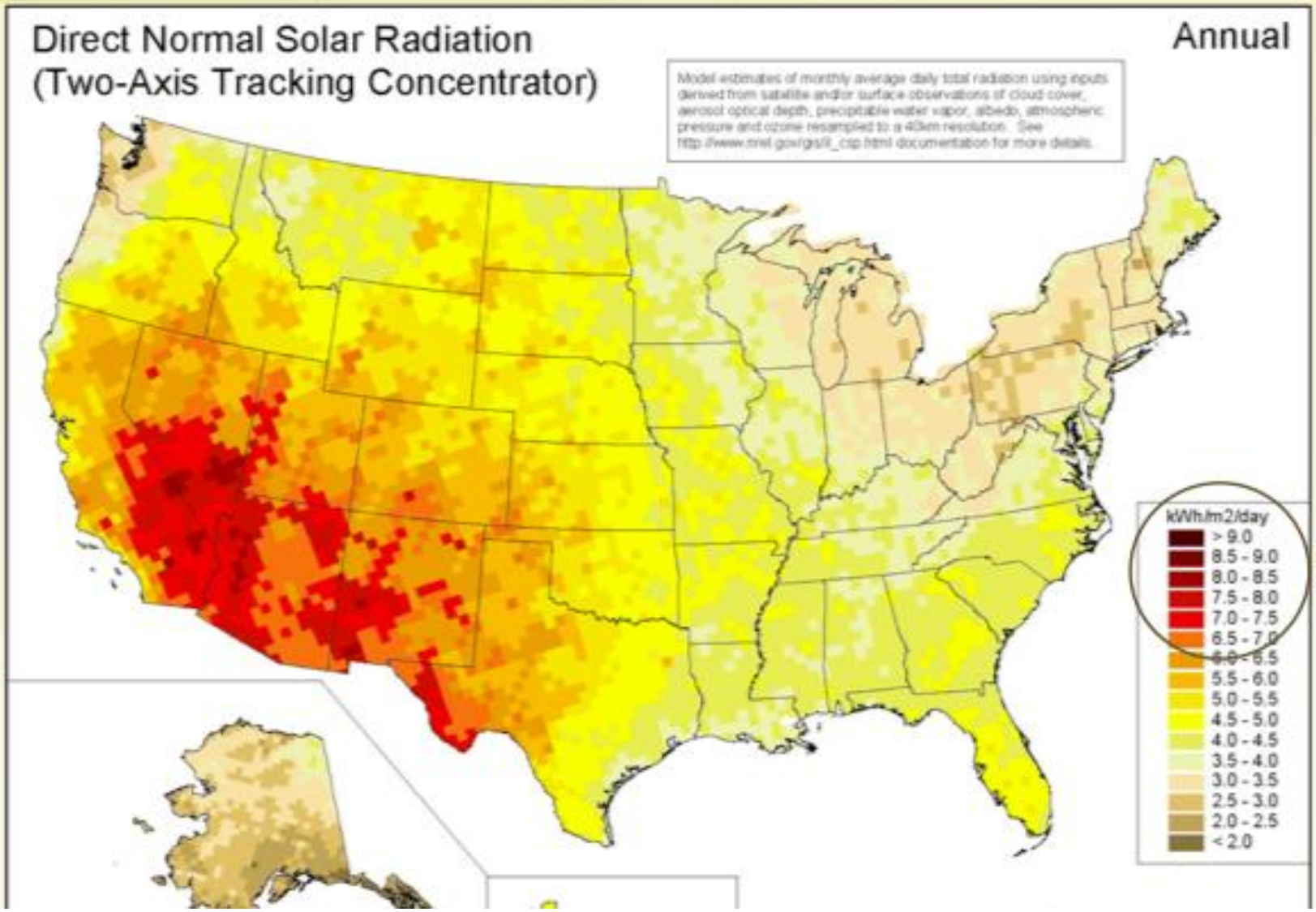
Spatial mapping for identifying sites
for renewable energy
(that minimize negative consequences)

Identify:

Renewable energy resource

(e.g., NREL solar and wind maps)

