GCEP

GCEP Annual Research Symposium

New Research Directions in a Rapidly Evolving Global Energy Landscape

September 30 - October 2, 2009

STANFORD UNIVERSITY

Exergy and Carbon Flow in Natural and Human Systems

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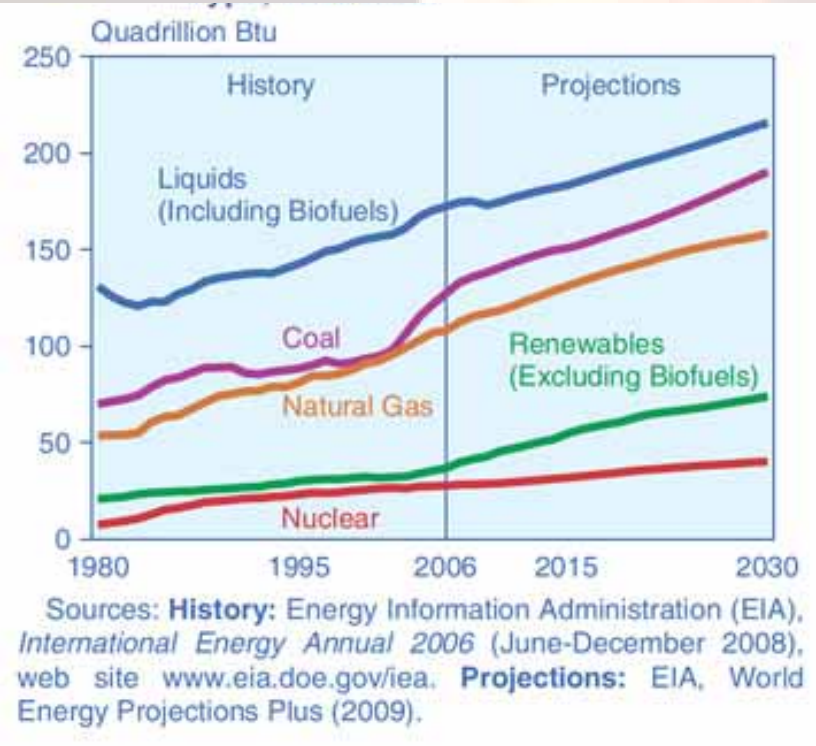
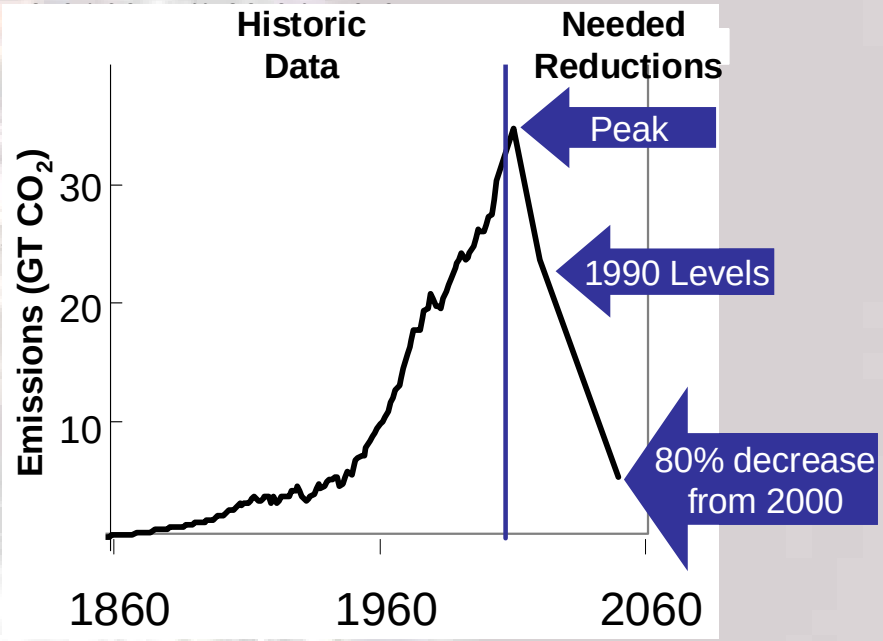
Global Climate & Energy Project

The Technology Challenge



Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2006* (June-December 2008), web site www.eia.doe.gov/iea. **Projections:** EIA, World Energy Projections Plus (2009).



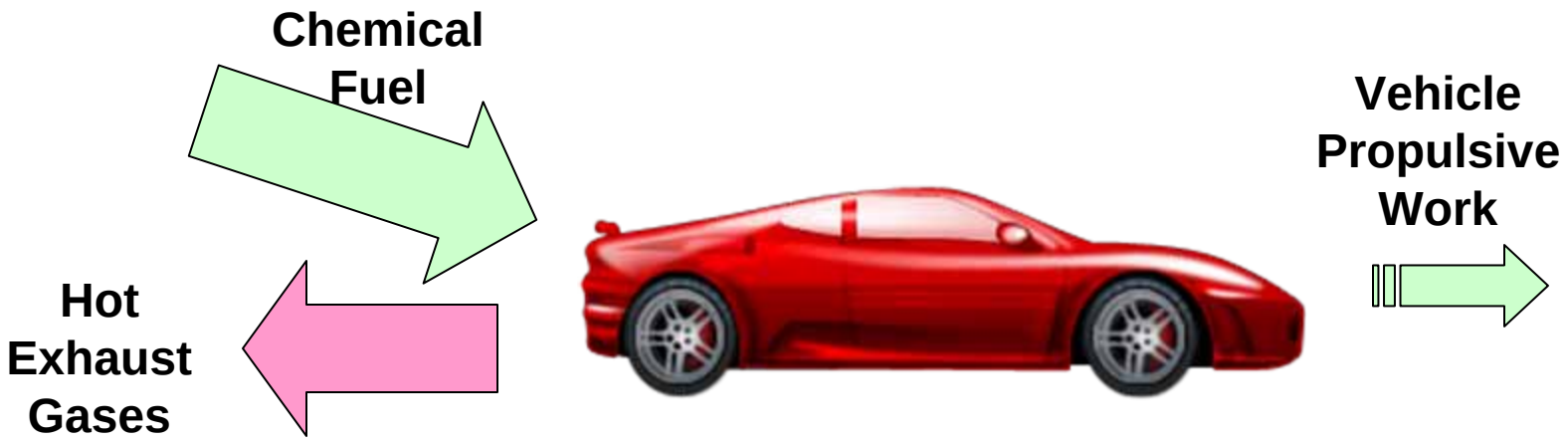
We need a portfolio of new technologies to achieve these CO_2 emissions reductions while meeting growing energy demands.

Motivation for Exergy Analysis

- As we consider future energy technology choices for addressing this challenge, we need:
  - a consistent basis for comparing energy resources and their conversions in terms of their thermodynamic potential; and
  - an understanding of the impact they will have on the global carbon cycle.
- Exergy and carbon maps can serves as a useful data source in:
  - Determining new research directions
  - Formulating future energy policies
  - Educating the public

Concept of Exergy

- Exergy is the useful portion of energy that allows us to do work and perform energy services.
- Energy is conserved, but exergy is not.

