Sustainability Research Opportunities

John C. Crittenden, Ph.D., N.A.E., P.E.
Director – Brook Byers Institute for Sustainable Systems
Georgia Research Alliance (GRA) Eminent Scholar in Sustainable Systems
Hightower Chair in Sustainable Systems
Georgia Institute of Technology
School of Civil and Environmental Engineering

Georgia Tech

email: john.crittenden@ce.gatech.edu
http://sustainable.gatech.edu/

Outline

- What is Sustainability ?
- Grand Challenges: Targets and Solutions
- Education
- Concluding Remarks

Sustainability

- We need to recreate the anthrosphere to exist within the means of nature. That is, use resources that nature provides and generate waste nature can assimilate without overwhelming natural cycles.
- This will require us to examine the interactions between the engineered, social and economic systems.

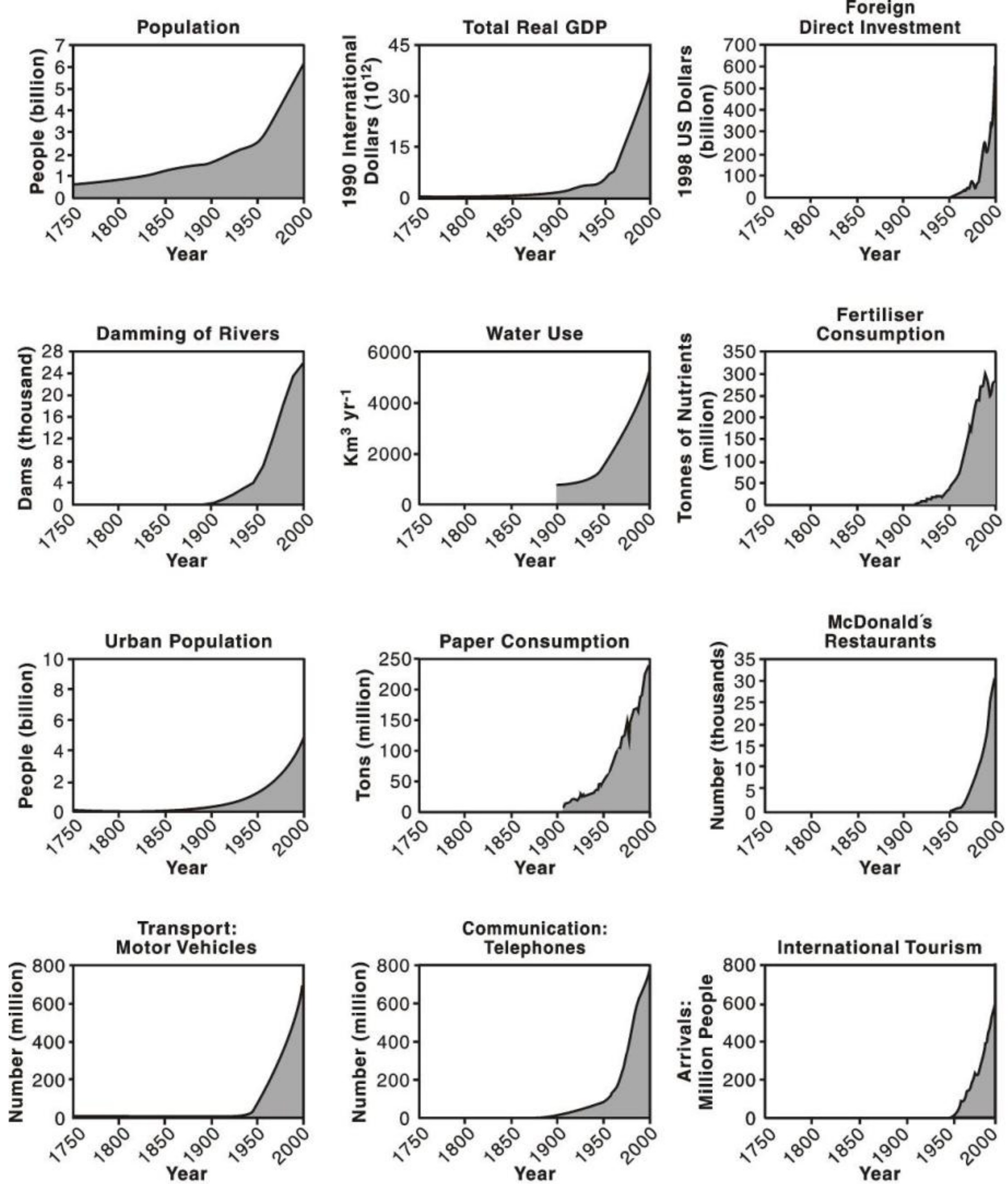
America's Grand Challenge - A Sustainable Future

John F. Kennedy inaugural address – January 20, 1961.

Inspired us to sacrifice for the greater good. Why not now?

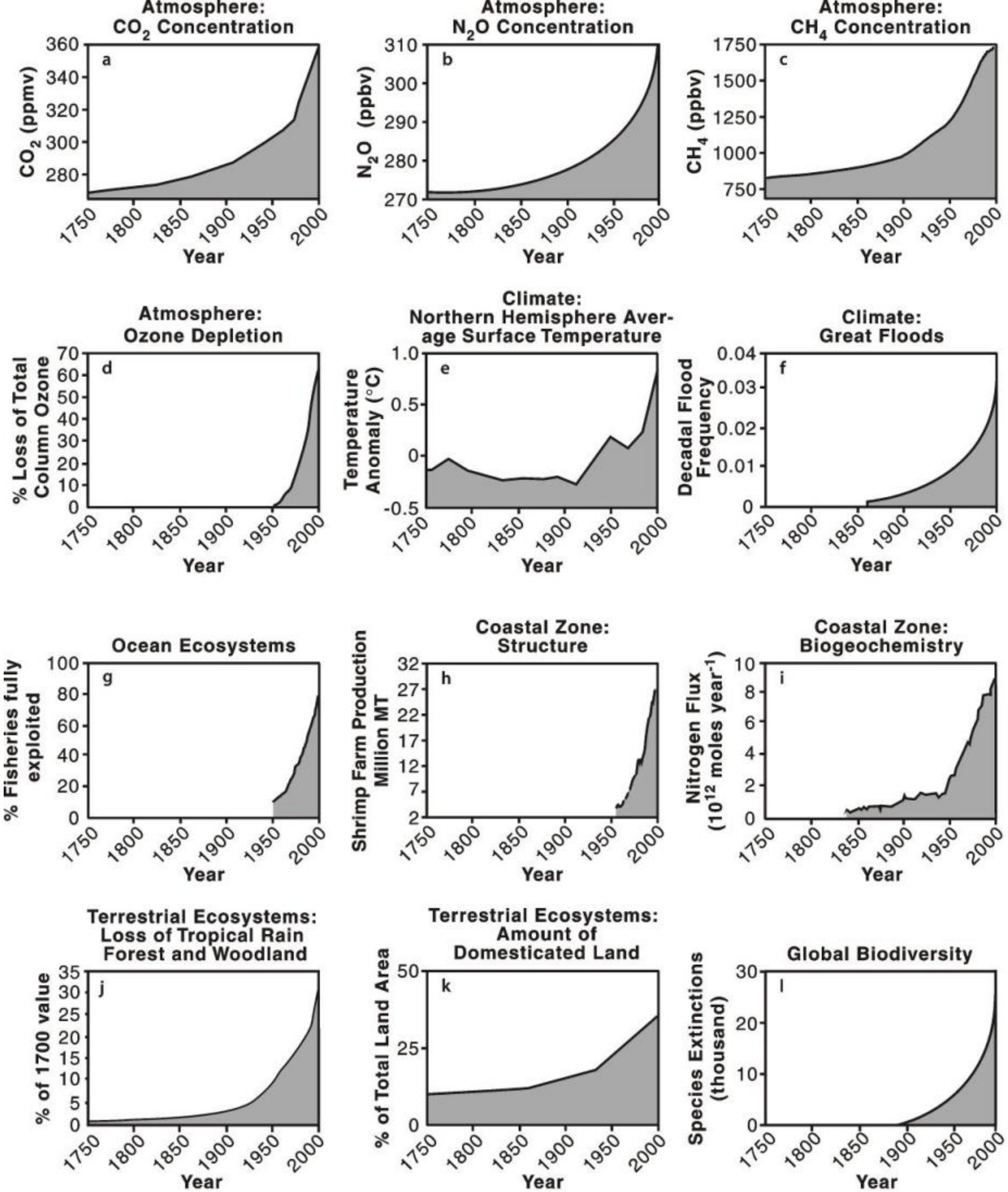
- Create an anthrosphere that exists within the means of nature. Uses resources that Nature can provide and generates wastes the Nature can assimilate.
- Provide the developing world opportunities to lead useful and productive lives
- Become a global leader in developing more sustainable technologies
- Achieve energy self-sufficiency by 2020 with efficiency, renewables and reduce Carbon Emissions 70%
- Become the most generous country in the world again by providing medicines, technology transfer, and aid to people in developing nations everywhere