Where? SOUTH-WEST A SOLAR MECCA



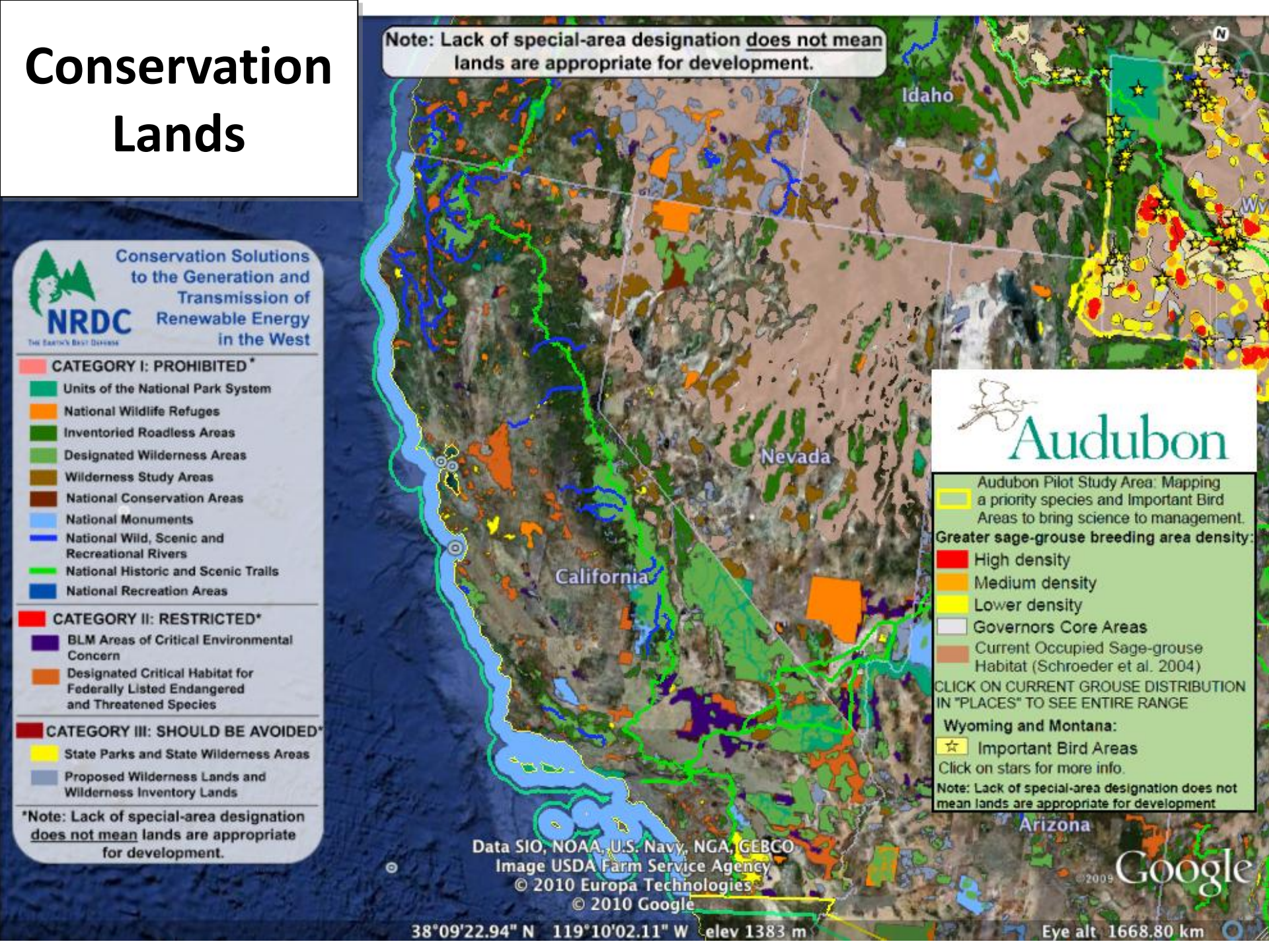
top rat

Identify:

Renewable energy resource

Protected areas

Conservation Lands



Identify:

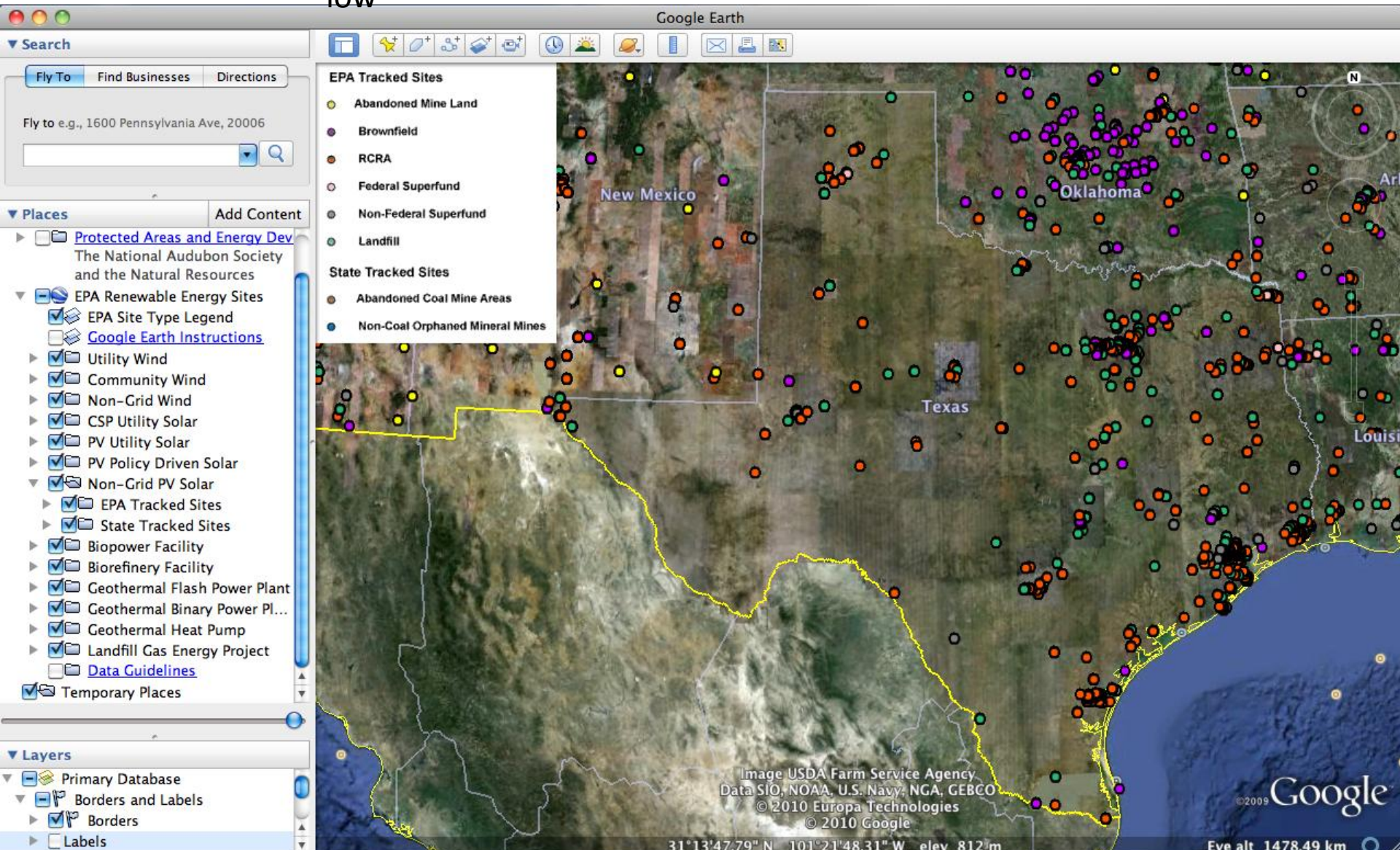
Renewable resource

Protected areas

Degraded Sites

EPA Renewable Energy Interactive Mapping Tool

→ Identifies already degraded sites where additional environmental risk is low



Identify:

Renewable resource

Protected and critical areas

Degraded Sites

Land Ownership and Access

Transmission Access

Identify *Potential Development Sites*

Environmental Aspects of Project Siting Process

1. **Identification of potential development sites – GET THIS RIGHT**
2. **Site selection and conceptual project design** (more detailed evaluation)
3. **Revise project design** based on a site-specific map of environmental constraints (including costs)
4. **Permitting to satisfy federal, state, and local requirements** (NEPA, CEQA, etc.)