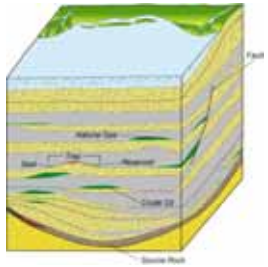


- Exergy is available only in materials and flows we call resources and is converted into exergy carriers convenient to use in our homes, vehicles, and factories
- Exergy is calculated from thermodynamic properties of a substance relative to the properties of a reference environment

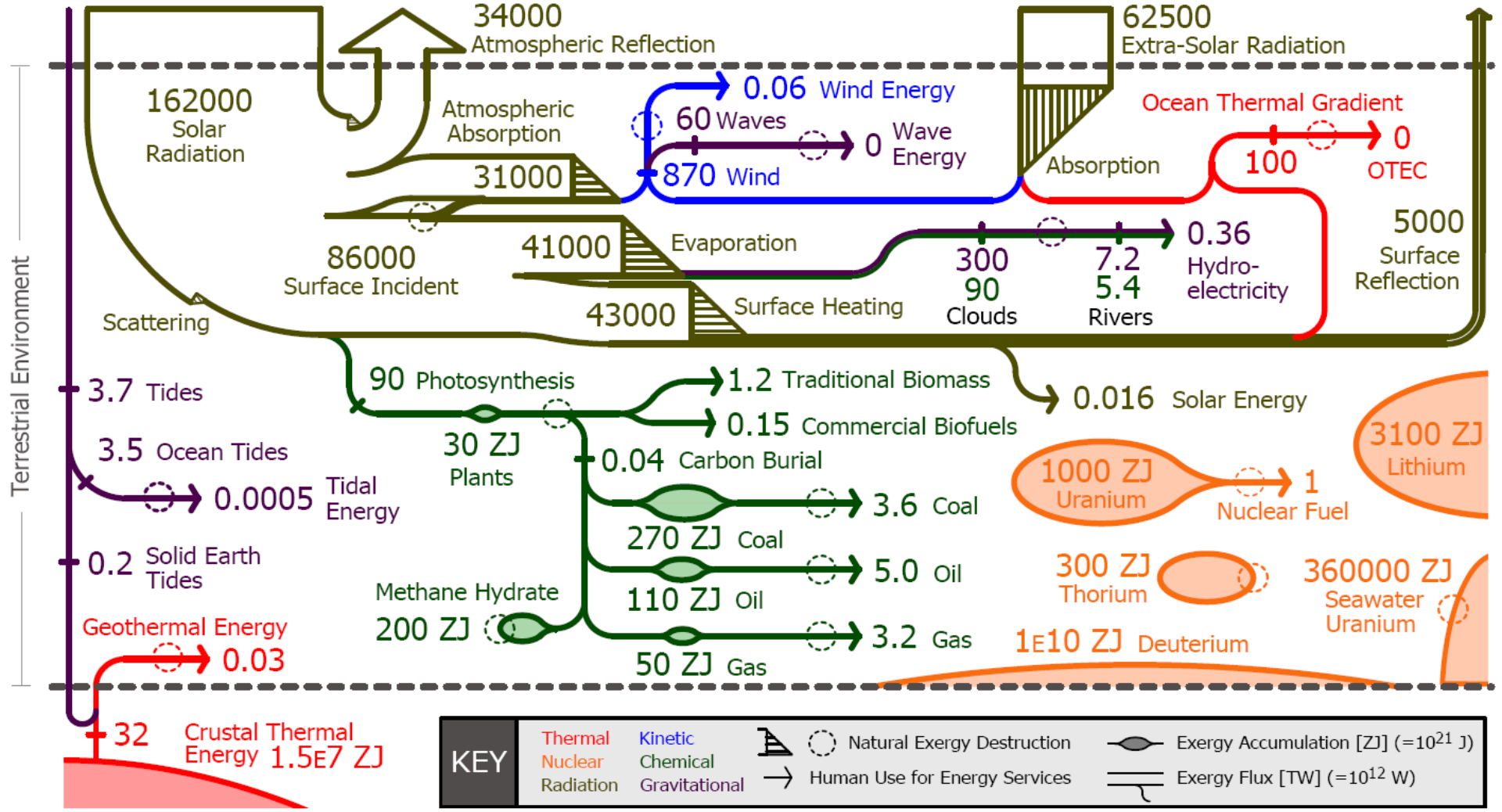
Components of Exergy and Carbon Data

Data in the maps are of three types:

- Carriers are mediums through which exergy and/or carbon flow through the system.
  - The flow of exergy and carbon through carriers is measured in units of watts (joules/second) and grams/second, respectively.
- Transformations are processes by which exergy and carbon are passed from one carrier to another.
  - A loss of exergy is incurred due to inherent inefficiencies of energy conversion but the total mass of carbon is conserved throughout the system.
- Accumulations are stores of exergy and/or carbon, measured in units of joules and grams, respectively.
  - Maybe primary resources or intermediate stores

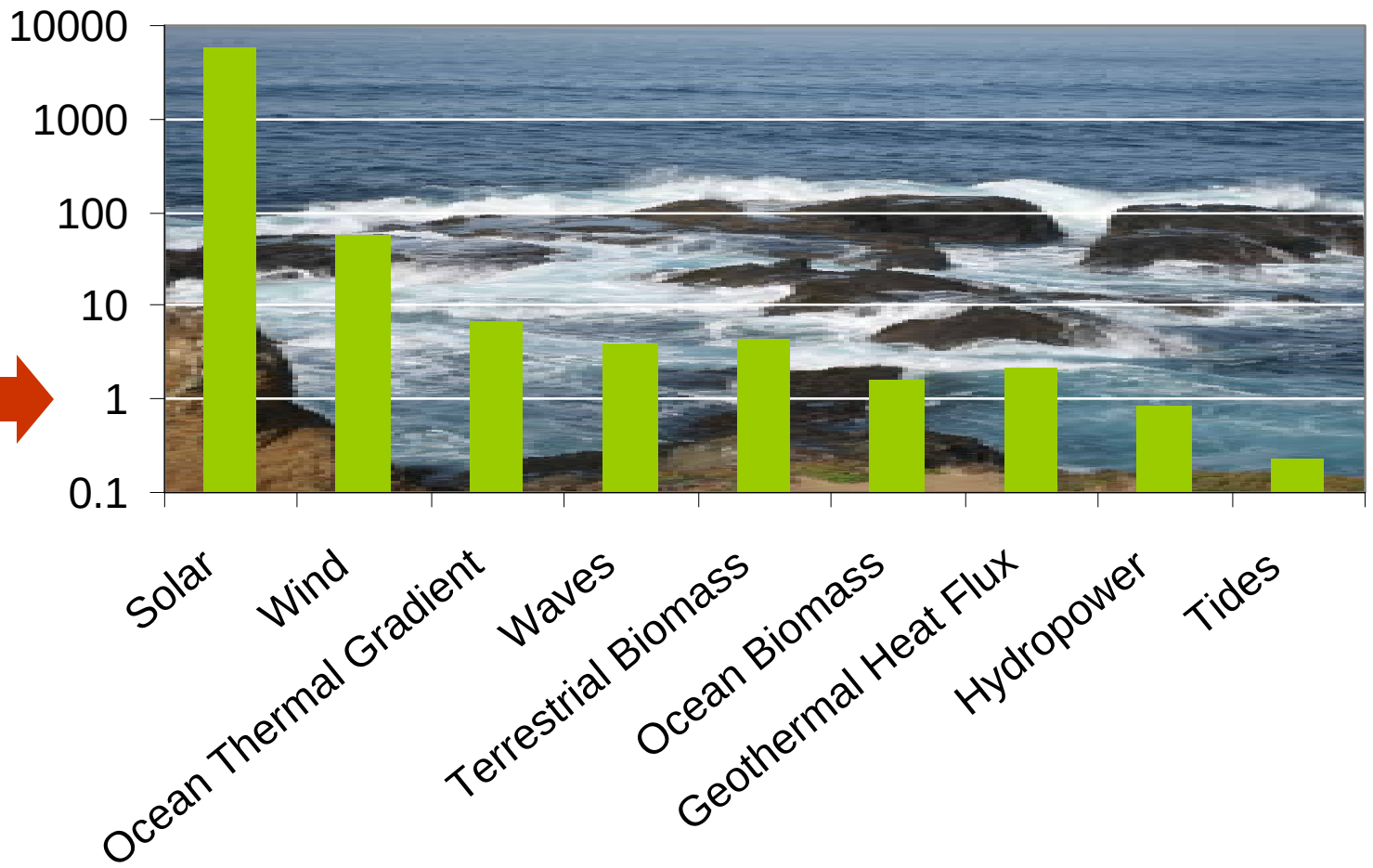


What resources can we use?
Exergy flow of planet Earth (TW)



