Sustainable Engineering: Emergence of a New Paradigm

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Outline of the Presentation

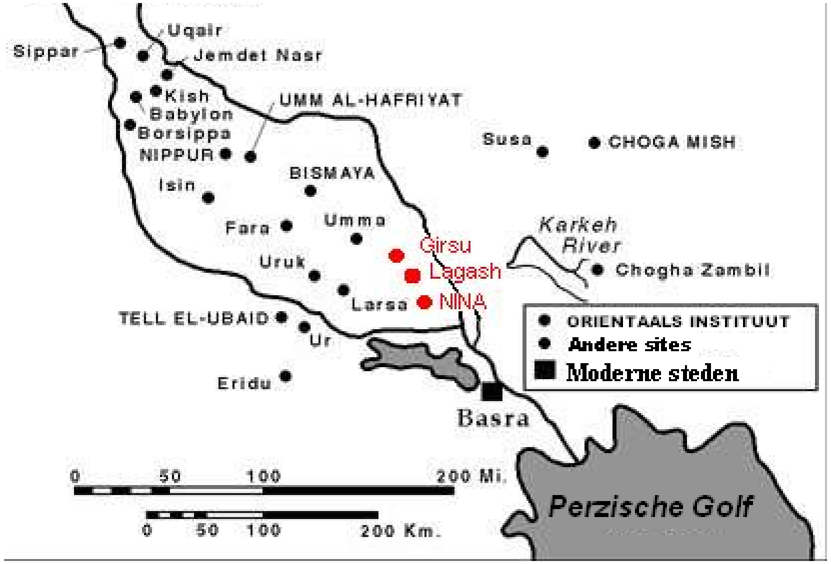
1. What we can learn from history and from modern data
2. “Sustainable Engineering” and indicators of sustainability
3. Roles of the engineer
4. The Center for Sustainable Engineering

Historical Perspectives on Sustainability

Sumerians in Mesopotamia 3000 BC

-- smelted copper using wood to provide heat energy, resulting in deforestation. When wood became scarce, recycling of copper began.

-- irrigated their fields in hot, dry conditions using water with high solids content: agricultural productivity fell as salts accumulated. Civilization collapsed around 1700 BC.

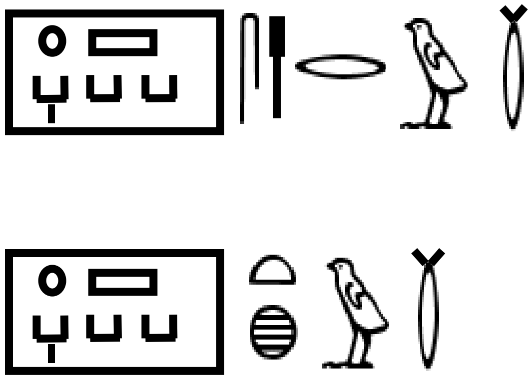


Historical Perspectives on Sustainability

Egyptians 2500 BC

-- used imported timber from Lebanon to build boats to bring granite blocks from Aswan up to Giza to build the pyramids.

-- boats were dismantled to provide wood for heat energy to make mortar for the pyramids and to smelt copper & gold.



Historical Perspectives on Sustainability

Greeks 800 BC

-- smelted bronze using local copper alloyed with tin imported from England

-- when tin became unavailable due to collapse of international trade, the Greeks recycled bronze religious artifacts to make weapons to defend themselves

Historical Perspectives on Sustainability

Greeks 400 BC

-- Plato wrote laws banning deforestation and described the possibility of resource wars

-- Aristotle described the differences between renewable and nonrenewable resources and how they should be used

Historical Perspectives on Sustainability

Romans 0-300 AD

-- transported olive oil in ceramic jugs that were discarded at a dump site where broken jugs now tower 35 m high

-- a portion of these broken jugs were used as construction material in later years of the Roman Empire

-- glass recycling became a big business in the later years

-- Roman architects designed houses with south-facing windows

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Historical Perspectives on Sustainability

Romans 0-300 AD

-- built aqueducts that could carry up to 1 million m^3 of water/day

-- built over 900 public bath houses, some with a capacity of 2000 bathers

-- had a per capita water consumption comparable to values today

Now consider modern civilization
Global scale problems: CFCs

CFCs as refrigerants developed in 1930's

- Former refrigerants were SO_2 and NH_3
- CFCs: nonflammable, nontoxic, chemically stable
- Besides refrigerants, CFCs widely used as aerosol spray propellants, industrial solvents, fire suppressants

Discovery in 1980's (WMO, 1999)

- Stratospheric O_3 depletion in the Antarctic allowed more uv radiation to reach earth's surface
- Caused by chlorine atoms from CFCs
- Stability: 1 Cl atom can destroy 10^5 O_3 molecules