Great Acceleration: Increasing Human Activities



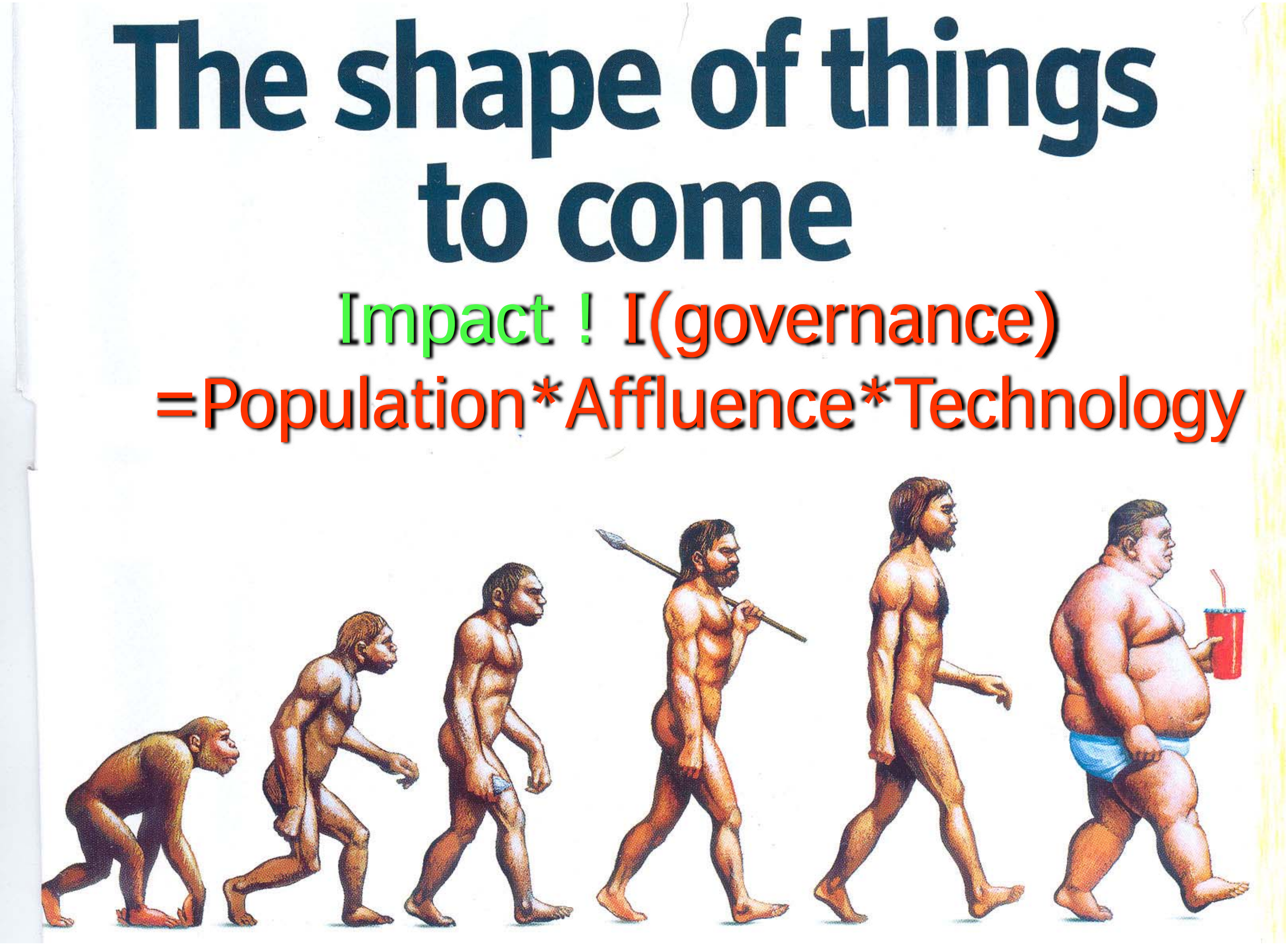
- Steffen, W.; Sanderson, A.; Tyson, P. D., et al. *Global Change and the Earth Systems: A Planet Under Pressure*; Springer-Verlag: Heidelberg, Germany, 2005

Environmental and Ecological Consequences



- Steffen, W.; Sanderson, A.; Tyson, P. D., et al. *Global Change and the Earth Systems: A Planet Under Pressure*; Springer-Verlag: Heidelberg, Germany, 2005

US Economy - Consumption



Automobiles

	I^1 = (impact)	P x (population)	A x (affluence)	T (technol.)
	gallons (billion)	pop. (million)	vmt/ capita	gallons/ mile
1970	80.1	205	5073	1/13.0
2002	129.8	288	9107	1/20.2
change	+62%	+41%	+80%	-36%

Source data from TRANSPORTATION ENERGY DATA BOOK: EDITION 24–2004;
Credit: Greg Keolian

Green Engineering Principles

- **Principle 1:** Designers need to strive to ensure that all material and energy inputs and outputs are as inherently nonhazardous as possible.
- **Principle 2:** It is better to prevent waste than to treat or clean up waste after it is formed.
- **Principle 3:** Separation and purification operations should be designed to minimize energy consumption and materials use.
- **Principle 4:** Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency.
- **Principle 5:** Products, processes, and systems should be "output pulled" rather than "input pushed" through the use of energy and materials.
- **Principle 6:** Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition.
- **Principle 7:** Targeted durability, not immortality, should be a design goal.
- **Principle 8:** Design for unnecessary capacity or capability (e.g., "one size fits all") solutions should be considered a design flaw.
- **Principle 9:** Material diversity in multicomponent products should be minimized to promote disassembly and value retention.
- **Principle 10:** Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows.
- **Principle 11:** Products, processes, and systems should be designed for performance in a commercial "afterlife".
- **Principle 12:** Material and energy inputs should be renewable rather than depleting.