Renewable Global Exergy Flows

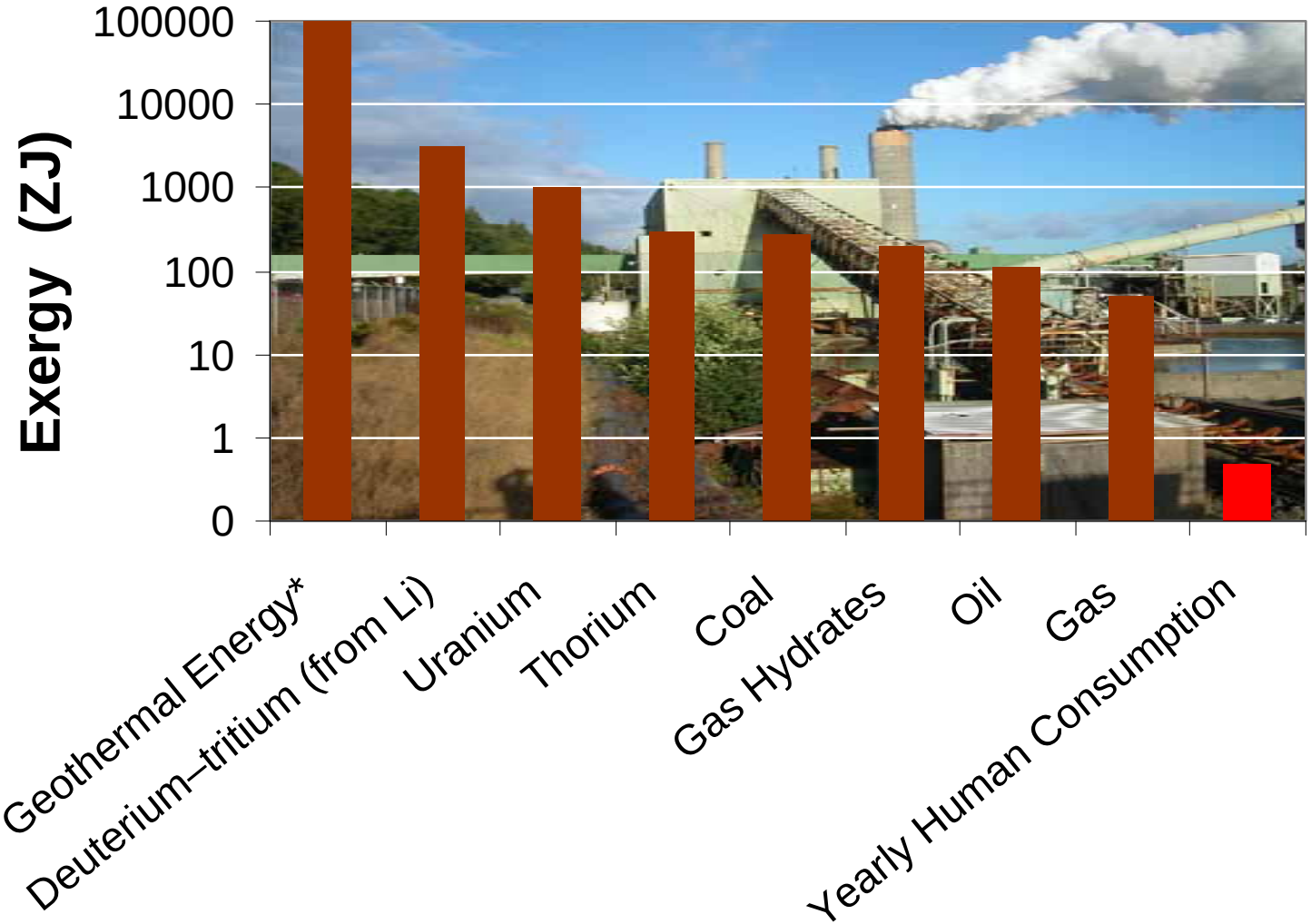
Human Use of Energy (15 TW)



Exergy sources scaled to average consumption in 2004 (15 TW)

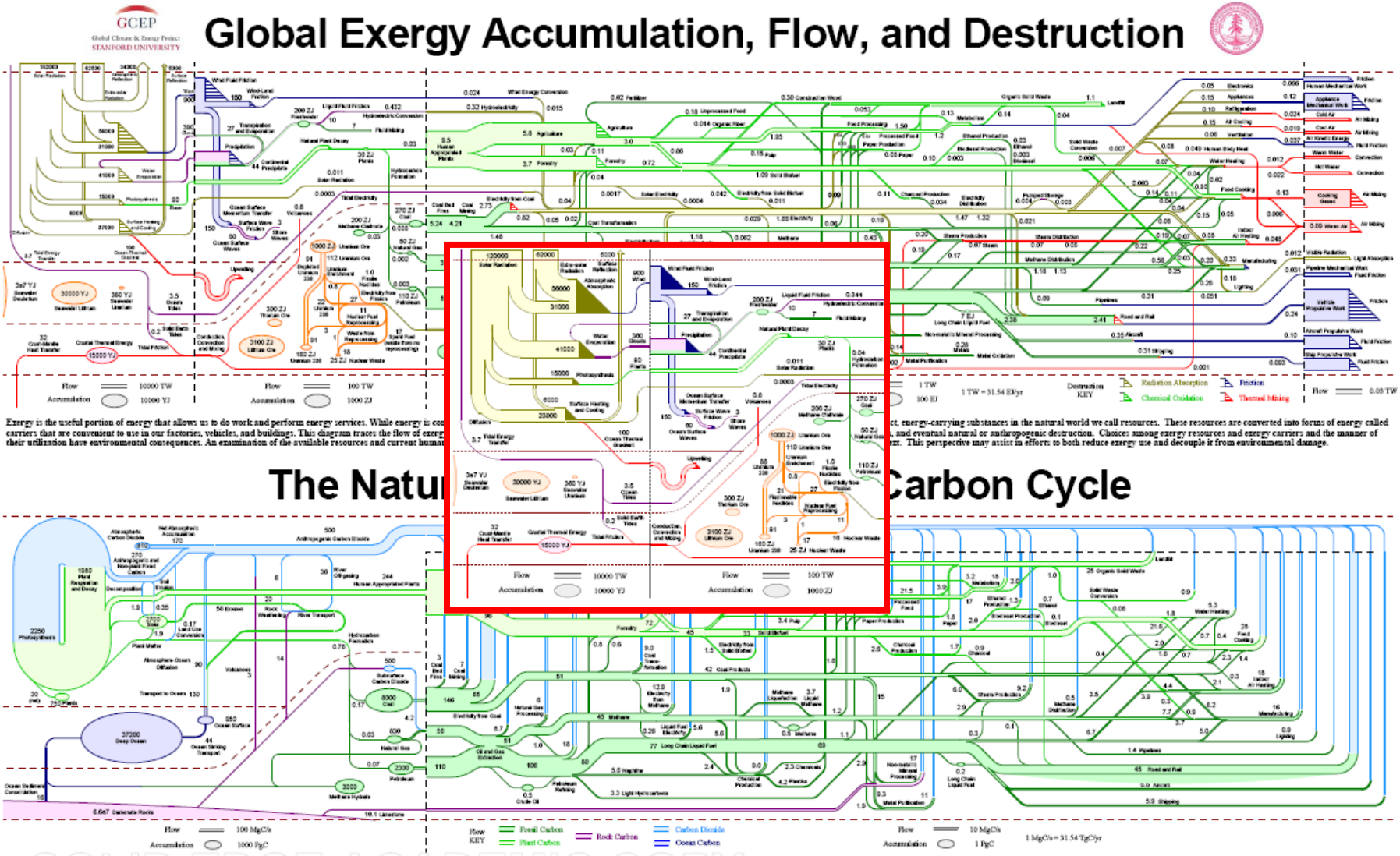
From Hermann, 2006: Quantifying Global Exergy Resources, Energy 31 (2006) 1349–1366