American Wind Energy Association (AWEA) 2008

Multi-criteria analysis allows good accounting of the current situation…but what about other potential future values?

Ecosystem services assessment: ***evaluating trade-offs among different ecosystem services on a particular piece of land or water***

What are ecosystem services?

Seafood
Food Crops & Livestock
Forest Products
Energy Crops

Carbon storage
Provision of Water
Fire Prevention
Flood Control
Sedimentation Control
Pest Control
Pollination

Spiritual Values
Educational Values
Inspiration
Aesthetic Values
Social Relations
Sense of Place
Recreation
Tourism

Options: e.g., Biodiversity

Ecosystem service assessment tools

Computer Models with Spatial Map Products

InVEST

MIMES

ARIES

IBAT

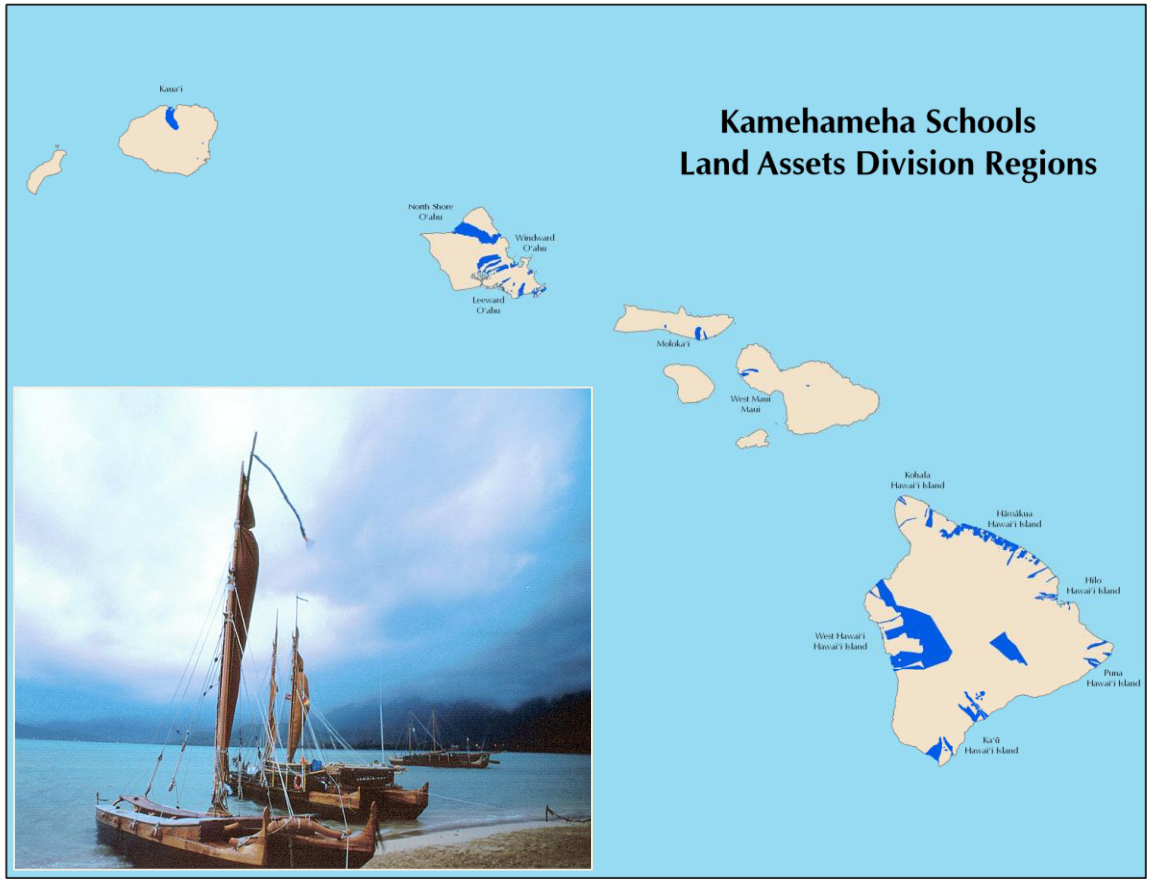
Structured Questions leading to Risk or Opportunity Analysis