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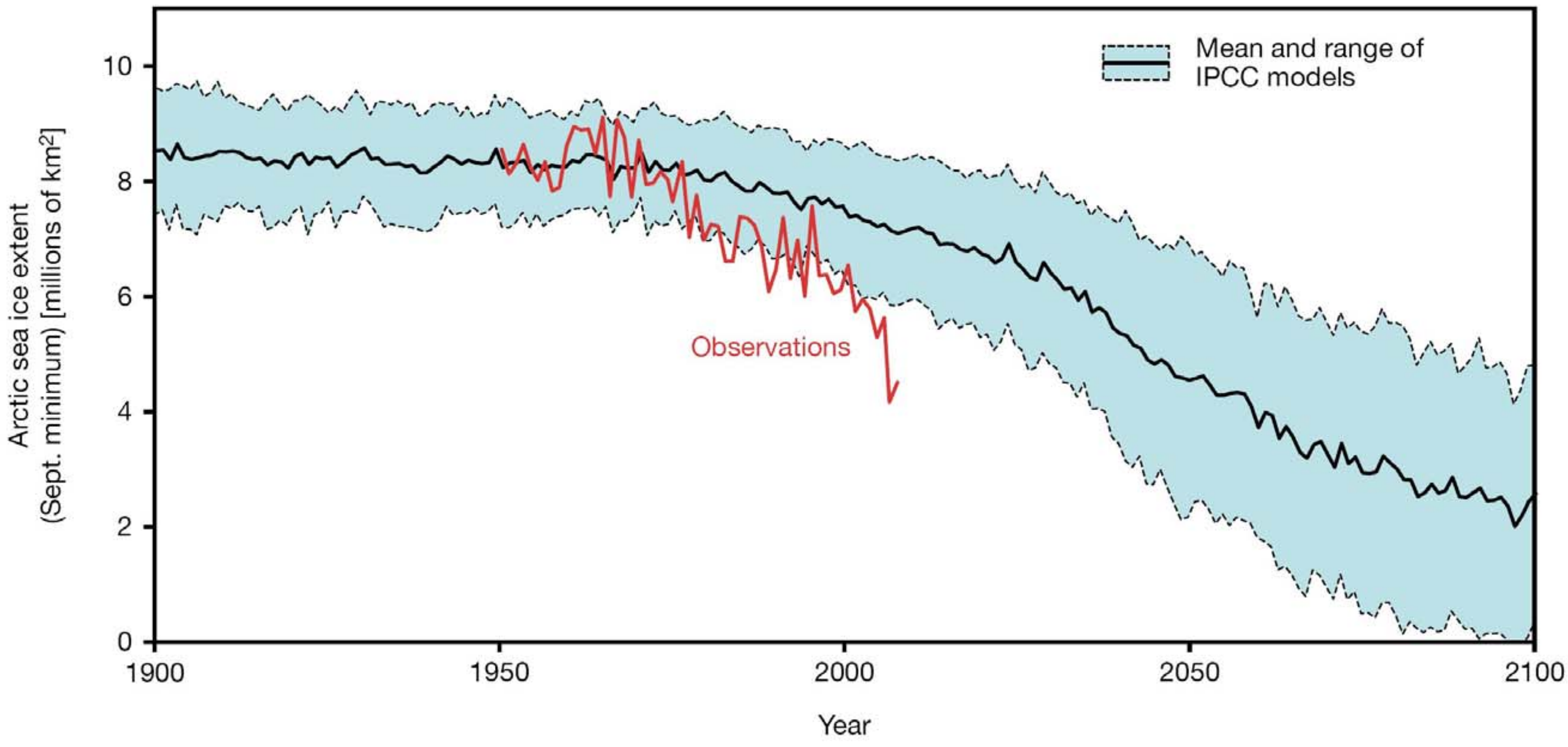
Global scale problems: Climate Change



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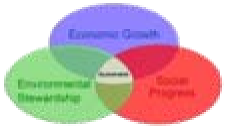
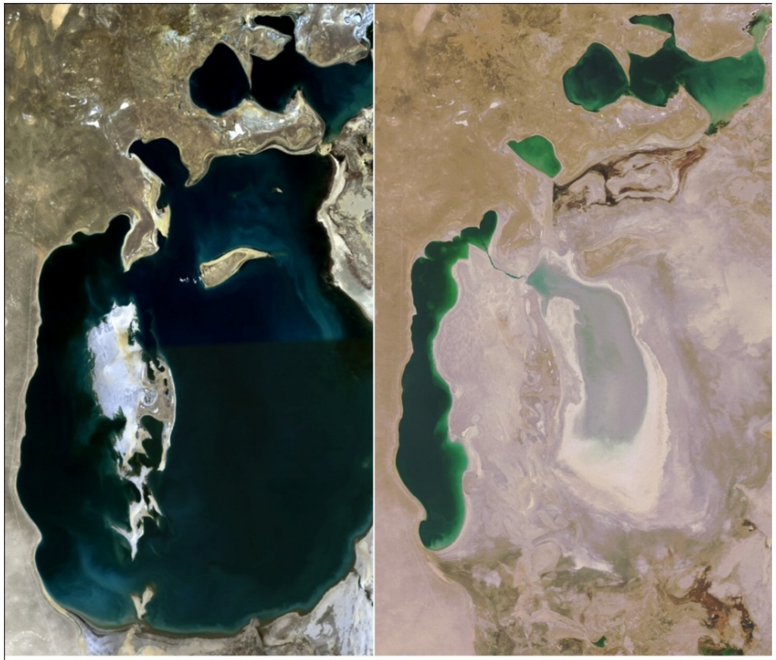