- Paul Anastas

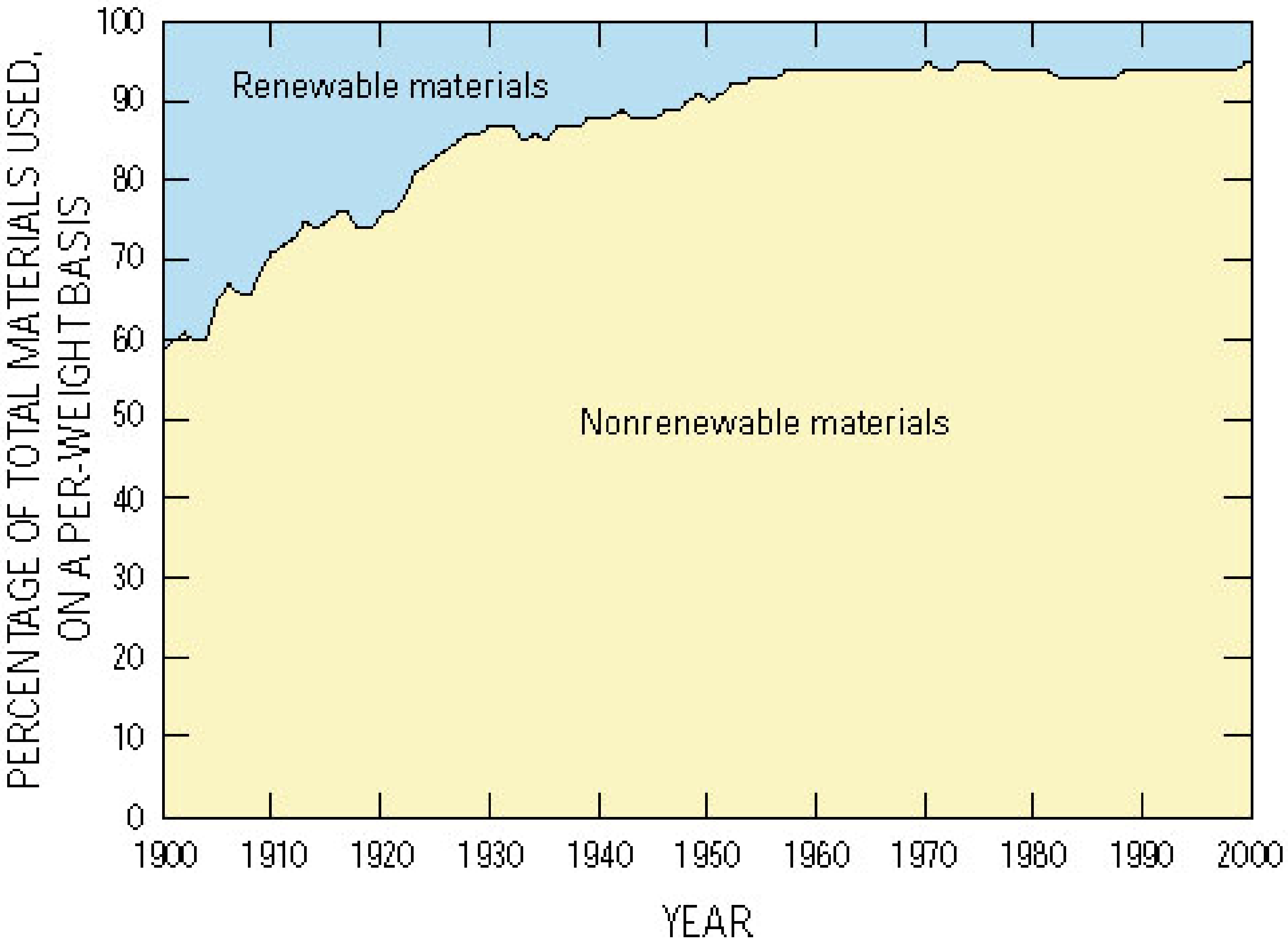


Figure 3. Renewable and nonrenewable materials used in the United States. Use of nonrenewable resources has increased dramatically in the United States during the 20th century (modified from Matos and Wagner, 1998, fig. 2).

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Great Engineering Achievements of the Last Century

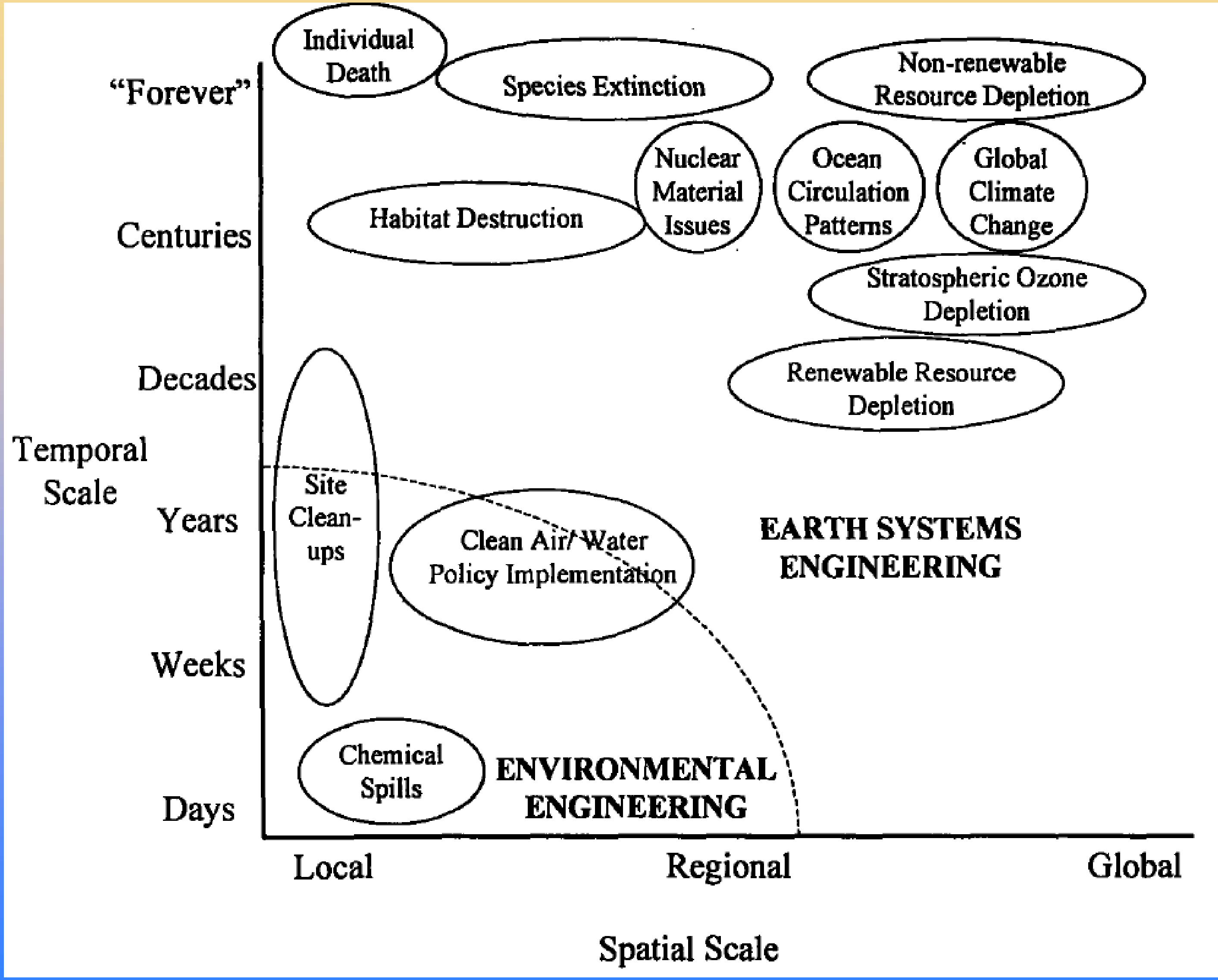
1. Electrification
2. Automobile
3. Airplane
4. Water Supply and Distribution
5. Electronics
6. Radio and Television
7. Agricultural Mechanization
8. Computers
9. Telephone
10. Air Conditioning
11. Highways
12. Spacecraft
13. Internet
14. Imaging
15. Household Appliances
16. Health Technologies
17. High-Performance Materials
18. Laser and Fiber Optics
19. Nuclear Technologies
20. Petroleum and Petrochemical Technologies

- Impact on quality of life was the strongest determining factor.
- All these technologies were predicated on the basis of cheap abundant dirty fuels for 100 Years.
- Is our research portfolio continuing this trend?

Credit: Joe Hughes

Spatial and Temporal Space of Earth Systems Engineering

Source: J. of Industrial Ecology, vol. 2, No. 3, 1999



Environmental Engineering versus Earth Systems Engineering

Source: J. of Industrial Ecology, vol. 2, No. 3, 1999

Characteristic	*"Environmental engineering"*	*"Earth systems engineering"*
Scientific model	Reductionist (e.g., based on toxicology)	Integrative (e.g., based on industrial ecology)
Scale	Short term/local	Long term/regional or global
Culture/ethical content	Low	High
Technology	Minor adaptations	Major evolution of technology systems
Nature of engineered system	Primarily technical and economic	Coupled human–natural systems
Engineering psychology	Control and complete systems definition	Management of complex "noncontrollable" systems
Focus	Artifact design, construction, and performance	Systems dynamics: links, feedback loops, nonlinearities, and discontinuities
Goal	"Home run"—fix problem for good	Continuous process maintaining dynamic systems in desired states

Sustainability Uncertainty Principle: Similarly to the Heisenburg uncertainty principle, if one takes a microscopic view and examines only a select few human and industry activities and does not consider all the activities that have an impact on the economy, environment and social conditions, then the less certain one can be about whether sustainable choices are being made, because one needs to consider all human and industrial activity in a given region. Moreover, sustainability is more than Ecoefficiency or Environmentally Responsible Manufacturing. It includes social processes including informed decision making, improving social conditions, social justice and equal opportunity. Impacts of various choices on the social fabric can not be considered by looking only at industrial and economic activity and their environmental impacts.