NVI

ESR

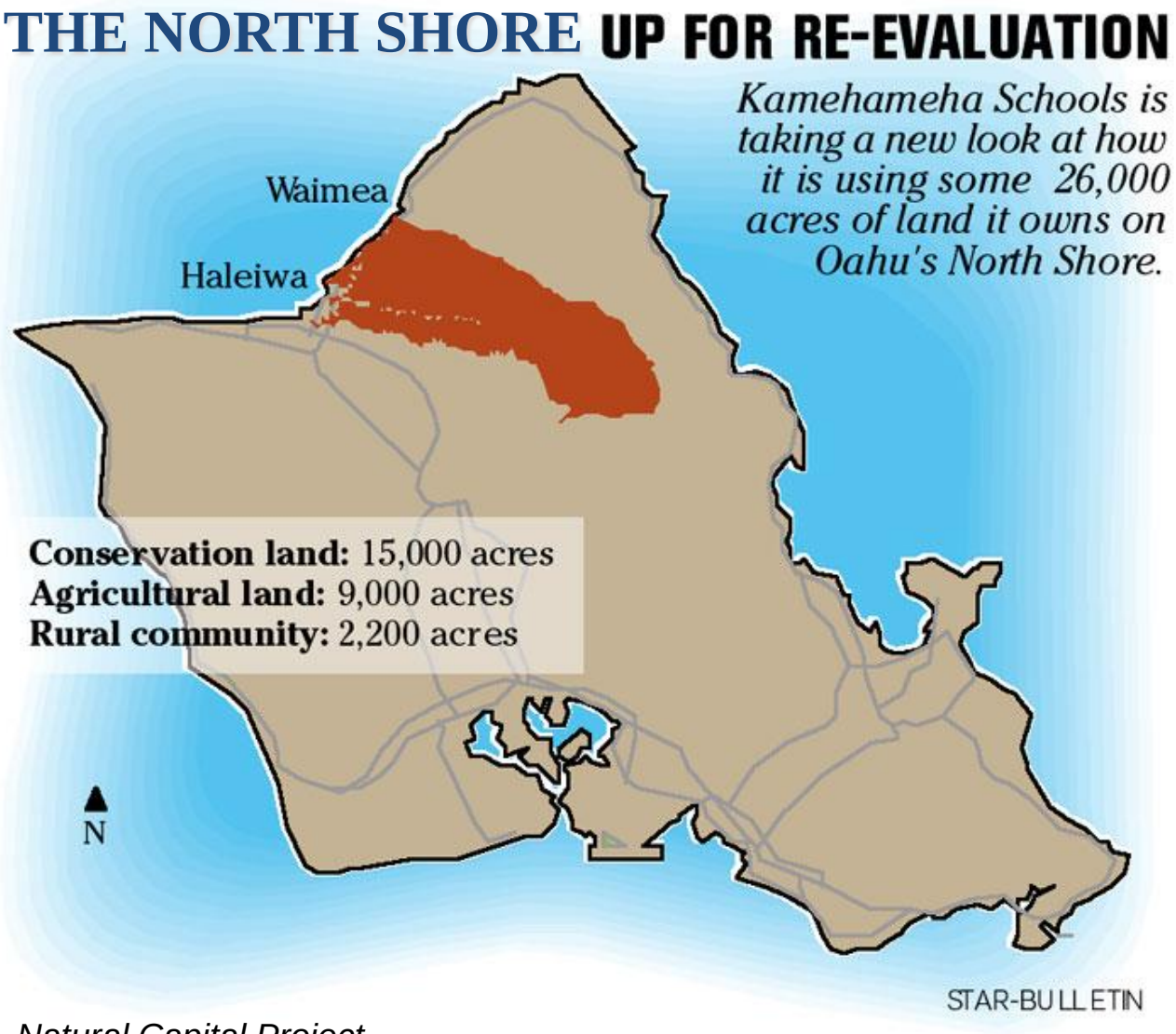
BBOP

Case Study: Use of InVEST in Hawai'i



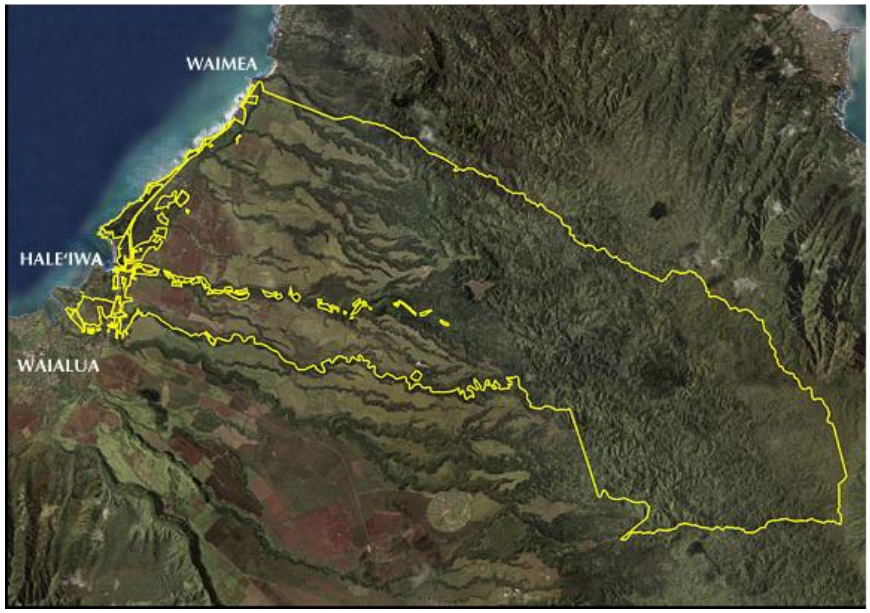
Joshua Goldstein, personal communication
Contact joshua.goldstein@colostate.edu for permissions