Destruction of the Aral Sea
4^{th} largest body of freshwater

-- rivers feeding the Aral Sea (on border between Uzbekistan and Kazakhstan) were diverted for cotton farming beginning in the 1960's

-- water is now essentially gone, dry lake bed responsible for episodes of dust contaminated with fertilizers and pesticides



NASA Photographs

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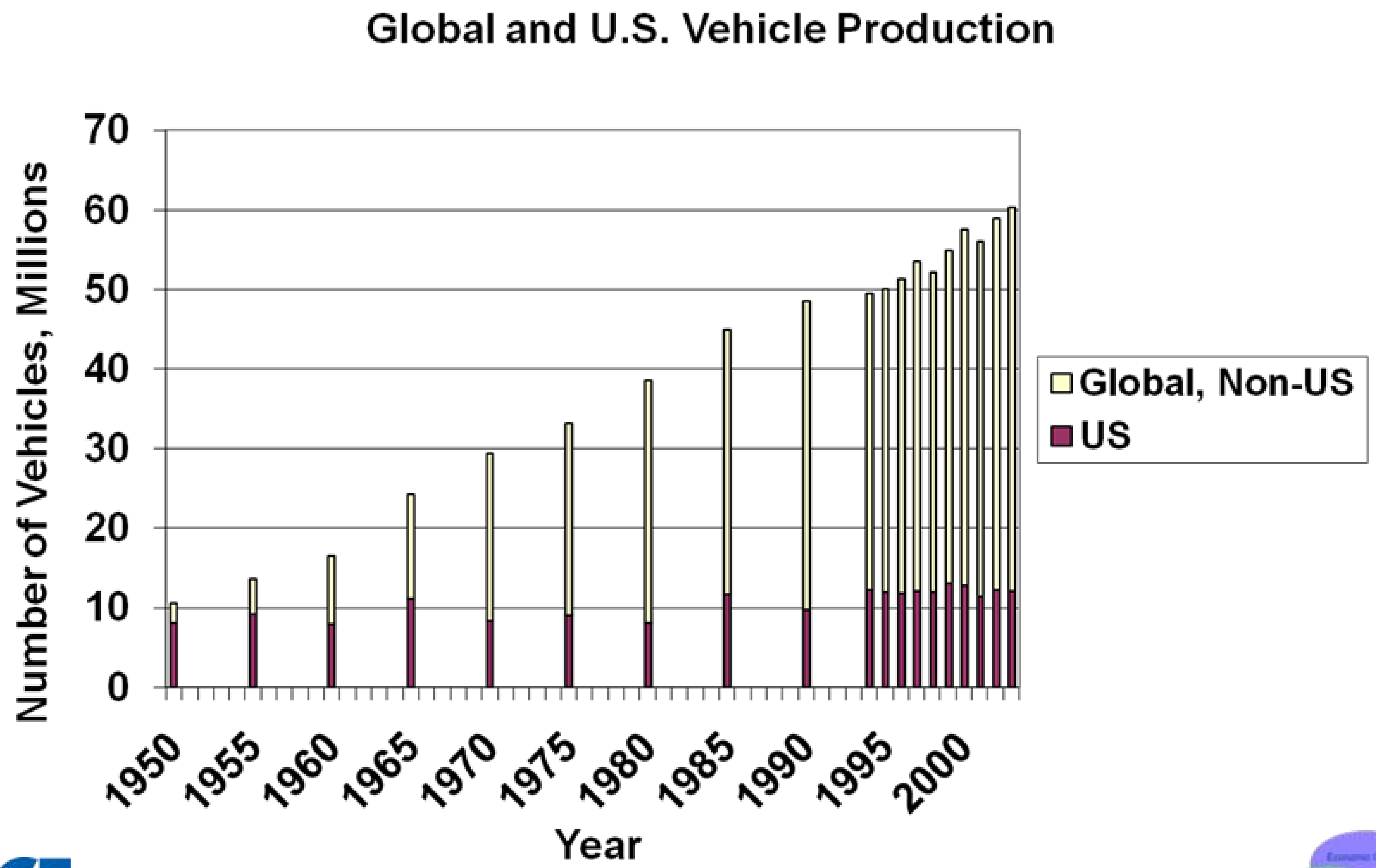
Motor Vehicles