Global Exergy Stores



From Hermann, 2006: Quantifying Global Exergy Resources, Energy 31 (2006) 1349–1366

Global Exergy and Carbon Flows

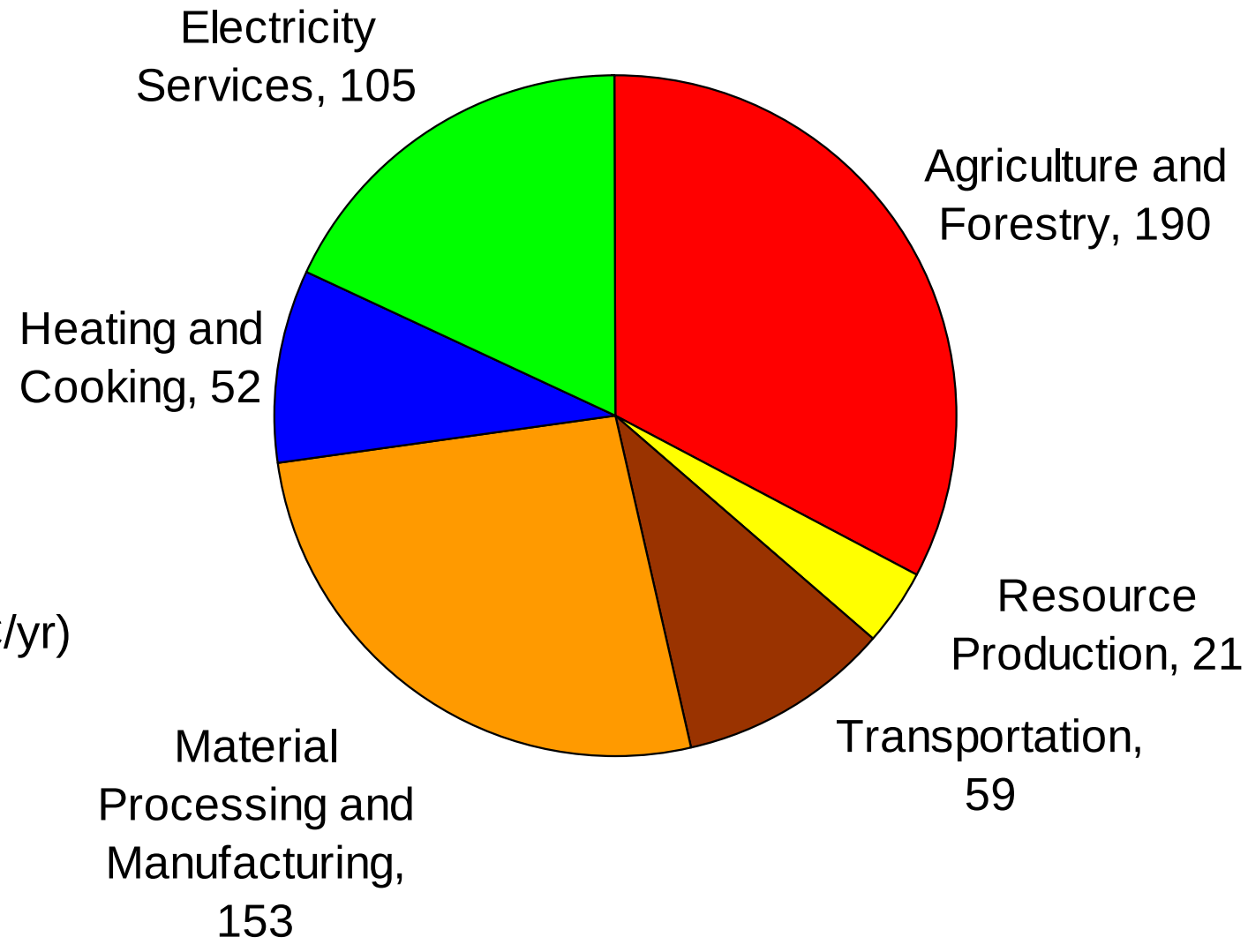


Energy is the useful portion of energy that allows us to do work and perform energy services. While energy is co ct, energy-carrying substances in the natural world we call resources. These resources are converted into forms of energy called carriers that are convenient to use in our factories, vehicles, and buildings. This diagram traces the flow of energ , and eventual natural or anthropogenic destruction. Choices among exergy resources and energy carriers and the manner of their utilization have environmental consequences. An examination of the available resources and current humai ext. This perspective may assist in efforts to both reduce energy use and decouple it from environmental damage.

The ability of carbon-based molecules to store a large amount of useful energy, or exergy, has made carbon an important energy carrier in natural and human energy systems. Carbon is being reintroduced to the biosphere through the human use of fossil fuels at a rate far exceeding its natural sequestration. This large and accelerating transfer of carbon to the atmosphere and upper ocean may lead to global environmental changes that would adversely impact our quality of life. This diagram traces the flow of carbon through the subsurface, the biosphere, and the human energy system. The energy conversions that lead to the sources of anthropogenic carbon dioxide are illustrated. In conjunction with the global exergy diagram above, alternative energy pathways that either do not require fossil carbon or store it in reservoirs other than the atmosphere and ocean surface can be examined in the context of current energy use and carbon flow.