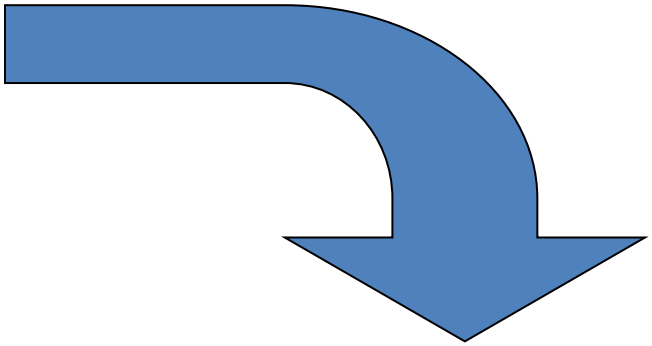
Kamehameha Schools

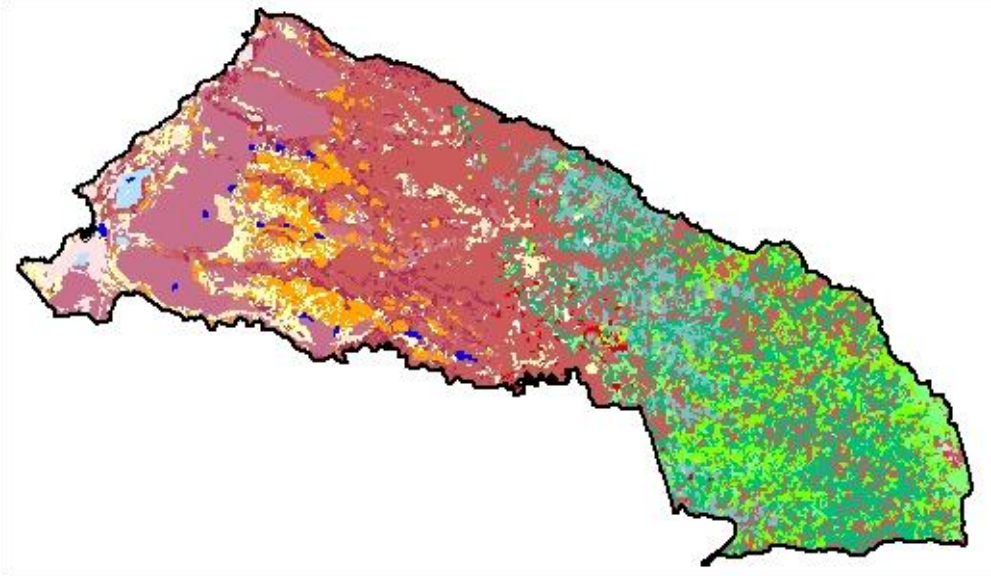


Joshua Goldstein, Natural Capital Project

Land Use / Land Cover Map



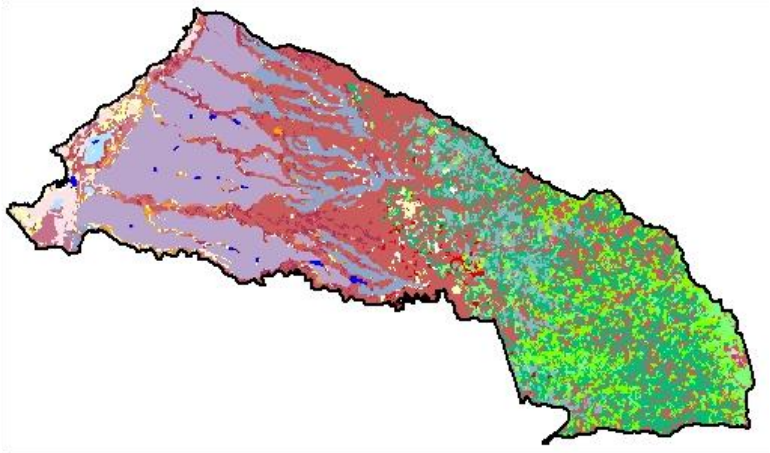




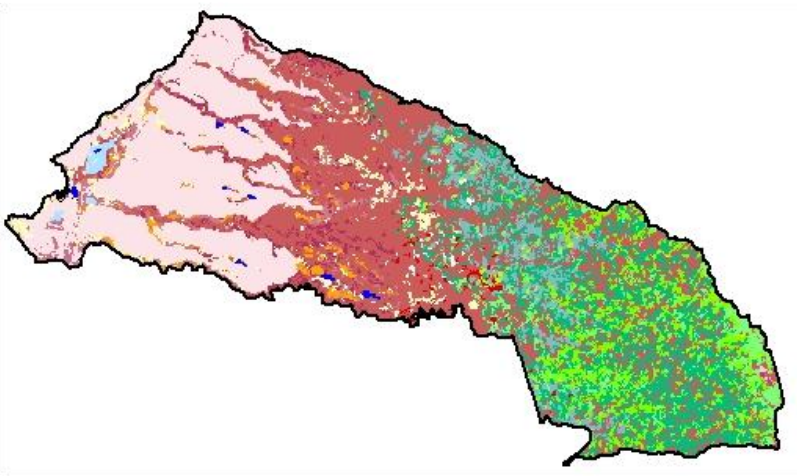
Joshua Goldstein, Natural Capital Project