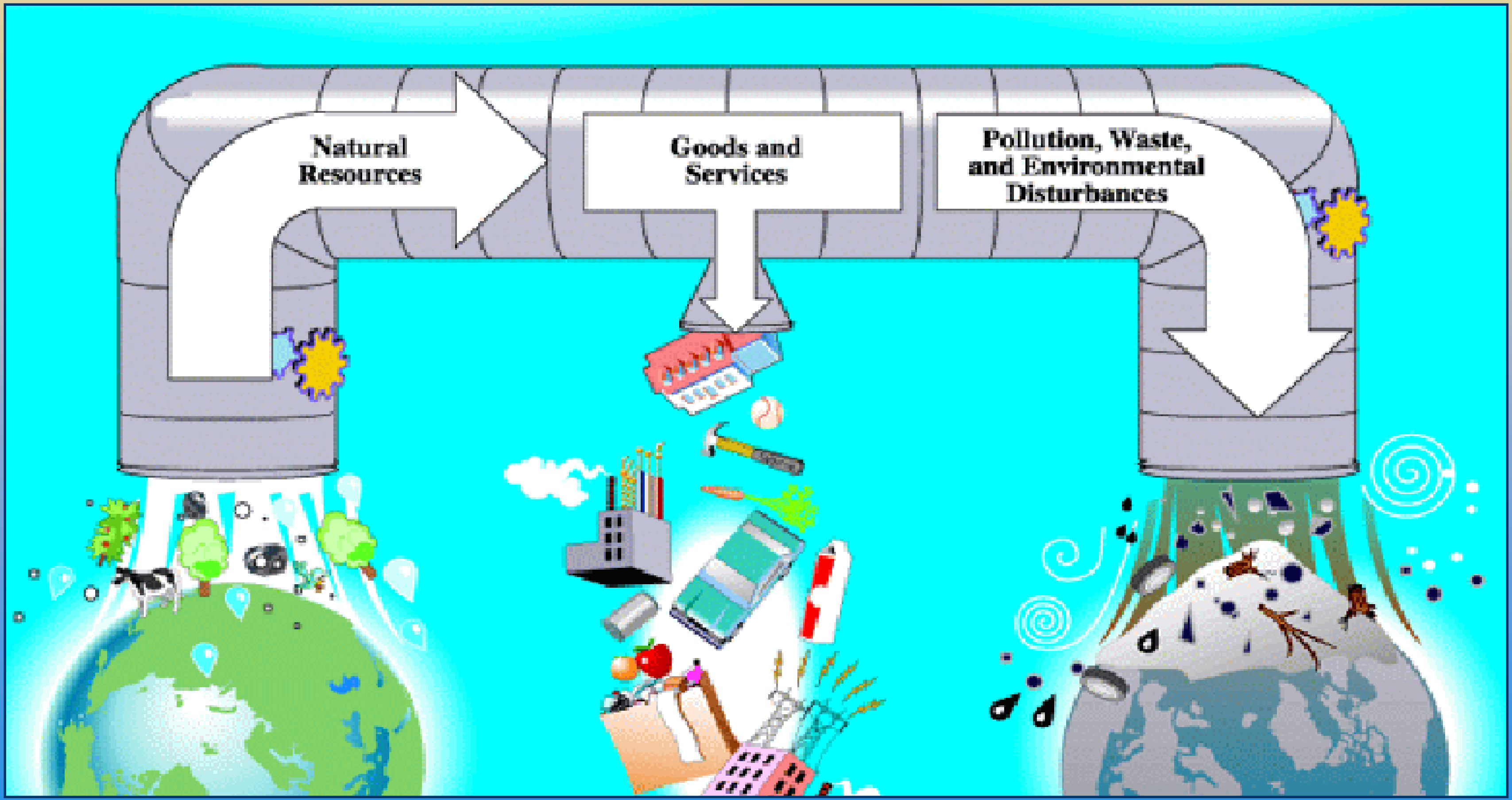
Technology is Not Enough - Need to Consider the Demand Side

affluenza, n. a painful, contagious, socially transmitted condition of overload, debt, anxiety and waste resulting from the dogged pursuit of more. (de Graaf [1])

affluenza, n. 1. The bloated, sluggish and unfulfilled feeling that results from efforts to keep up with the Joneses. 2. An epidemic of stress, overwork, waste and indebtedness caused by the pursuit of the American Dream. 3. An unsustainable addiction to economic growth. (PBS [1])

Increasing Material Use Depletes Resources and Impacts the Environment:

Engineering alone is not the answer. How many hybrids can the earth sustain? We need to think about reducing demand.



Credit: Jonathan Lash (2005)

CO_2 Target – 70% Reduction

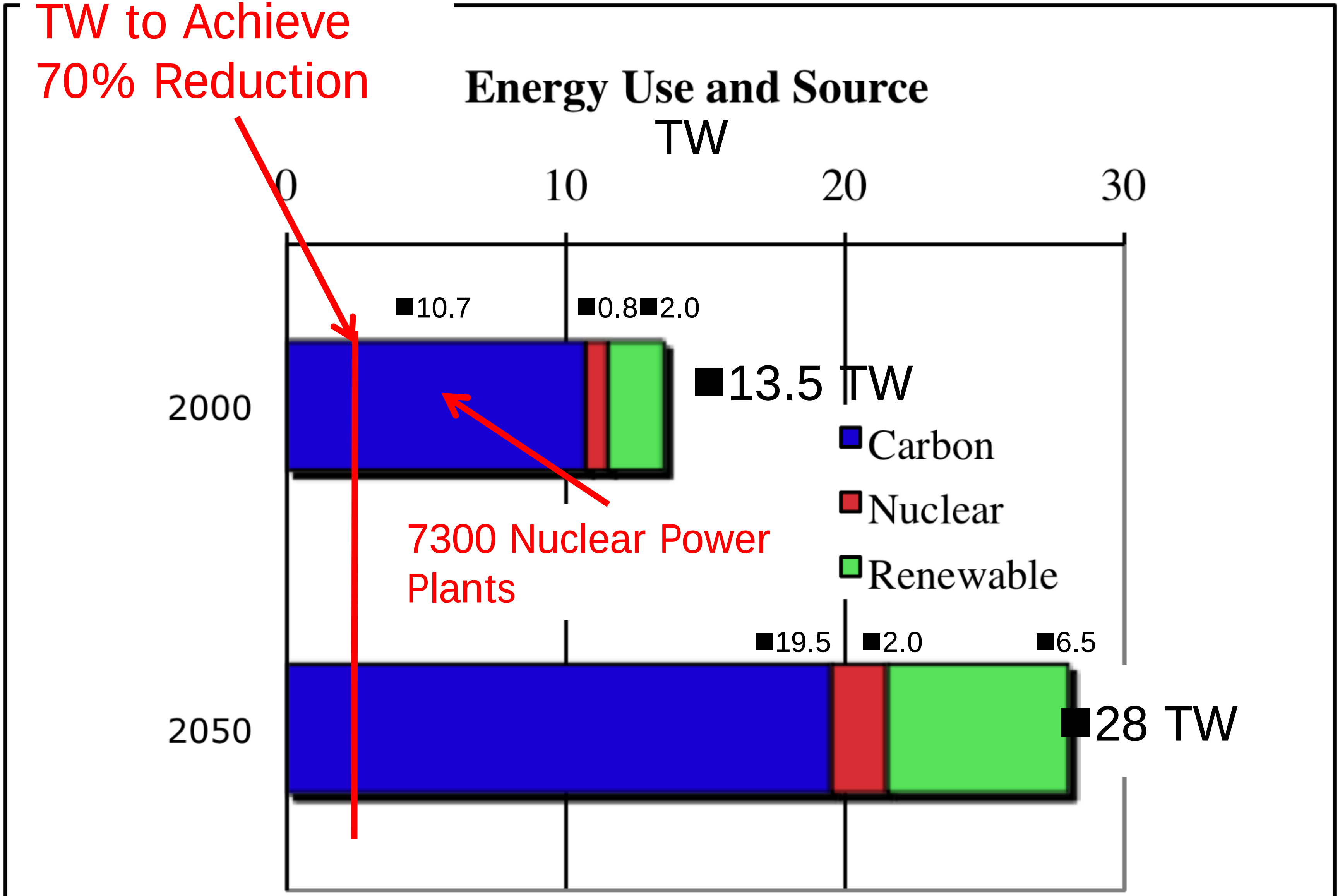
NCAR study to be published in *Geophysical Research Letters(2009)*

- Supercomputer studies with the NCAR-based Community Climate System Model (CCSM)
- Negative effects of climate change are unavoidable, but...
- If CO2 stabilized at 450 ppm, worst effects could be avoided.
- Sea-level rise would be about 14 cm (thermal expansion).
- Permafrost and Land Based Glacier Melt would largely be avoided.
- Business-as-usual = 750 ppm by 2100

Decision Time – Climate Change

- Avoid the unmanageable
- Manage the unavoidable

Need to cut to 3.2 TW to Achieve 70% Reduction



Not Meant as Nuclear Power - Bashing but Nuclear Option = 16,300 Plants (Build 1/day for 44 years!)