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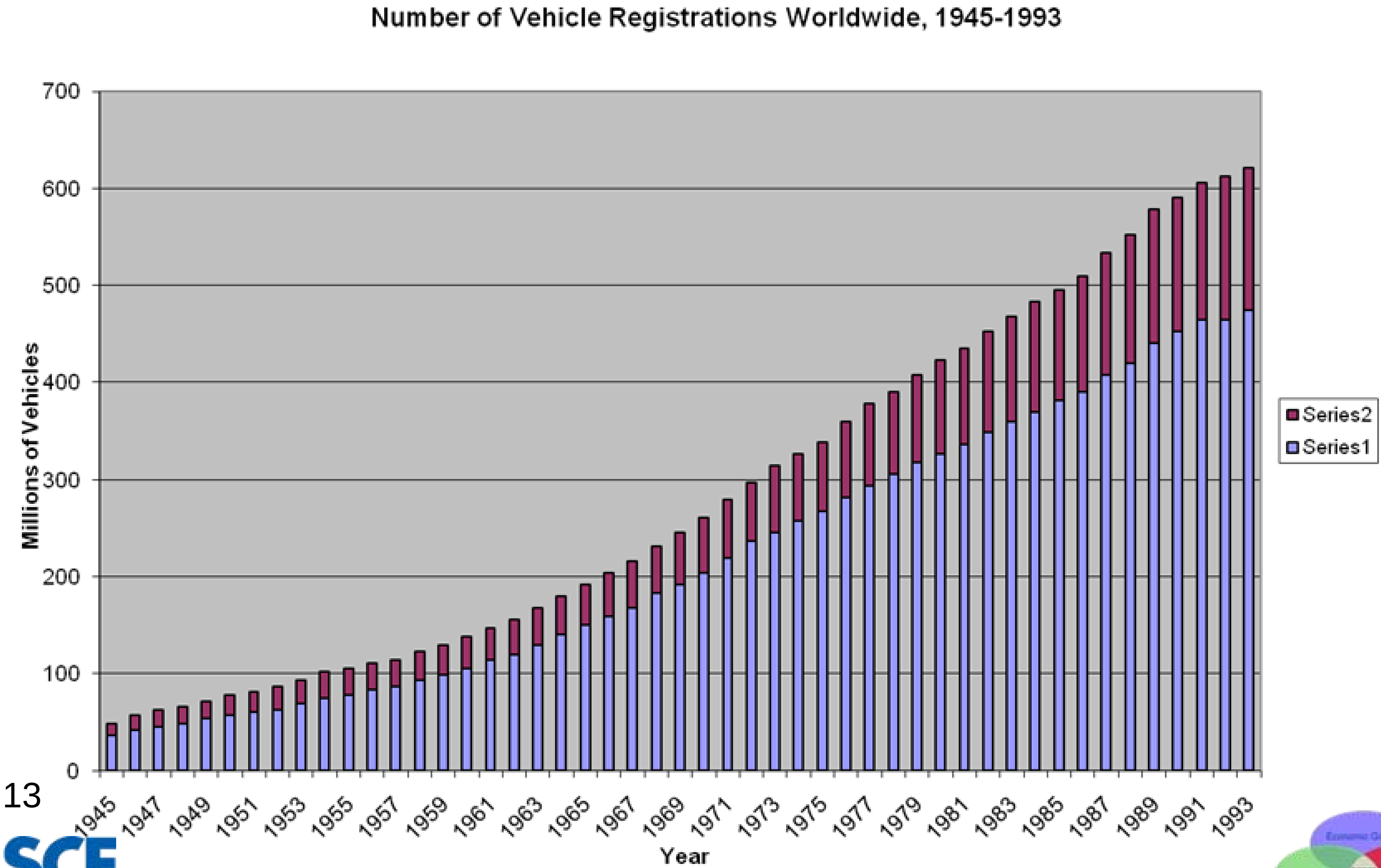
Motor Vehicles



Motor Vehicles

New vehicle production ~ 60 M/yr → Total global vehicle population ~ 800 M → Old vehicle retirement ~ 40 M/yr

Global vehicle population is increasing

- Average in G7 ~ 750 veh/1000 pop.
- Average in China ~ 24 veh/1000 pop.

Wikimedia photo – public domain

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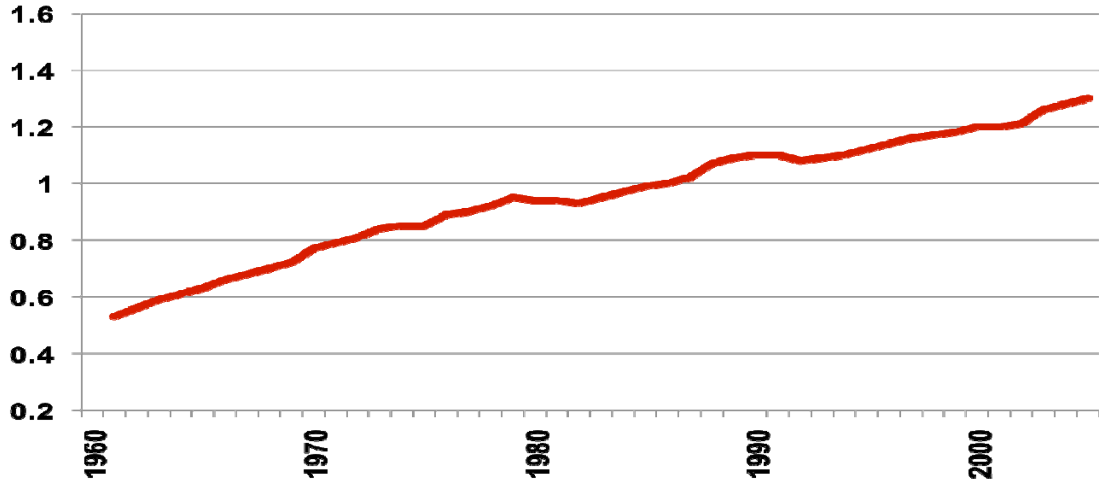
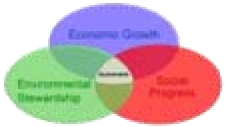
What have we learned from history and by examining today's trends?