Scenarios

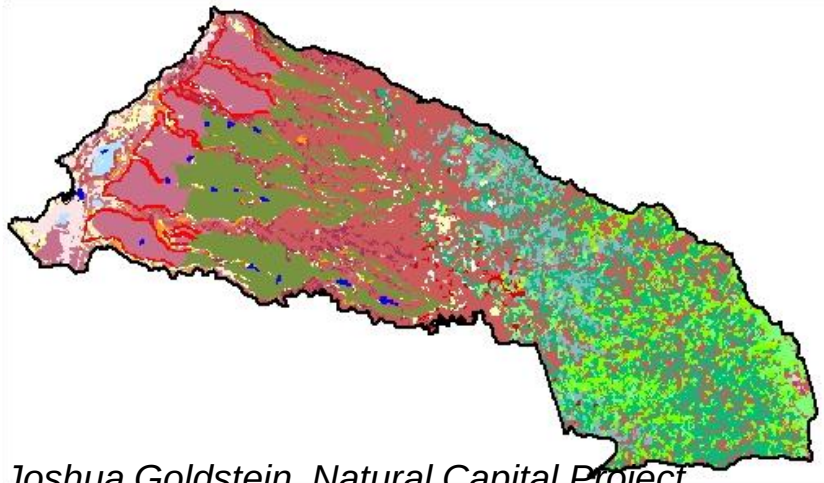
Biofuels



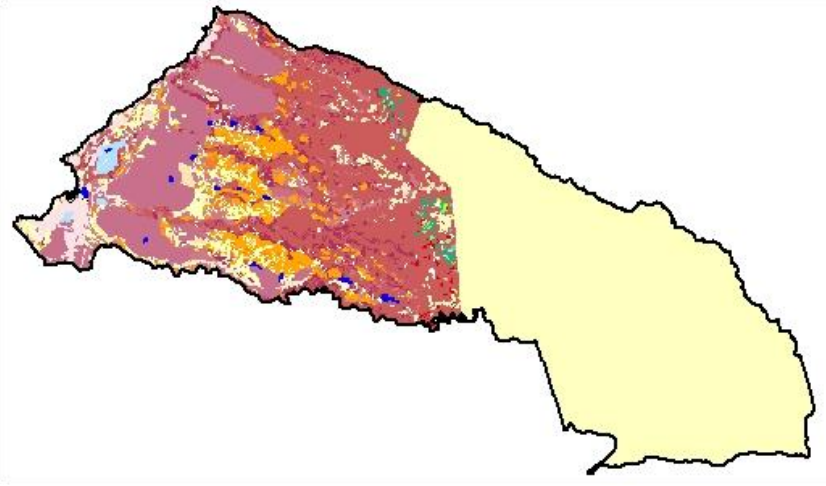
Subdivision



Sust. Agriculture & Forestry



Deforestation



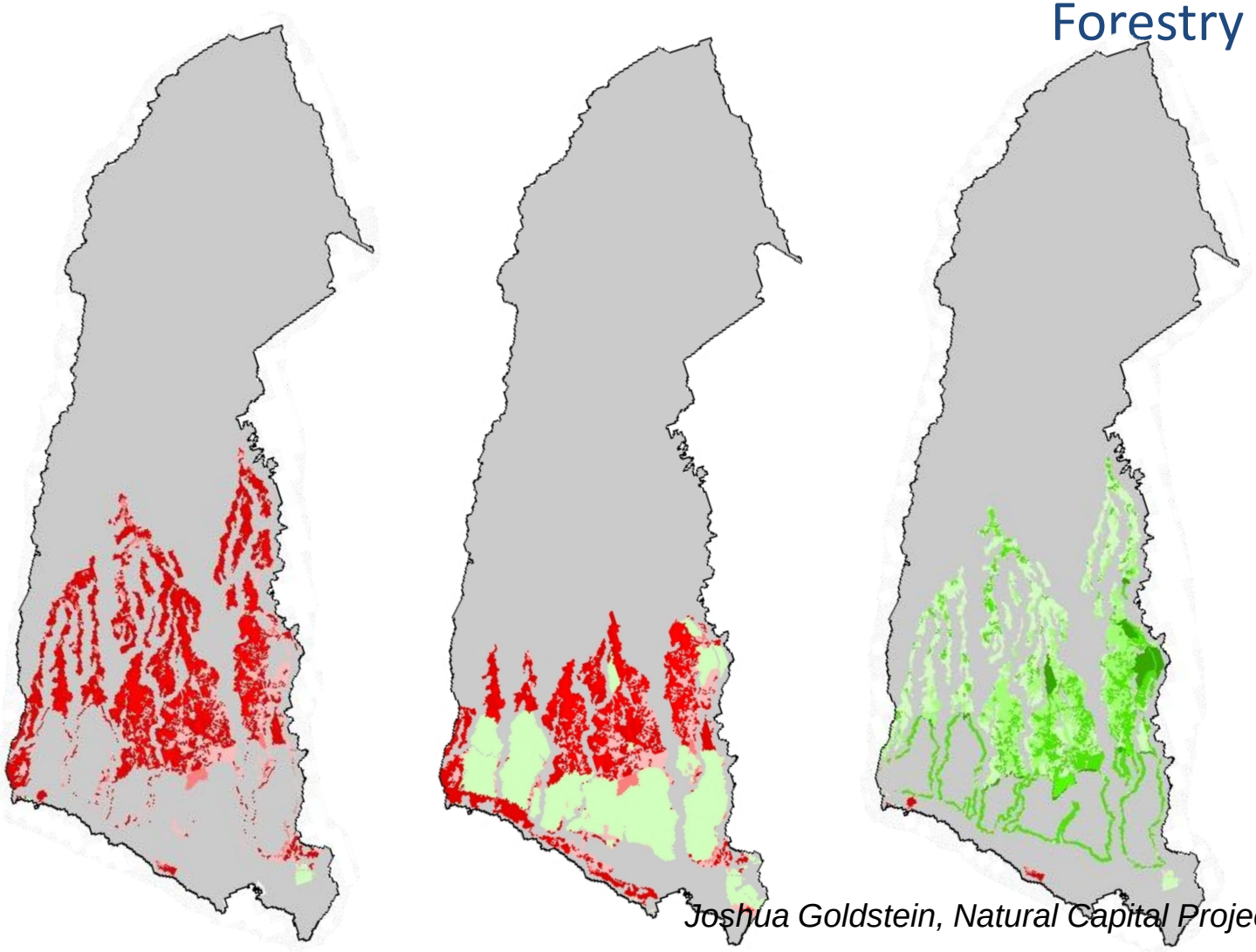
Joshua Goldstein, Natural Capital Project