Earth Systems Engineering and Management – Demand Side

- Turn off all transportation – 14% reduction in Carbon Dioxide Emissions
- Turn off all commercial and residence use – 68% reduction in Carbon Dioxide Emissions
- Stop all deforestation – 22% reduction in Carbon Dioxide Emissions

Decision Time – Climate Change

- Avoid the unmanageable
- Manage the unavoidable

Urban Transformation

- Double the urban infrastructure in the next 35 years (Took 5,000 years to get to this point)
- Challenge will be to insure that we develop long terms social, economic and environmental assets and not liabilities.
- It will last more that 50 years and 80 to 90% of the impact is during the use phase.
- Currently 49% of the world's population and 81% of the US population lives in urban areas, a figure which is expected to grow to 61% and 87%, respectively, 2030 (UNEP, 2005)

Engineering Complex Systems – Big Science Opportunities

- Predict the emergent properties of urban systems (e.g., economic structures, material, energy use, traffic and transportation patterns, urban health, heat island, land use and density, air quality, local regional and global impacts of the resource demands and waste generation)
- Understand how the flows of resources (information, energy, and materials) are utilized and reduce material and energy investments
- Develop the cyber infrastructure to gather information monitor, model and visualize the complex emergent properties
- Develop the pedagogy of engineering complex systems in the context of sustainability of urban systems

Biofuels and CO_2

A non-systems approach to carbon reduction.

Current biofuels markets and policies illustrate how ignoring a systems approach when dealing with complex systems can be detrimental.

- Food price spikes
- Increased land in agricultural production, land use conversion
- Increased fertilizer use

- Increase in green house gasses?

- Increase in N2O from fertilizers. It is 300 times more potent and lasts longer than CO2.

Biofuels and CO_2

Land conversion from natural ecosystem to biofuel crop

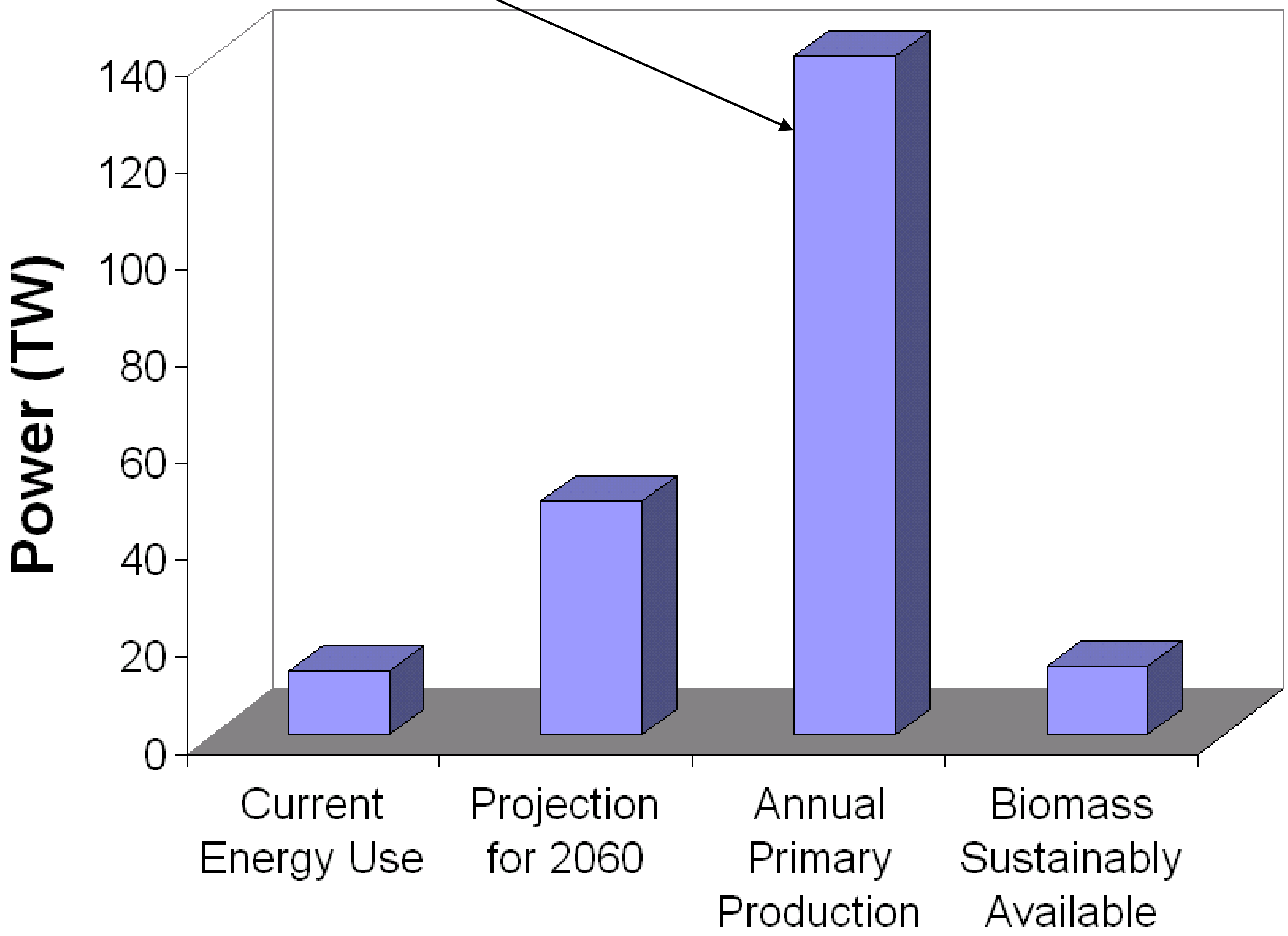
Habitat	Carbon debt ($Mg\ CO_2\ ha^{-1}$)	Annual repayment ($Mg\ CO_2\ ha^{-1}\ yr^{-1}$)	Time to repay carbon debt (Yr)
Indonesian/Malaysian rainforest to palm biodiesel	610	7.1	~86
Indonesian/Malaysian peat land rainforest to palm biodiesel	3000	7.1	~420
Amazonian rainforest to soybean biodiesel	280	0.9	~320
Cerrado woodland to sugarcane ethanol	165	9.8	~17
Cerrado grassland to sugarcane ethanol	85	0.9	~37
US central grassland to corn ethanol	134	1.2	~93

- **Prairie Marginal Grass Land** in the US could be converted with **No Debt**. How much is there?

Credit: Joseph Fargione, Jason Hill, David Tilman, Stephen Polasky, Peter Hawthorne, 2008