- Early human civilizations had local shortages of energy, water, food, and materials. This affected standard of living.
- Today we have these as well as other problems on a global scale.
- Engineers are needed to assist in developing solutions.

Number of planet earths





2. Consider “Sustainable Engineering” – What is the relationship between “sustainability” and “engineering”?

- 2.5 Billion people live in areas without proper sanitation facilities

- 2 Billion people subsist on less than $2 per day

- “90% of the people who design things are addressing the problems of the richest 5% of people in the world” – Paul Polak of International Development Enterprises

- Design for sustainability: affordability as a key variable in design

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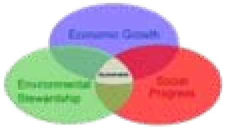
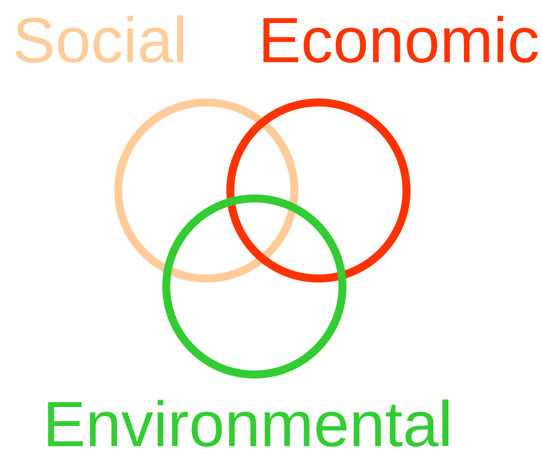


The modern view of sustainability

First publicized by the World Council on Environment and Development (WCED) in 1987:

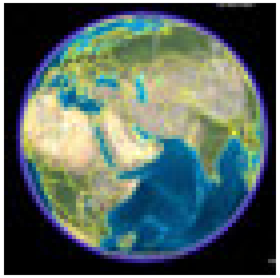
> “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”

Modern view of Sustainability includes social, economic, and environmental components

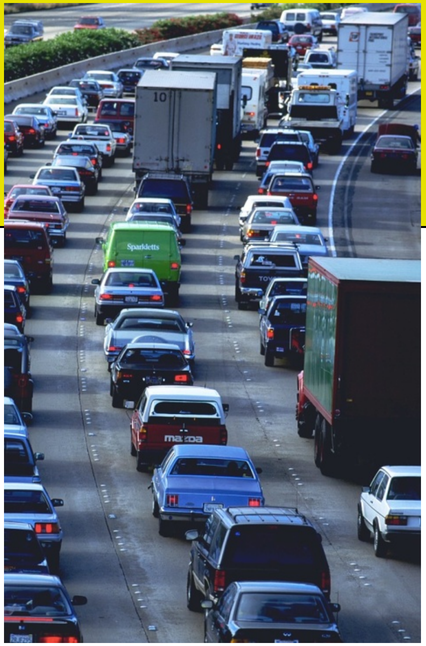


“Sustainability” is a nebulous term, but it…

- embodies principles we need to incorporate into our decision-making at all levels
- is a genuine reflection of society’s concerns about the future (population increases, resource wars, global change – climate, biodiversity, deforestation, ozone hole)
- is a pathway to capture attention of leaders and the public to promote lifestyle changes



So, we see that…



Sustainability is a relatively new concept

It is immature: experts don’t agree

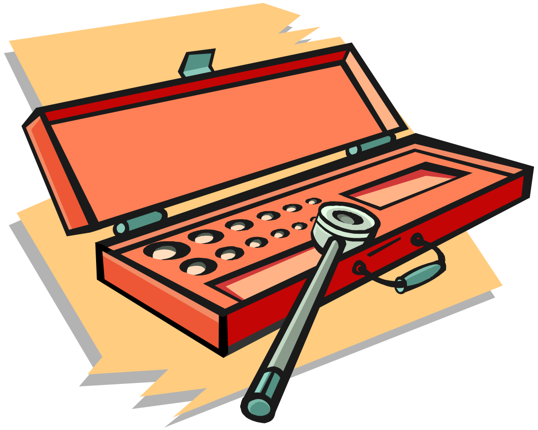
It is heavily “value-laden”

It generates a lot of media attention

Thus sustainability cannot be a technological or scientific construct – rather it is a *cultural construct.*

What are the characteristics of Engineering?

- Applied problem solving
- Pragmatic
- Depends on structured heuristics
- Highly quantitative



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Thus we have a mismatch.

- **Sustainability is a cultural construct that depends on societal values and requires assumptions about the future**

- **Engineering is a technological construct that must provide precise solutions to problems today, and may be sensitive to assumptions about the future**

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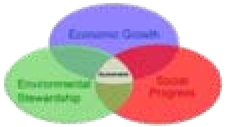
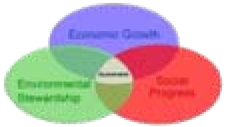


Engineers attempting to solve societal problems in a sustainable way can run into trouble if they:

-- don’t account for social and cultural issues
-- don’t consider global scale implications and long-term future
-- handle unpopular decisions inappropriately, e.g., if they ignore details, don’t bring all stakeholders together to discuss options, or make a poor decision
-- convince themselves that the world fully understands implications of most engineering decisions (we don’t)

We need a new paradigm: Sustainable Engineering



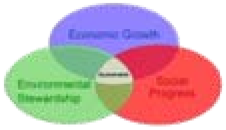
Indicators of Sustainability

- How can we gauge our progress toward sustainability?