Scenarios impact ecosystem services:
change in carbon storage

Biofuels

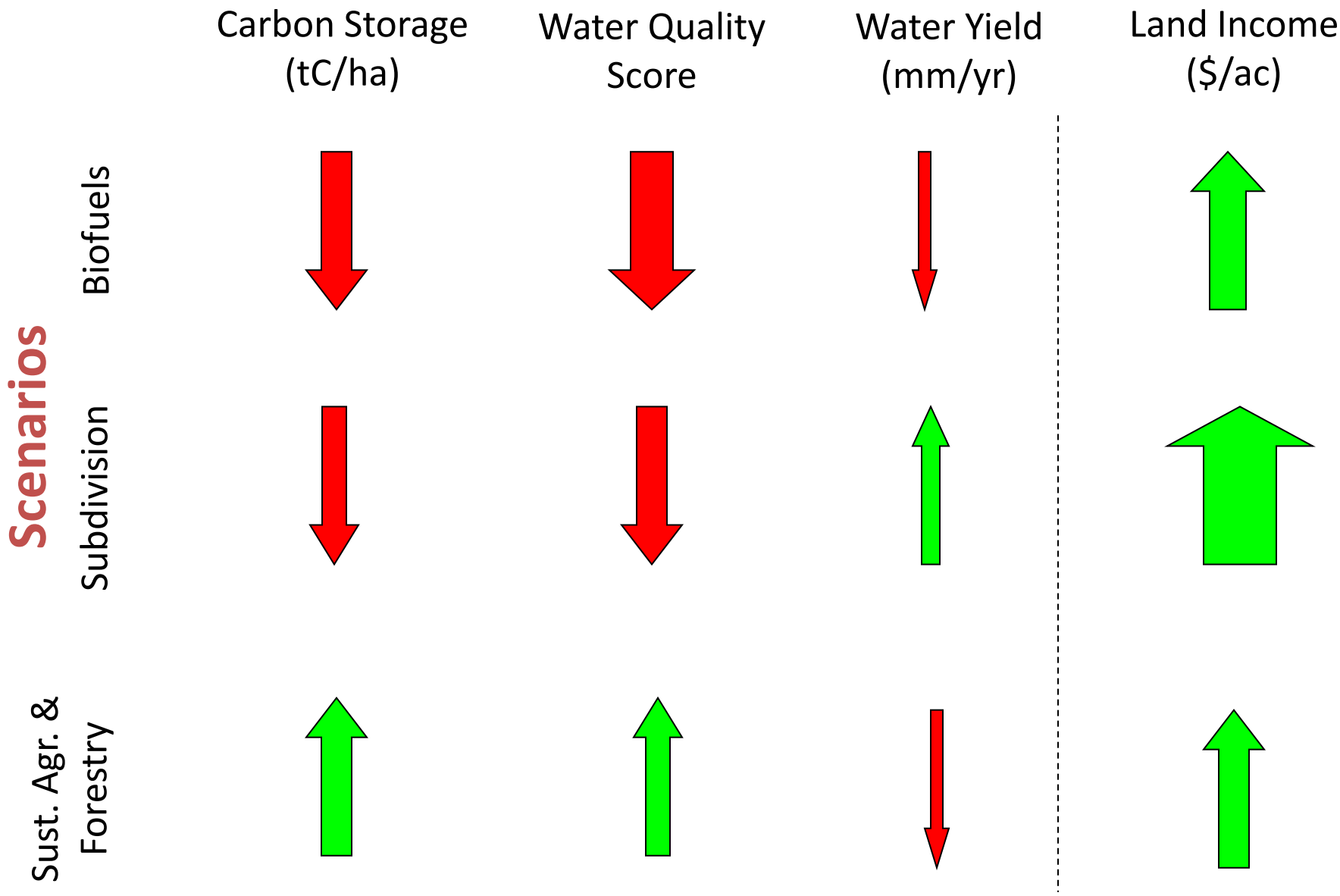
Subdivision

Sust. Agr. & Forestry



Joshua Goldstein, Natural Capital Project

Changes in Ecosystem Services



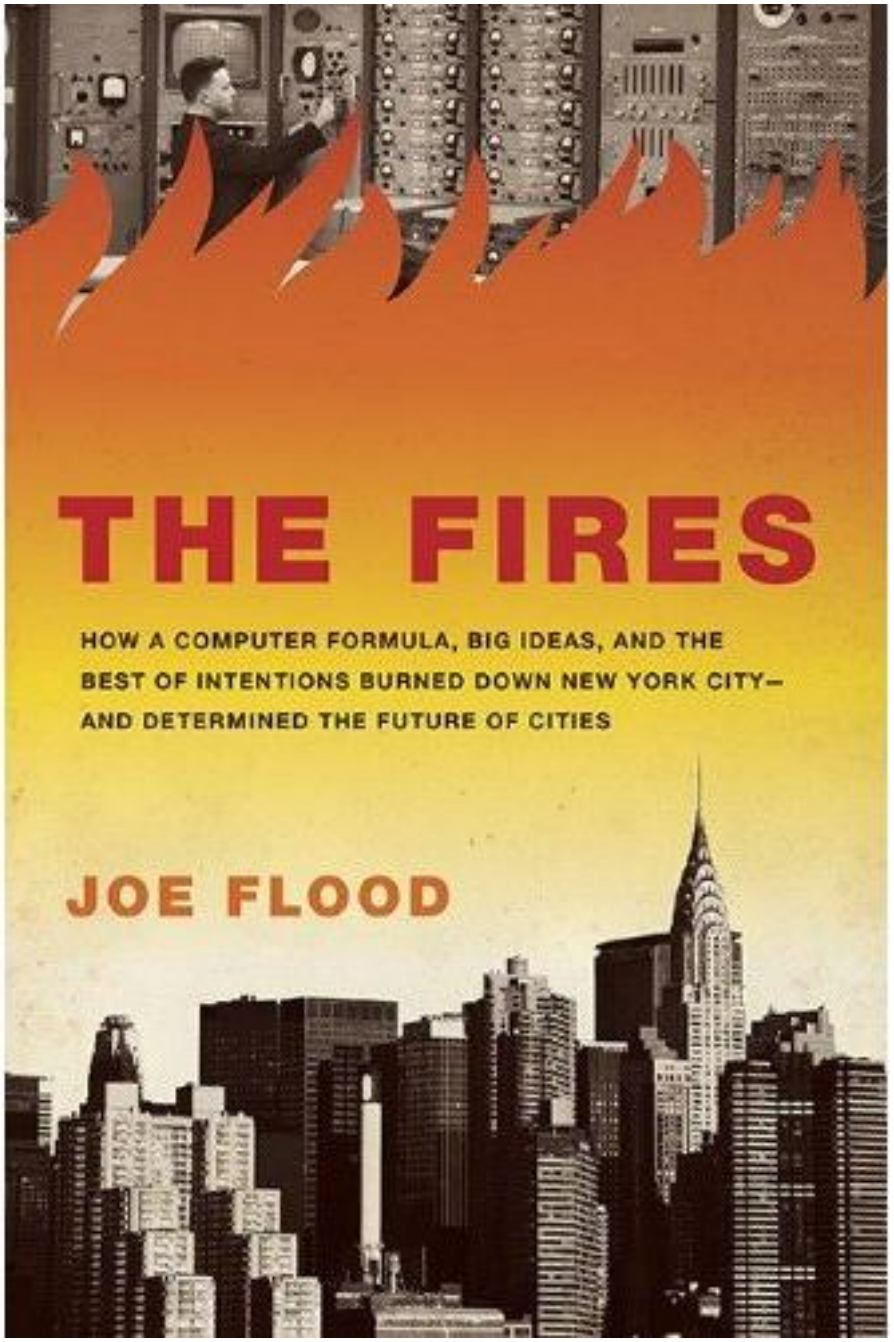
Joshua Goldstein, Natural Capital Project