Energy from Biomass

Only 0.08% of the incident solar ray of 178,000 TW



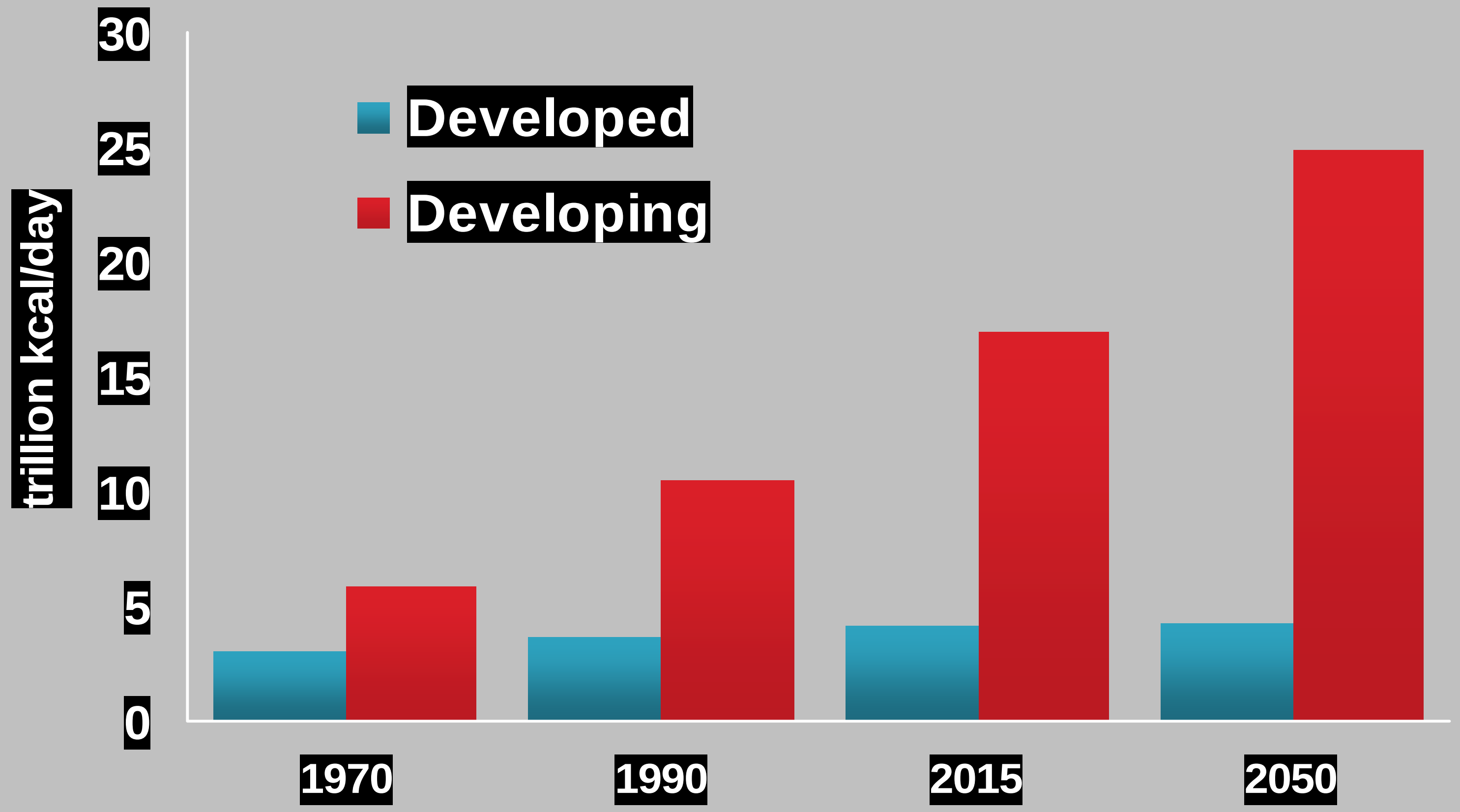
Credit: Andrew Kato Marcus

Pick your mix

There is no single answer!

A mix of solutions will be required: Wind, Nuclear, Hydro, Solar, Conservation, etc.

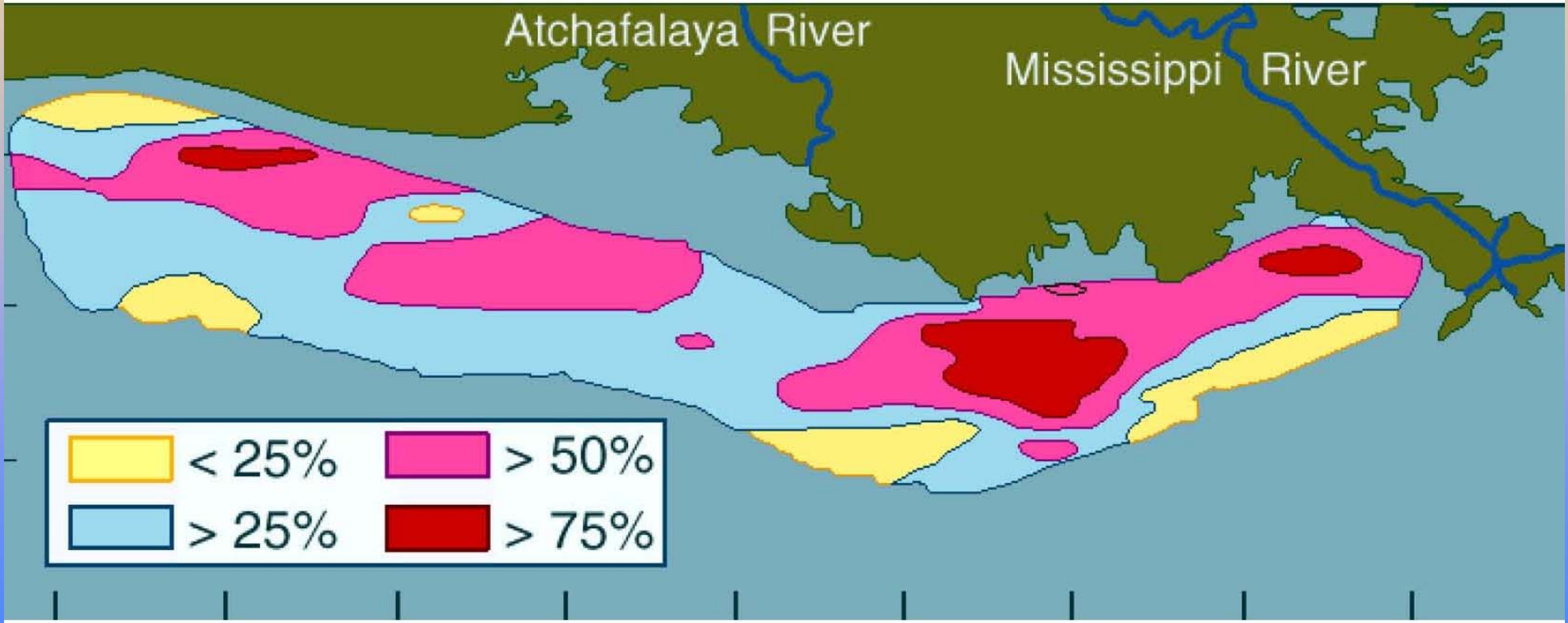
Increasing Food Demand Threatens Ecosystems



Credit: Jonathan Lash (2005)

Extent of Hypoxia in the Gulf

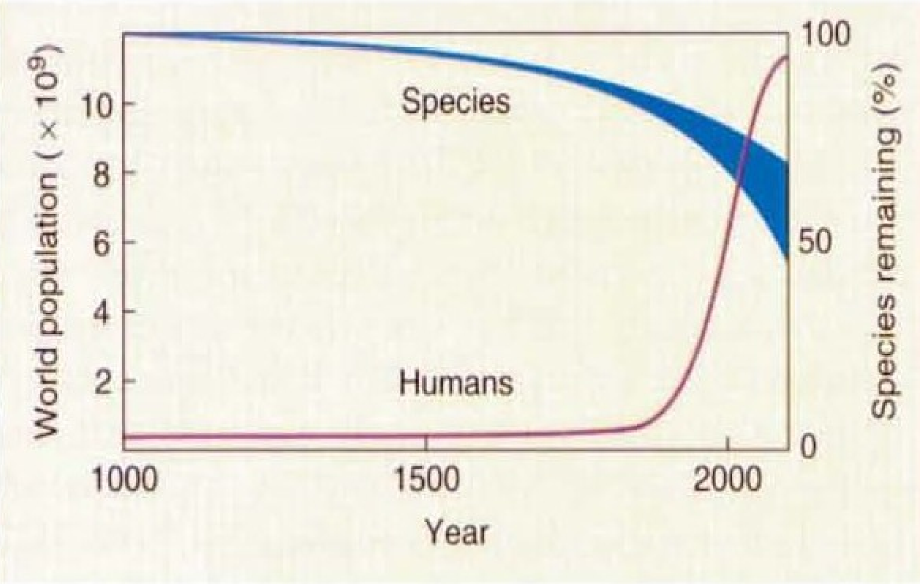
Frequency of Occurrence 1985 - 1999



Distribution of frequency of occurrence of midsummer hypoxia — based on data from Rabalais, Turner and Wiseman

Credit: Jerald Schnoor

Grand Challenge   Biodiversity decline



Perhaps 40,000 species per year are lost out of ~4-14 million total (but only 1.7 million are known).