Prepared by I-Chun Hsiao (based on the work of Wes Hermann and and A.J. Simon), Global Climate and Energy Project at Stanford University (http://gcep.stanford.edu), © 2009. Contact: gcep@stanford.edu

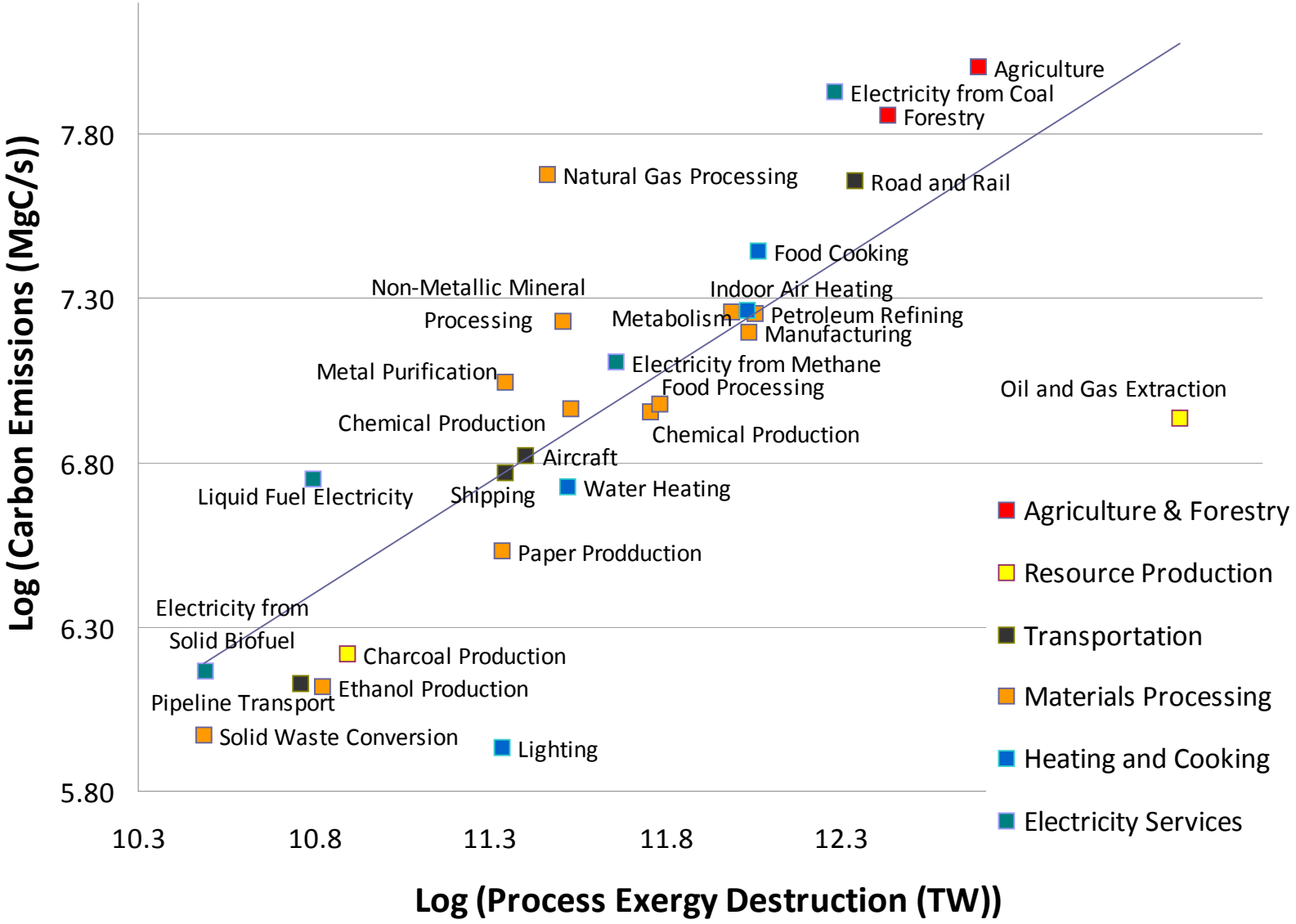
Global Carbon Flows from Energy Service Sectors of the Human Energy System (Mg C/s)



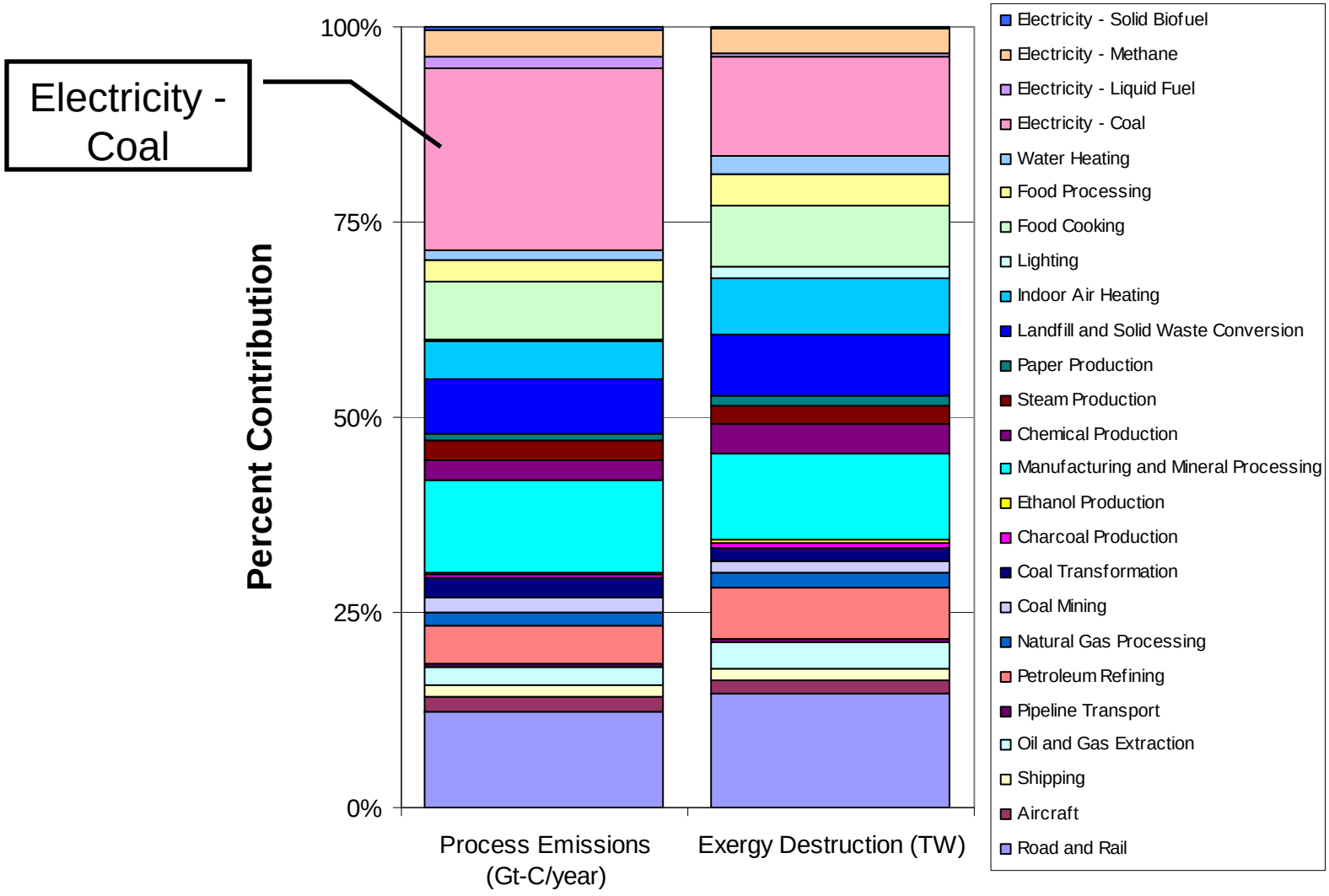
1 MgC/s =

31.5 MtonneC/yr)

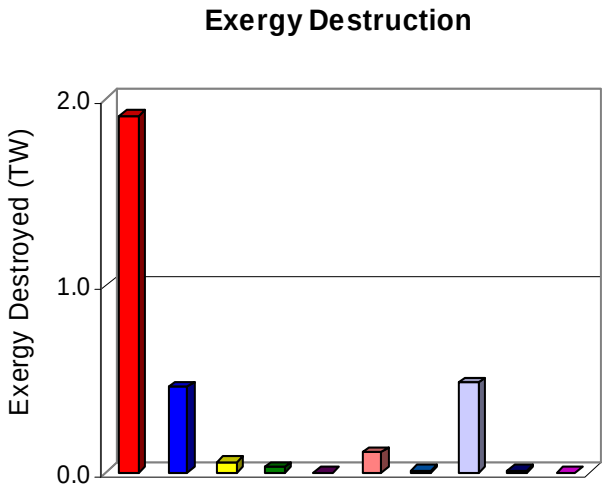
Global Carbon Emissions versus Process Exergy Destruction