Less sustainable ⟷ More sustainable

- What would we consider an acceptable endpoint?
- What variables can be quantified?

Consider: (1) a city
(2) a building
(3) human activities



What variables can define a "sustainable city"?

-- Use of water, materials, and energy per person
-- Production of waste per person
-- Average commuting distance and time
-- Vulnerability to natural hazards: earthquakes, weather extremes, uv radiation
-- Infrastructure: utilities, transportation networks, communications networks
-- Services: public health and safety facilities, crime control, fire protection, recreation
-- Population density and "footprint" per person

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Consider a city as a "system" with flows of material and energy.

Flows of all materials in and out of Vienna

Air 36

Off-gas 43

Water 147

Construction materials, consumer goods 12-18

Fossil Fuels 2

Sewage 144

Export Goods 3

Solid Wastes 3

Accumulation 4-10

Values in metric tons per person per year
Brunner and Rechberger (2004)

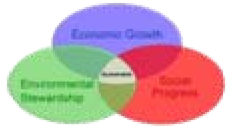
Population of the Ten Largest Cities in 1900 and in 2001

1900	Millions	2001	Millions
London	6.5	Tokyo	26.5
New York	4.2	Sao Paolo	18.3
Paris	3.3	Mexico City	18.3
Berlin	2.7	New York	16.8
Chicago	1.7	Mumbai	16.5
Vienna	1.7	Los Angeles	13.3
Tokyo	1.5	Calcutta	13.3
St. Petersb.	1.4	Dhaka	13.2
Manchester	1.4	Delhi	13.0
Philadelphia	1.4	Shanghai	12.8

Source: *State of the World 2003*, World Resources Institute

What variables can define a “sustainable building”?

-- Energy use in each phase of life cycle
-- Material use in each phase of life cycle
-- Ease of disassembly and reuse
-- Flexibility of use: movable walls,
movable furniture
-- Comfort: lighting, noise, vibrations,
microclimate, air quality
-- Use of gray water
-- Compatibility with the surroundings



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Components must work together as a system to enable the building to function as intended, e.g., residence, office, store, school, hospital, …

- Design
- Construction
- Operation

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Building Design

Examples of designs to promote sustainability (some based on LEED)

- **Materials: non-toxic, local, high recycled content, recyclable, low energy to produce, produced from renewables, produced by fair labor practices**
- **Energy consumption: passive or active solar, on-site renew. energy, alternatives to AC (fans), insulation, low-energy lighting, green power**
- **Water: appropriate landscaping, water use reduction, use of gray water, leak avoidance**

Building Construction

Examples of ways to promote green construction practices

- **Efficient management of labor, materials, equipment**
- **Minimization of construction waste**
- **Integration of perspectives of owners, contractors, specialty trades, and building managers**

Building Operation

Examples of ways to promote green operation of Buildings:

- **Education of occupants about building controls**
- **Individual appliance metering**
- **Timers on lights, computers, appliances, thermostats**
- **Incentives for occupants to conserve: sliding scale costs for energy and water**

What variables can define sustainable human activities?

-- Fraction of people who recycle
-- Fraction of people who take public transportation
-- Extent to which a local government promotes
enacting of environmental regulations
-- Extent to which a local government enforces
environmental regulations
-- Measure of environmental attitudes:
New Ecological Paradigm Scale (NEPS)

3. Roles of the engineer

As examples, consider three resources critical to society:

(1) land

(2) water

(3) metals and minerals

Resource 1: Land

- **The total potentially arable land in the world is about 3.5 Billion hectares (CIA Factbook, 2005). Besides farms, this includes land currently occupied by cities as well as forests, natural grassland, shrub lands, and other ecosystems. Roughly half of this land is currently used for food production.**

- **Land is one of our most important resources. It is needed to support natural ecosystems which:**
  - **-- harvest the sun's energy (reducing local entropy)**
  - **-- convert carbon dioxide from the air to glucose and other hydrocarbons to provide energy for web of life**
  - **-- reduce global warming**
  - **-- purify water for re-use**
  - **-- provide diversity of living plants and animals that are necessary for agriculture**

Engineers must help safeguard the land.

Resource 2: Water

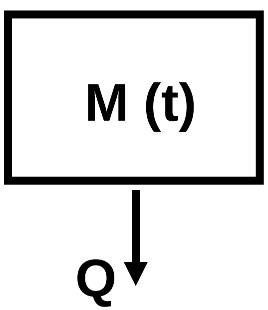
- **Water may be the limiting factor in determining the carrying capacity of the earth.**
- **Water is distributed unequally around the globe: e.g., the Amazon River Basin has 14% of the world's fresh water but only about 0.4% of the world's population.**

Resource 3: Metals and Minerals

- **Metals are typically found in ores of varying percentages:**

  -- Iron ore is ~40% iron
  -- Lead ore is ~2.5% lead
  -- Copper ore is ~1% copper
  -- Gold ore is ~0.0003% (300 ppm) gold