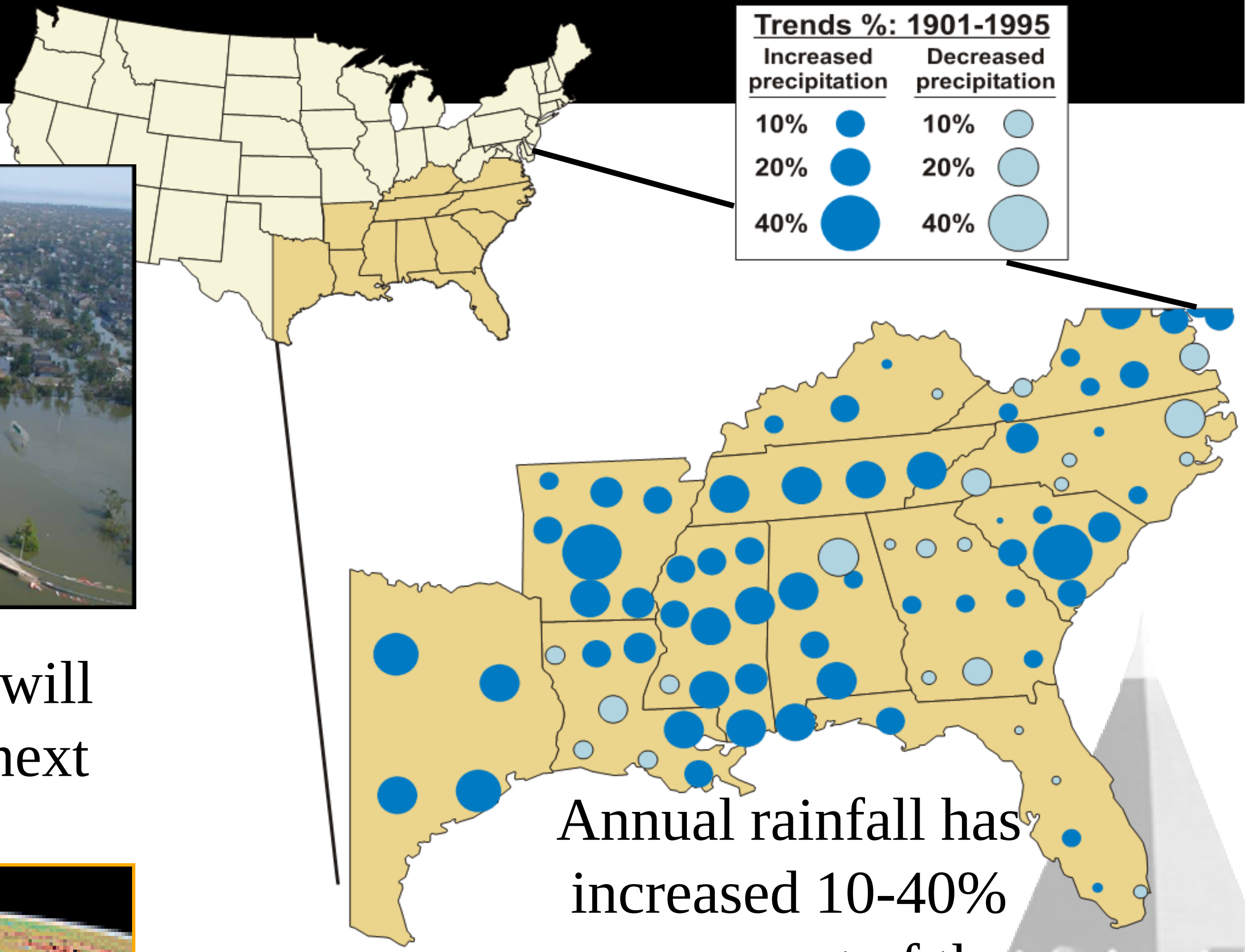
E. O. Wilson (2002) *The Future of Life*

Graph from M. Soule, UCSD.

Credit: Jerald Schnoor

Climate Changes

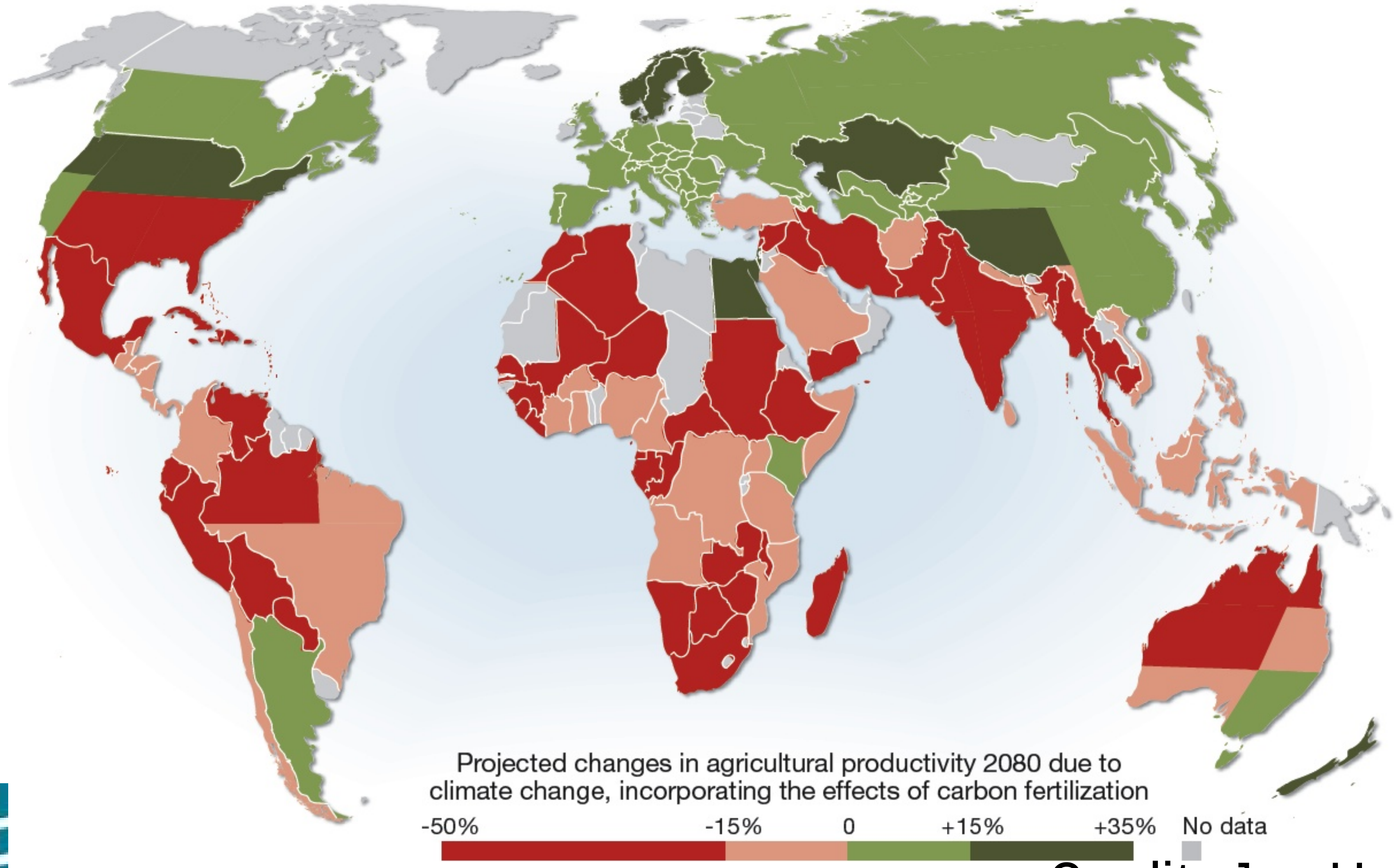
Sea level rise will accelerate in next 100 years



Annual rainfall has increased 10-40% across most of the Southeast.

Credit: Joe Hughes

Agriculture and Infrastructure



Credit: Joe Hughes

Global Water and Sanitation

4 billion suffer chronic water borne disease

2.3 billion lack any sanitary facilities

1.3 million children die each year from diarrhea

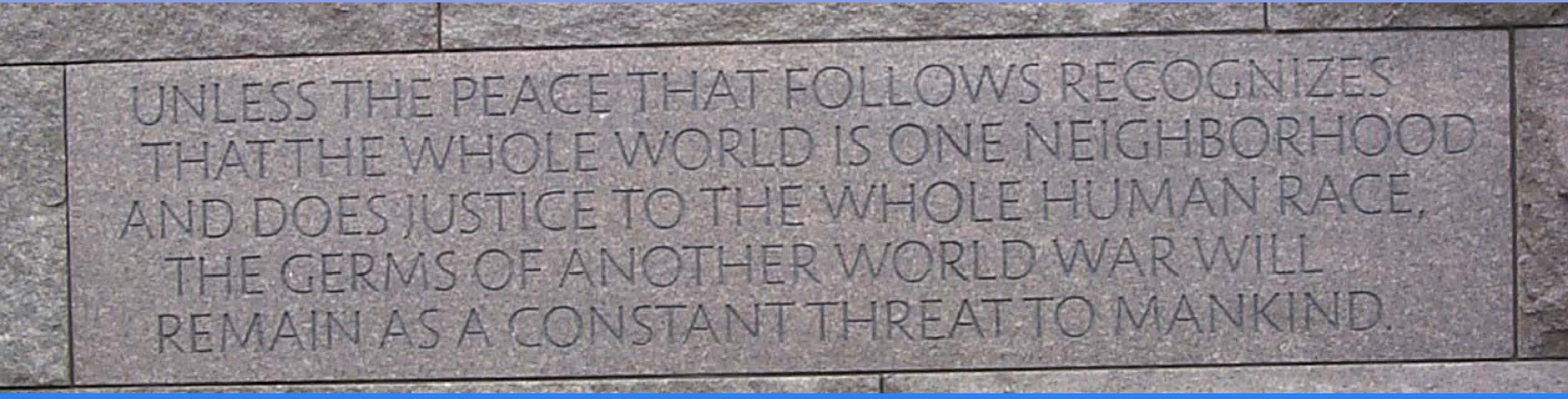
Credit: Joe Hughes

Connection Between Sustainability, and Oppression, Tyranny and Terrorism

We must develop opportunities for all regardless of background, ethnicity and beliefs.