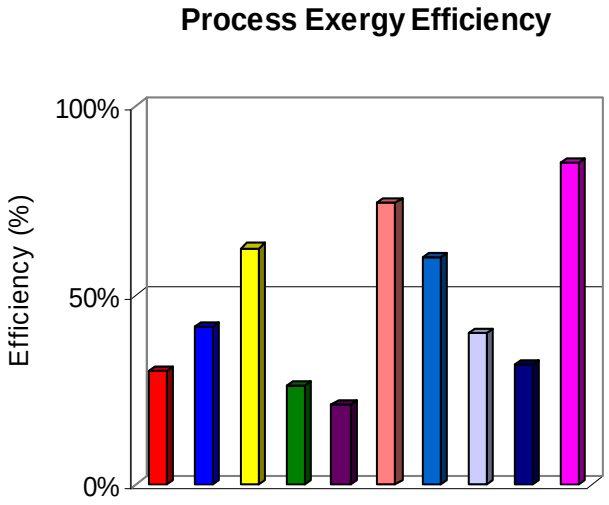
Relative Fractions of Global Exergy Destruction and Carbon Flows

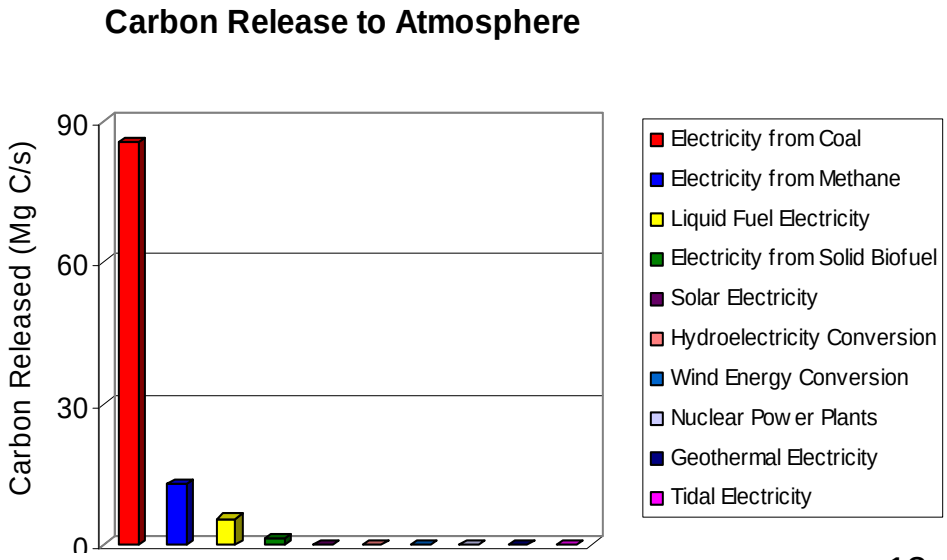


Global Exergy Destruction and Carbon Flow in the Electricity Sector

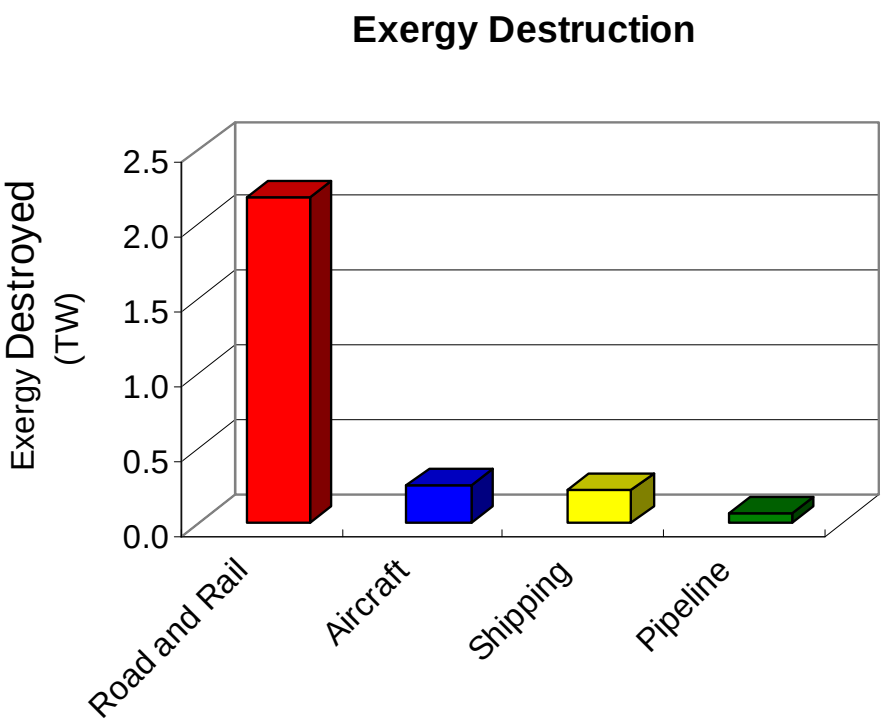


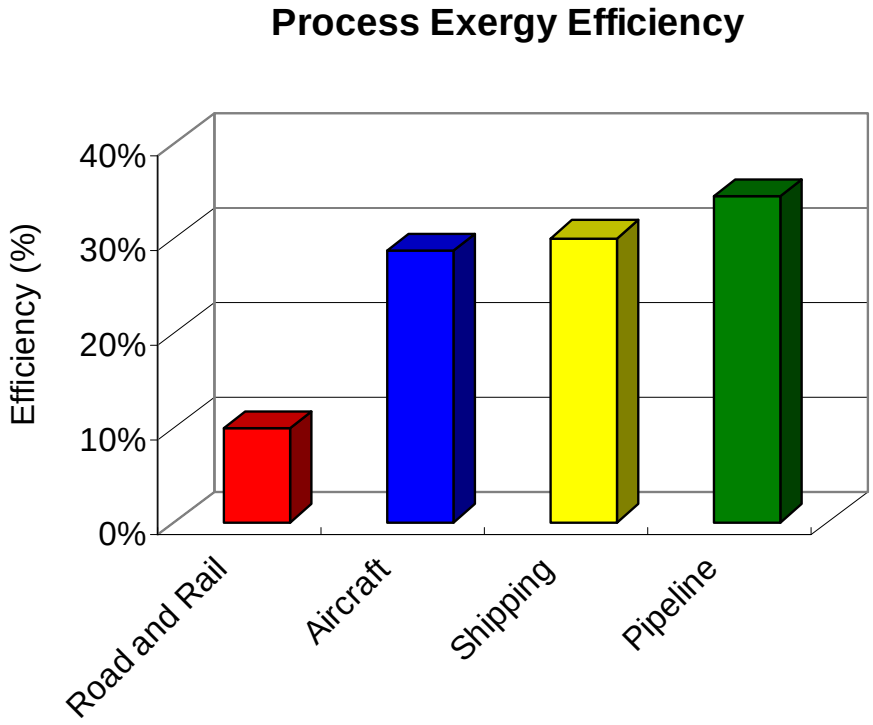
- The electricity sector is dominated by coal in terms of exergy destroyed and carbon emissions.