Tools and Approaches for Measuring and Evaluating Tradeoffs, Co-Benefits, and Unintended Consequences

- Life Cycle Assessment Models
- Econometric Models
- Ecosystem Process Models
- Ecosystems Services Models
- Vulnerability Analyses
- Integrated Assessment Models
- Multi-criteria spatial data, including ground-based measurements and remotely sensed data
- Metrics and Indicator Systems
- Certification systems
- Stakeholder engagement and decision support systems

Models are only as good as their assumptions and data…

Without engagement of decision makers, they're likely to get it wrong.



In the future…

- Need better integration of models,
  linking decisions with impacts,
  at local and regional scales,
  evaluating trade-offs and co-benefits as well as impacts,
  incorporating uncertainty analysis

- Need for more focus on decision support, development of new ways of engaging stakeholders and decision makers

- Assessment in all sectors, not just energy

- Need for more explicit learning by doing


Thank you!

References

- American Wind Energy Association (AWEA), 2008, "Wind Energy Siting Handbook." http://www.awea.org/sitinghandbook/
- Audubon Society wind power development map including bird habitats: http://earth.google.com/outreach/showcase.html#kml=Audubon_Priority_Bird_Areas_and_Responsible_Wind_Development
- Campbell et al, 2008, "The Global Potential of Biofuels on Abandoned Agriculture Lands." Environmental Science and Technology.
- Endelevu Energy, 2008, "A Roadmap for Biofuels in Kenya: Opportunities and Obstacles"
- EPA Renewable Energy Interactive Mapping Tool: http://www.epa.gov/oswercpa/mapping_tool.htm
- EPA, 2009, "Draft Regulatory Impact Analysis: Changes to Renewable Fuel Standard Program"
- EPA, 2010, "Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis" http://www.epa.gov/otaq/renewablefuels/420r10006.pdf
- Fingerman et al., 2008. "Integrating Water Sustainability into the Low Carbon Fuel Standard," Working paper on Water Sustainability, University of California, Berkeley. http://rael.berkeley.edu/sites/default/files/old-site-files/Fingerman_WaterSust.pdf
- Gelfand, Robertson, et al. in review; contact G. Philip Robertson, Michigan Sate University, for permissions
- Gibbs et al, 2008, "Carbon payback times for crop-based biofuel expansion in the tropics: the effects of changing yield and technology." Environmental Research Letters
- Global Trade Analysis Program (GTAP), 2010, https://www.gtap.agecon.purdue.edu/models/default.asp
- International Council on Clean Transportation (ICCT), 2010, "Low-carbon fuels summit." www.theicct.org/2010/05/lowcarbonfuels-summit
- Janetos et al (DOE). 2009. Science Challenges and Future Directions: Climate Change Integrated Assessment Research. http://www.sc.doe.gov/ober/IA%20Workshop_06-25-09.pdf
- Monroe (HDR/BVA), 2008, "Renewable Energy Resource Assessment: Solid Waste Management Division County of San Bernardino, California"
- Naylor et al, 2007, "The Ripple Effect" http://iis-db.stanford.edu/pubs/22064/Naylor_et_al_Env.pdf
- NRDC Conservation Solutions for RE mapping tool: http://www.nrdc.org/land/sitingrenewables/default.asp
- Pehnt, 2005, "Dynamic life cycle assessment (LCA) of renewable energy technologies." Renewable Energy.
- Renewable Energy Transmission Initiative (RETI), 2009, "Phase 1B Final Report." http://www.energy.ca.gov/reti/documents/index.html
- Renewable Energy Transmission Initiative (RETI), 2009, "Phase 2A Final Report." http://www.energy.ca.gov/reti/documents/index.html
- Roundtable on Sustainable Biofuels (RSB), 2010, http://energycenter.epfl.ch/page65660.html
- Schram (FAO Tanzania), 2008, "The Bioenergy and Food Security Project"
- Suyanto et al, 2004, "The Role of Fire in Changing Land Use and Livelihoods in Riau-Sumatra." Ecology and Society.
- Turner et al 2002.Proceedings of the National Academy of Science
- Wang et al, 2007, "Life-cycle energy and greenhouse gas emission impacts of different corn ethanol plant types." Environmental Research Letters. http://iopscience.iop.org/1748-9326/2/2/024001/fulltext
- Winrock International, 2009, "The Impact of Expanding Biofuel Production on GHG emissions" http://www.winrock.org/iip/pdf/The%20Impact%20of%20Expanding%20Biofuel%20Production%20of%20GHG%20emissions.pdf
- Zah et al. (2007). "Life Cycle Assessment of Energy Products: Environmental Assessment of Biofuels". Bern, Switzerland, EMPA Technology and Society Lab.