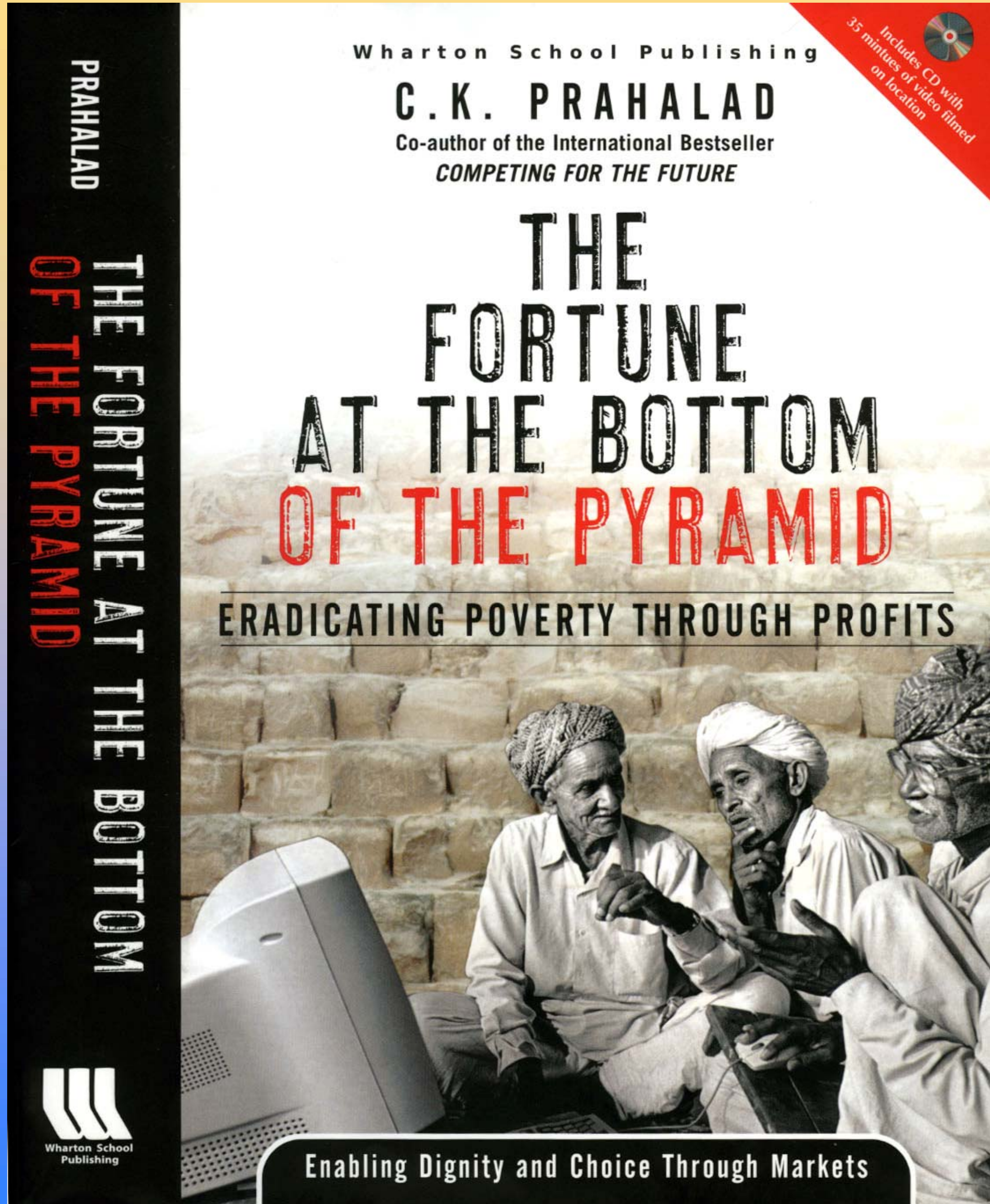
- If we need reduce poverty and provide a means for people to lead useful and productive lives, then we will make the world a safer, just and more prosperous and secure place.
- Sustainability is not about eco-efficiency for the rich, but rather the development of opportunity for all people.

Franklin D. Roosevelt Memorial (Washington, D.C.):



Connection Between Sustainability, and Oppression, Tyranny and Terrorism

- We need to develop markets, technologies, sanitation, and clean water for the bottom of the pyramid.
- We need to help the developing countries, many of whom are failed states, lift themselves up and become part of the world economy as suppliers of goods and services and consumers.
- These opportunities will no doubt be high tech solutions to low tech problems that use less energy, require less maintenance and fewer resources to develop. These lessons learned should help in our quest to reduce energy and resource consumption in the developed world.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Teaching Sustainable Engineering

The Engineer of 2020

National Academy of Engineering

Committee Chair – Dr. G. Wayne Clough Former President of GT and now Secretary of the Smithsonian

Effort to anticipate the role of engineering disciplines in the near future and to make recommendations for the adaptation of engineering curriculum.

Used scenario-based planning approach, concluding that:

- Interdisciplinary and systems-based approach should be emphasized
- Broad-based curriculum including global perspective, business, public service, and ethical foundation
- Graduates will need strong analytical skills, leadership, creativity, ingenuity and professionalism
- Entire engineering profession should frame public perception of engineers, educational institutions help build that frame

Teaching Sustainable Engineering

Center for Sustainable Engineering
Benchmarking Sustainable Engineering Education

Three approaches to incorporating sustainability

- Curricula – degree programs, inter- and intra department, multi-institutional, double majors, certificates and concentrations, core curriculum reform
- Courses – dedicated courses, integrate sustainability concepts into traditional courses, modules on sustainable technologies, cross-listed courses
- Research – funding $, student participation in research, focus categories similar to courses in sustainability, above

Teaching Sustainable Engineering

Center for Sustainable Engineering
Benchmarking Sustainable Engineering Education

"Typical" sustainable engineering course

- Upper division undergrad, or grad
- 10 – 30 students
- Dedicated to sustainability topically
- Half have a textbook, one-quarter of those are:
  - Allen and Shonnard
  - Graedel and Allenby
  - Bishop
  - Hendrickson, Lave, and Matthews
  - McDonough and Braungart
- Half address social and policy issues
- Life cycle approach emphasized (i.e. cradle to grave)

Teaching Sustainable Engineering

Center for Sustainable Engineering
Benchmarking Sustainable Engineering Education

Characteristics of sustainable engineering research

- NSF funds half, DOD is distant second
- 750 + undergrad and grad students funded, ~300 not supported but participate
- ~$235 million per year reported in survey

Problem of defining what research is “sustainable.”

Teaching Sustainable Engineering

Center for Sustainable Engineering (NSF CLIT Supported)

Provide a vetting process to develop sustainable engineering modules

Developed a web based storage and retrieval space for the education modules

Holds Annual Conferences for Stakeholder Engagement

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Concluding Remarks

- Big science and engineering efforts are needed to create an anthrosphere that exists within the means of nature.
- Develop technologies that use renewable materials.
- Need to develop technologies that improve the lives in undeveloped countries
  - High tech solutions to low tech problems, less energy, less complexity, resilient (Applicable to the Developed World?)
  - Incentivize the implementation – microcredit?
- Funding at NSF for sustainability is small compared to the magnitude of the problem (Sustainable Engineering: 3 million per year, Energy and Environment 6 million per year, EFRI has one offs for 20 million ? per year)
- Should NSF Engineering require a sustainability impact statement that is quantitative?

Two Planets meet in Space

- **Arranging our ideological deck chairs on the Titanic**
- **Sooner or later, the earth will come into equilibrium; that is, resources generated will equal resources used. There are two fundamental questions: 1) Will humans be part of the new earth that is in equilibrium. 2) If humans are, will it be a comfortable place or a place wrought with armed conflict and social injustice because of limited resources.**

Credit: Volker Karthopf