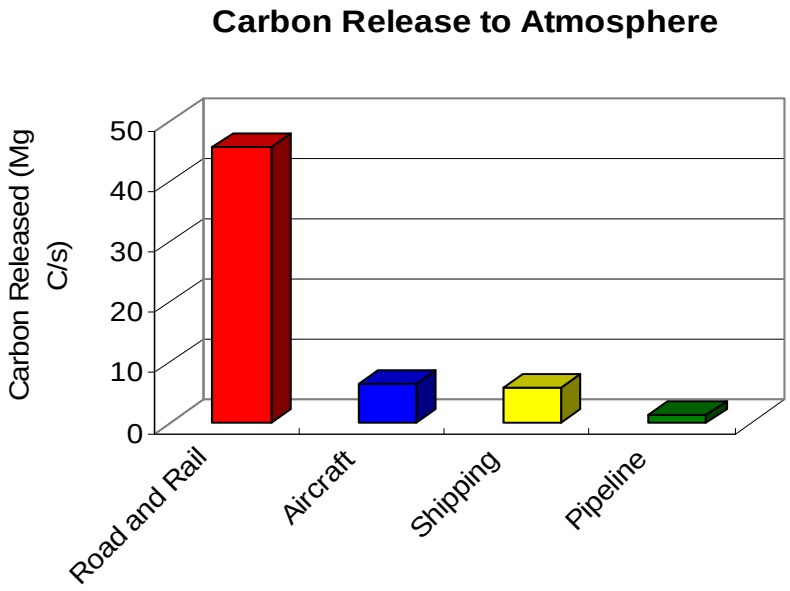
Global Exergy Destruction in the Transportation Sector

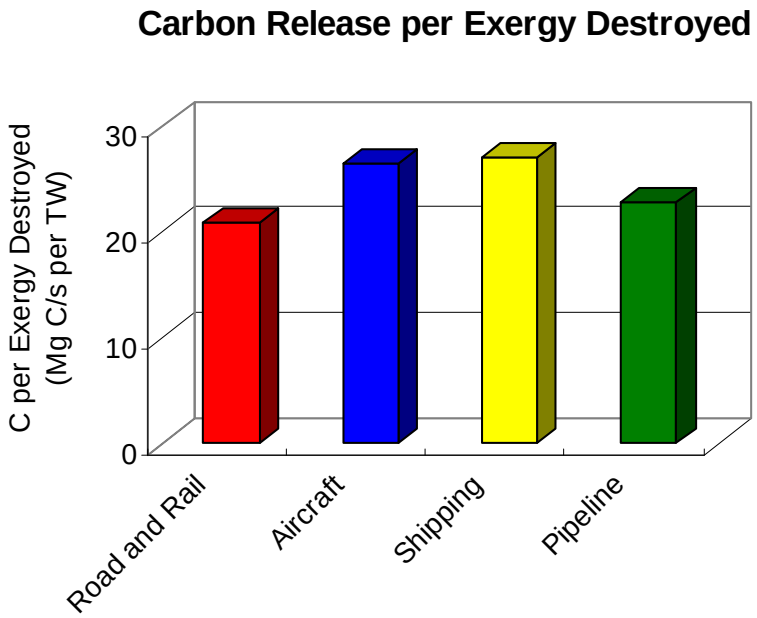


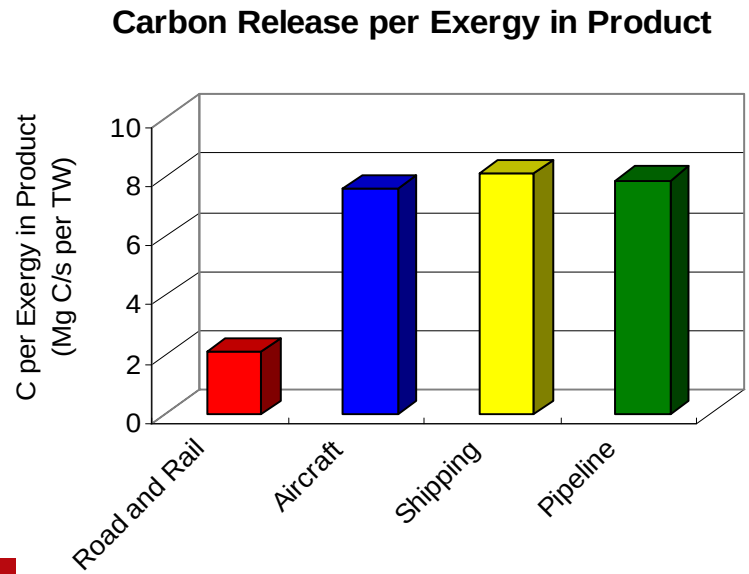


- Road and rail accounts for largest destruction of exergy in the global transportation system and this transformation occurs with the lowest efficiency

Global Carbon Flows in the Transportation Sector

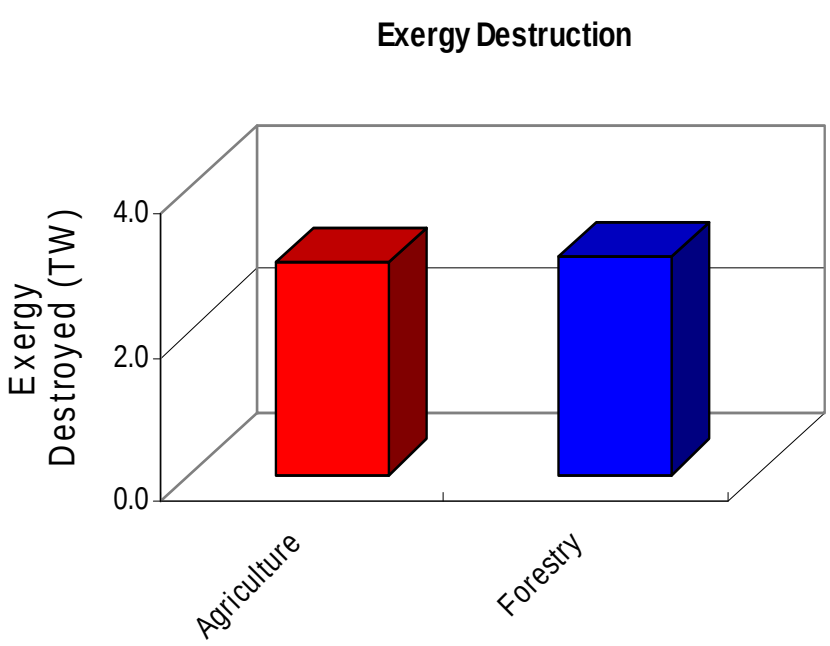


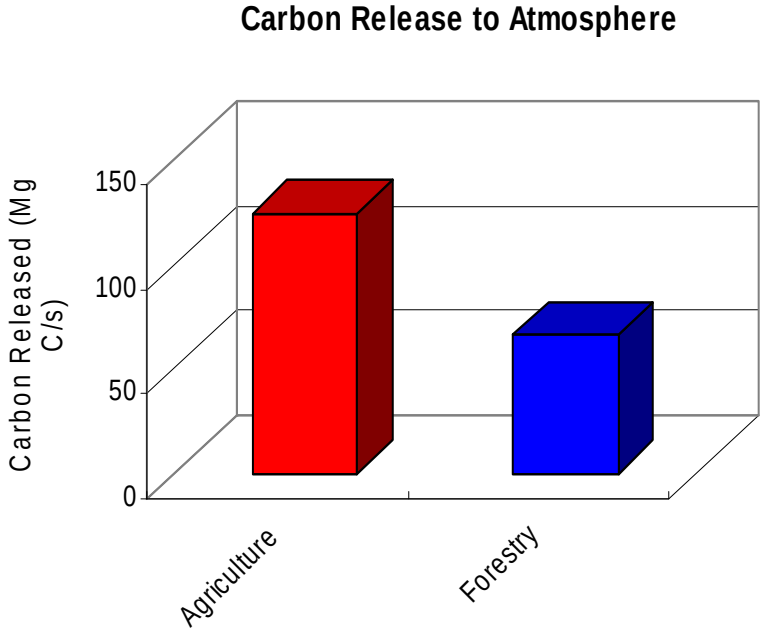




- Road and rail also accounts for greatest CO_2 releases in the transportation sector

