Sustainable Development through the Principles of Green Engineering

Julie Beth Zimmerman, PhD
Office of Research and Development, EPA
Civil Engineering, University of Virginia

Since going to bed (assume 9 pm), how many people has the global population increased by?

a) 2,336
b) 15,675
c) 50,604
d) 101,434

Since eating breakfast (assume 9 pm), how many people has the global population increased by?

a) 2,336
b) 15,675
c) 50,604
d) 101,434

What was the average fuel efficiency for automobiles in the US in 2004?

a. 12
b. 21
c. 24
d. 33

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d. 33

What was the fuel efficiency of Henry Ford's Model T?

a. 5
b. 8
c. 12
d. 25

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What is the percentage breakdown of raw materials extracted from the Earth end up in product versus end up as waste?

a. 70 (product) - 30 (waste)
b. 50 - 50
c. 10 - 90
d. 6 - 94

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How many synthetic chemicals (not known or manufactured before 1940) are in your body today?

a. 14
b. 53
c. 167
d. 239

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What is sustainability?

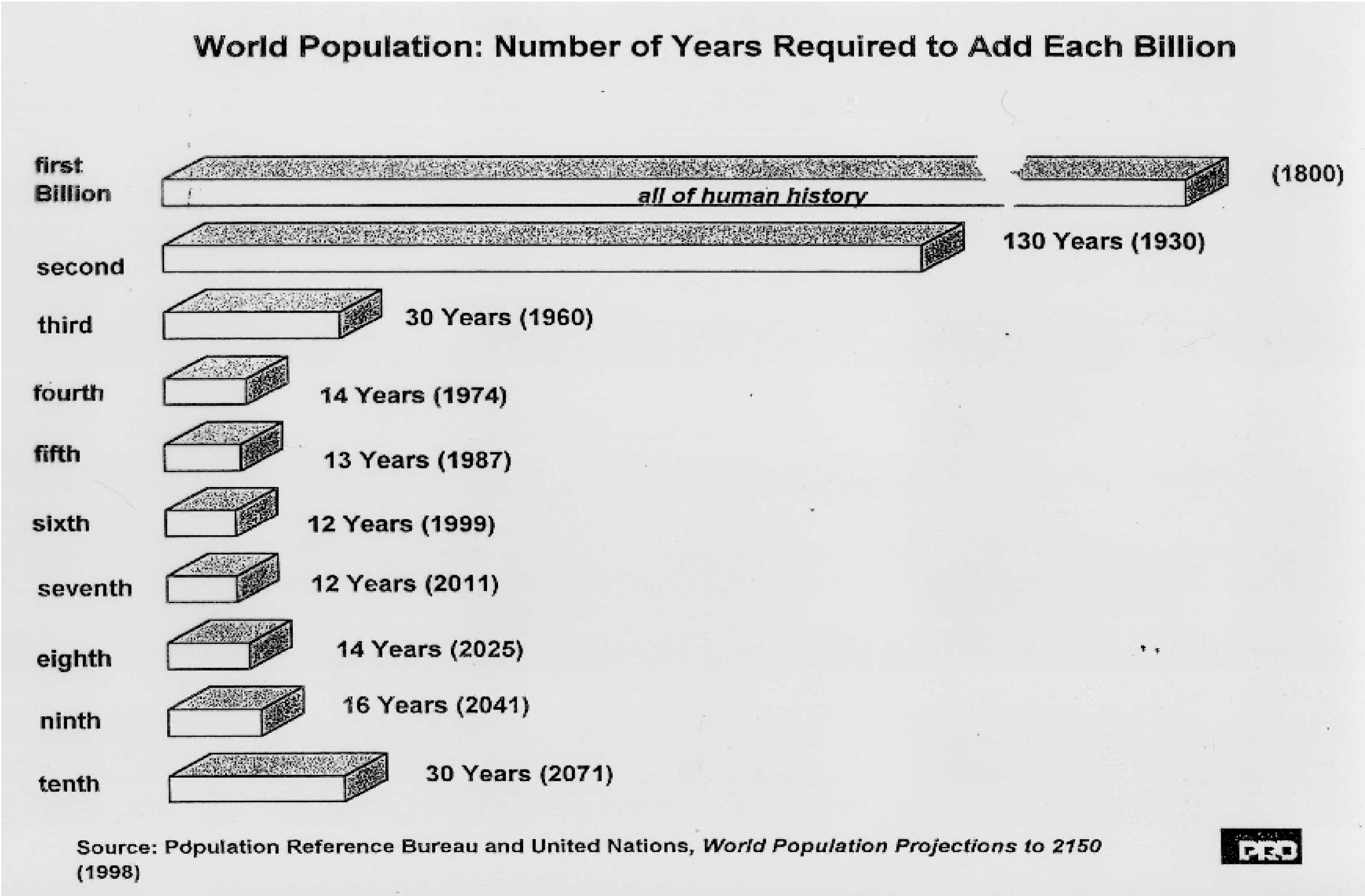
Meeting the needs of the current generation without inhibiting the ability of future generations to meet their own needs.