We sometimes model the flow of a metal out of the global reserves using the following equation:

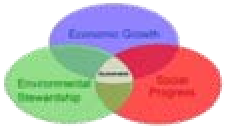


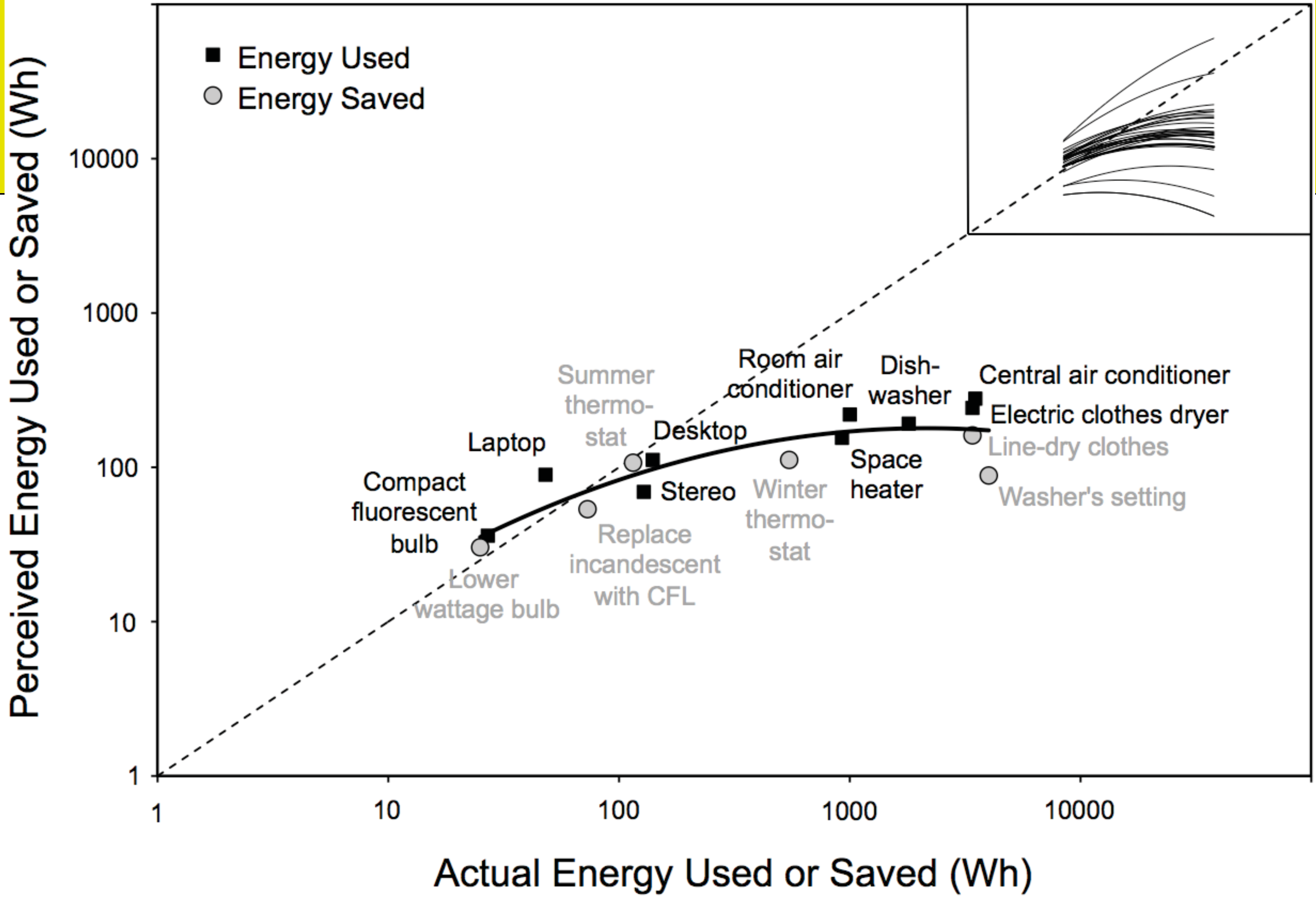
$$M(t) = M_o - Q\,t$$

This indicates the metal will ultimately be depleted unless new sources are found.