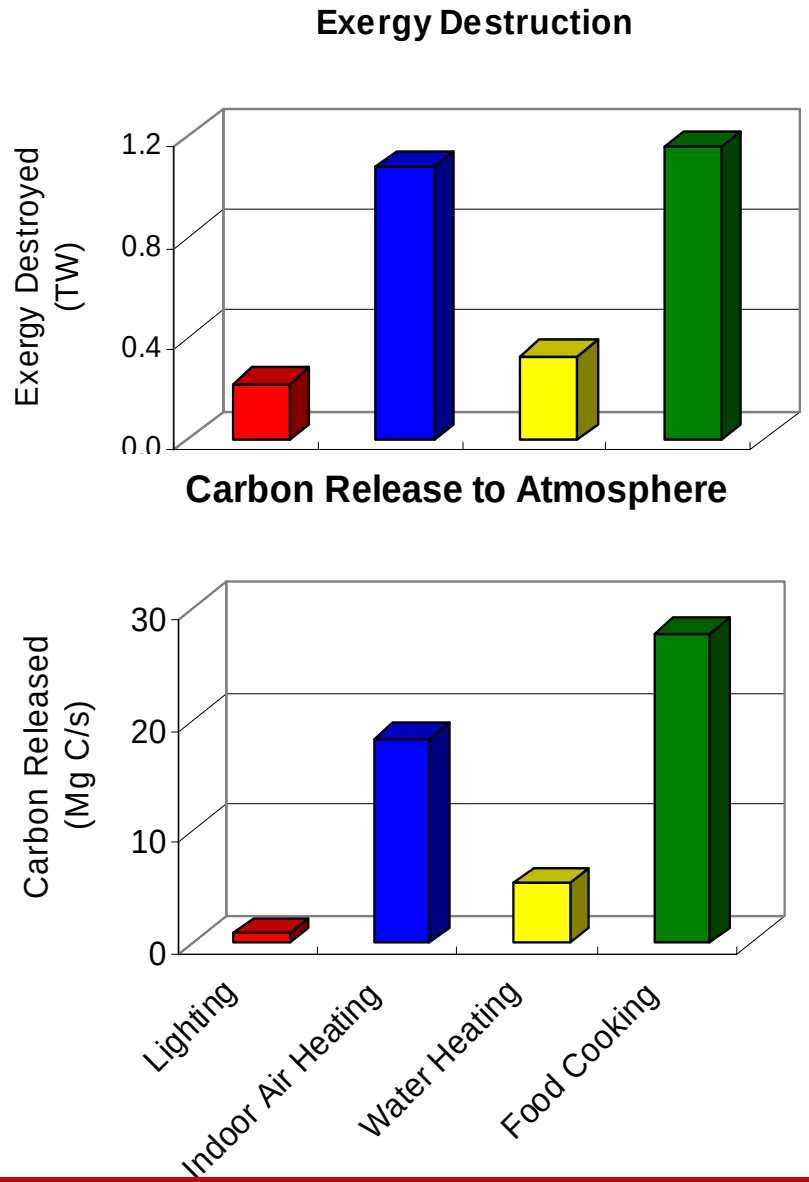
Global Exergy Destruction and Carbon Flows from Agriculture and Forestry

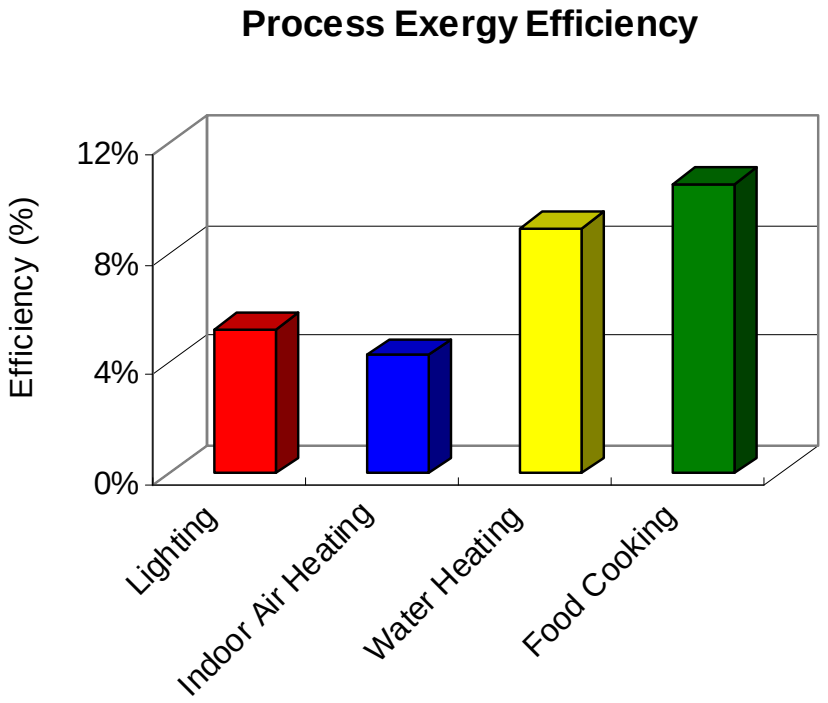




- Although not deployed primarily for energy production, agriculture and forestry represent significant pathways for exergy destruction within the human exergy system

Global Exergy Destruction and Carbon Flows for Heating, Lighting, and Cooking





- Very low conversion efficiencies

Future Analysis

- Maintain data with annual updates
- Deeper analysis of exergy destruction and carbon emissions, e.g.:
  - segmented across geographic regions
  - along specific energy pathways
- Define future scenarios and set parameters for technology pathways to achieve them, e.g.;
  - sustainable transportation system
  - sustainable electricity delivery system
- Develop new flow charts for:
  - Other greenhouse gases and materials (CH_4, N_2O, particulate matter, etc.)
  - Global warming potential
- Add time component to charts to yield a picture of the level of sustainability of global energy use.
- Develop user friendly web interface for exergy and carbon flow data.

Conclusions

- The transition to energy systems with much lower GHG emissions is one of the grand challenges we humans must face in this century.
- Carbon is currently being reintroduced to the biosphere through the human use of fossil fuels at a rate far exceeding its natural sequestration.
- Presented methodology for quantifying and linking together the major flows of exergy and carbon at a global level
- Can identify the energy conversions with potential to significantly impact the relationship between human exergy use and CO_2 emissions.
- Data provide a framework for analyses of the impacts of various technological advances and policy initiatives that could enable or encourage increased exergy efficiency or new energy pathways.

Acknowledgments

Wes Hermann
I-Chun Hsiao
Ljuba Miljkovic
A.J. Simon
Emilie Hung
Paolo Bosshard
Jenny Milne
Sally M. Benson
Lynn Orr