Brundtland Commission, 1987

Major Challenges to Sustainability

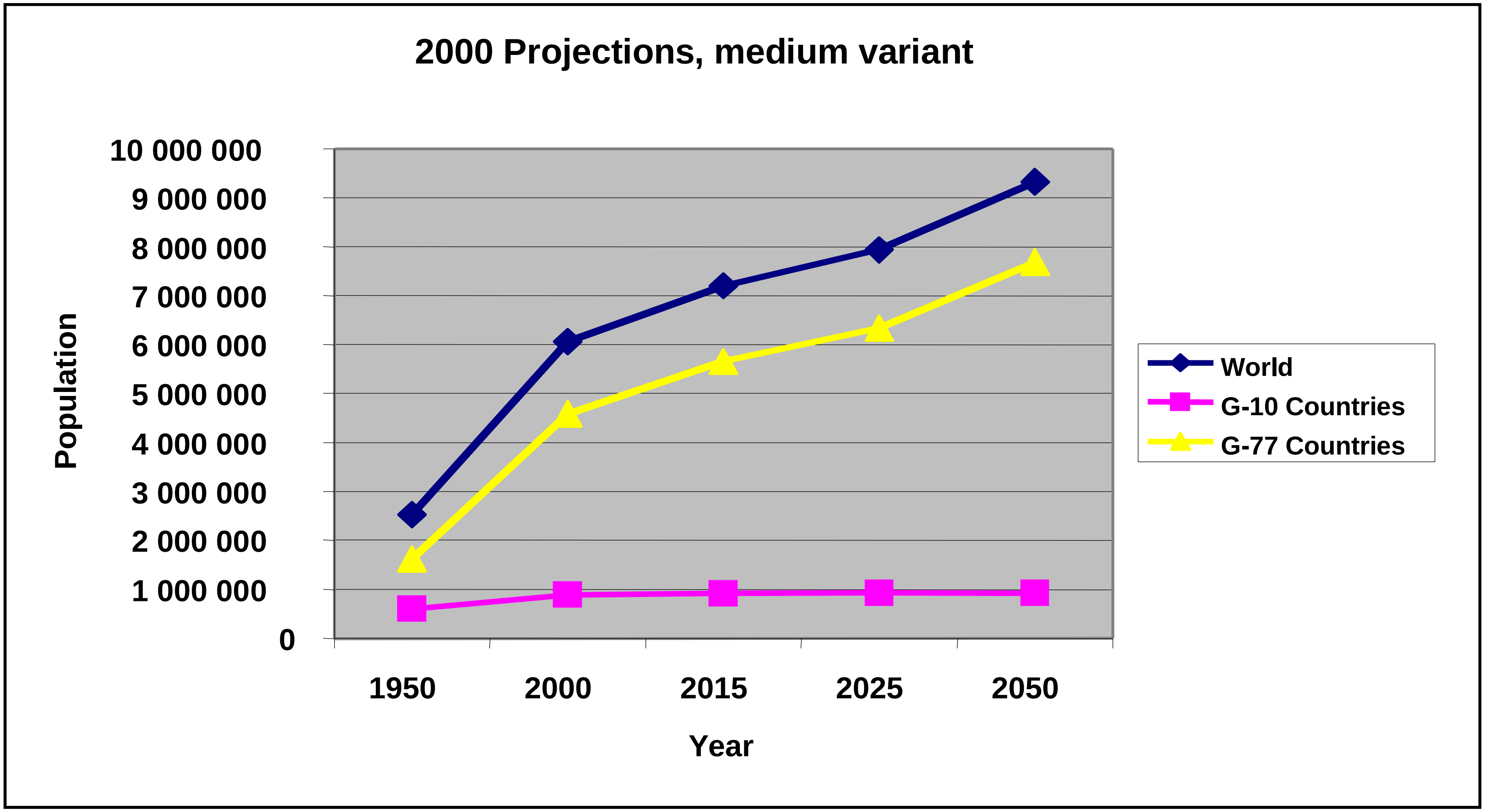
- → Population
- → Water
- → Energy
- → Global Change
- → Resource Depletion
- → Food Supply
- → Toxics in the Environment
- → Socio-political
- → Economics and the Market
- → Traditional design