But engineers working on these problems often encounter social obstacles

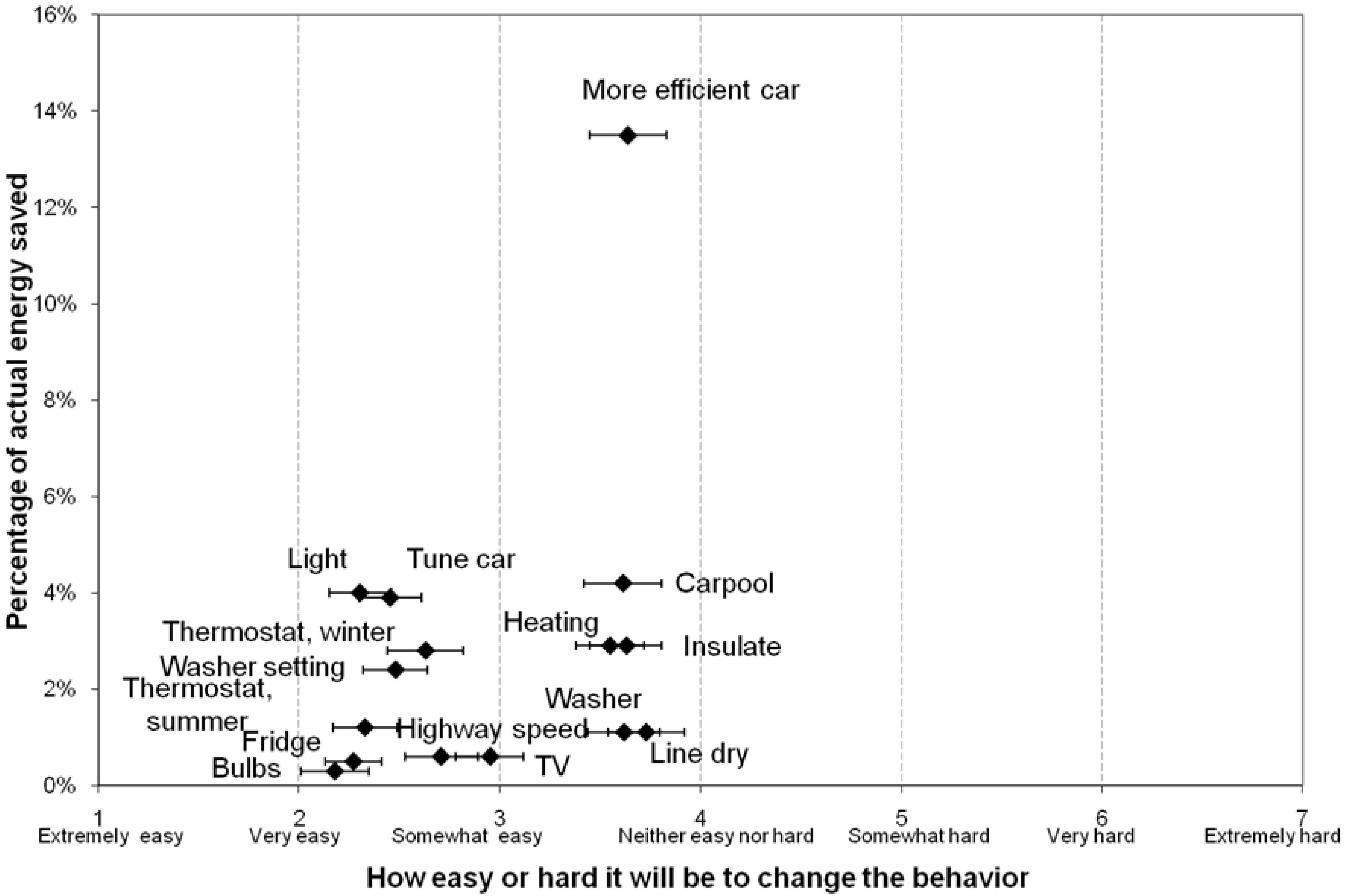
- New technologies must have attributes other than environmental impact or they may be ignored
- Rebound effect
- Drop-in-the-bucket effect
- If there are sacrifices to be made, others should make the sacrifices (NIMBY)
- “Build Absolutely Nothing Anywhere Near Anything” (BANANA)
- Poor understanding of technologies





4.38 Attari, Dekay, Davidson and Bruine de Bruin (*PNAS*, 2010)

Perceived difficulty of changing behavior



4. Center for Sustainable Engineering

Syracuse University: Cliff Davidson

Carnegie Mellon: Scott Matthews

Arizona State: Brad Allenby

University of Texas at Austin: Dave Allen

Georgia Tech: John Crittenden

Workshops of the CSE

For faculty who wish to bring Sustainable Engineering into their courses

30 participants per workshop

Make participants aware of the current status of Sustainable Engineering and availability of educational materials

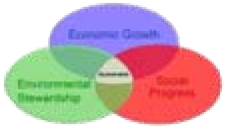
Develop a sense of community among engineering educators

First two workshops at Carnegie Mellon in 2006

Several workshops have been held since then (200 professors from > 100 universities)

CSE Electronic Library
www.csengin.org

- Can accommodate lecture notes, homework problems, class handouts, projects
- All material submitted will be peer reviewed
- Accepted submissions are posted for free and can be accessed for free
- Author is responsible for copyright
- Material is indexed by subject matter, intended audience, discipline within engineering, and keywords



Challenges in Changing the Way Engineers are Trained

- Long-term, global scale considerations should play a role in ALL engineering decisions.
- Non-technical issues such as cultural preferences, social responsibility, and values should be included.
- A “one size fits all” model must be avoided; local conditions and availability of nearby materials and energy should be considered.
- Training engineers for “lifelong learning” is essential.
- Engineering education should focus on processes rather than endpoints, as the solutions to engineering problems will change over time as our understanding improves.
- Diversity in the profession must be enhanced.

Summary

- **Most engineers currently in practice are not trained in Sustainable Engineering and thus have not been effective in making progress on some of the world's most pressing problems**
- **Strengthening education in Sustainable Engineering is important so the world's engineers can start putting SE into practice: making appropriate engineering decisions**
- **CSE has been established to help engineering faculty members train their students in Sustainable Engineering**