A billion here a billion there…



Population Trends

U.N. World Population Prospects, *2000 Revision*



Population

- → Empirical data shows that increased quality of life correlates with sustainable population control.
- → Increased quality of life, however, has historically resulted in increased damage to the biosphere and the earth’s ability to sustain life.

Humanity and the Environment

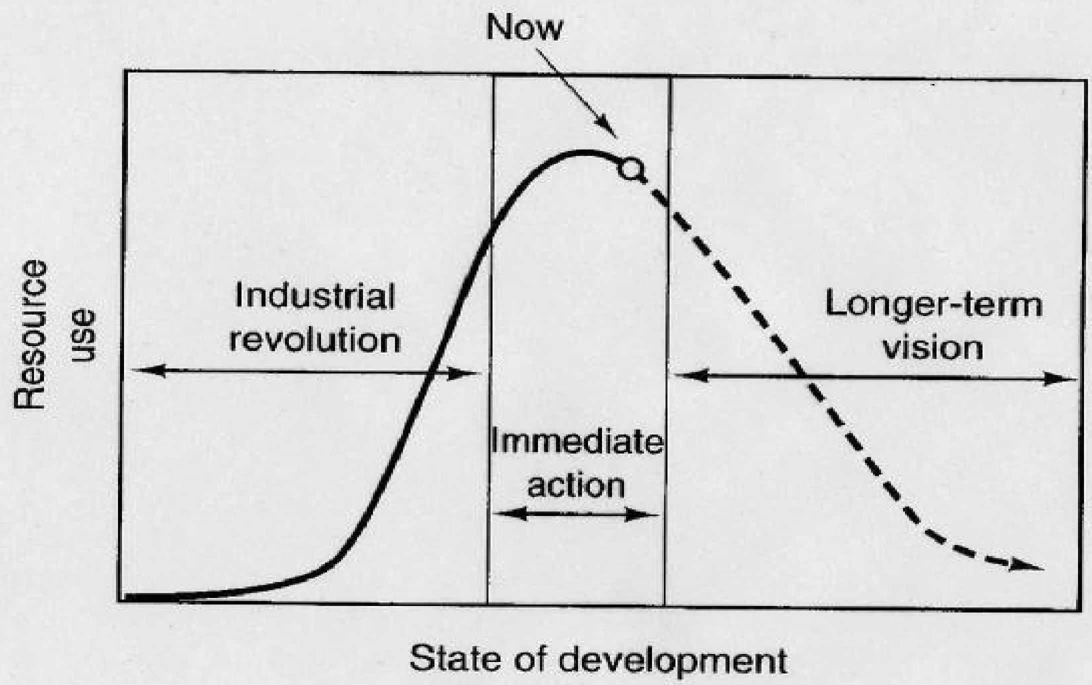


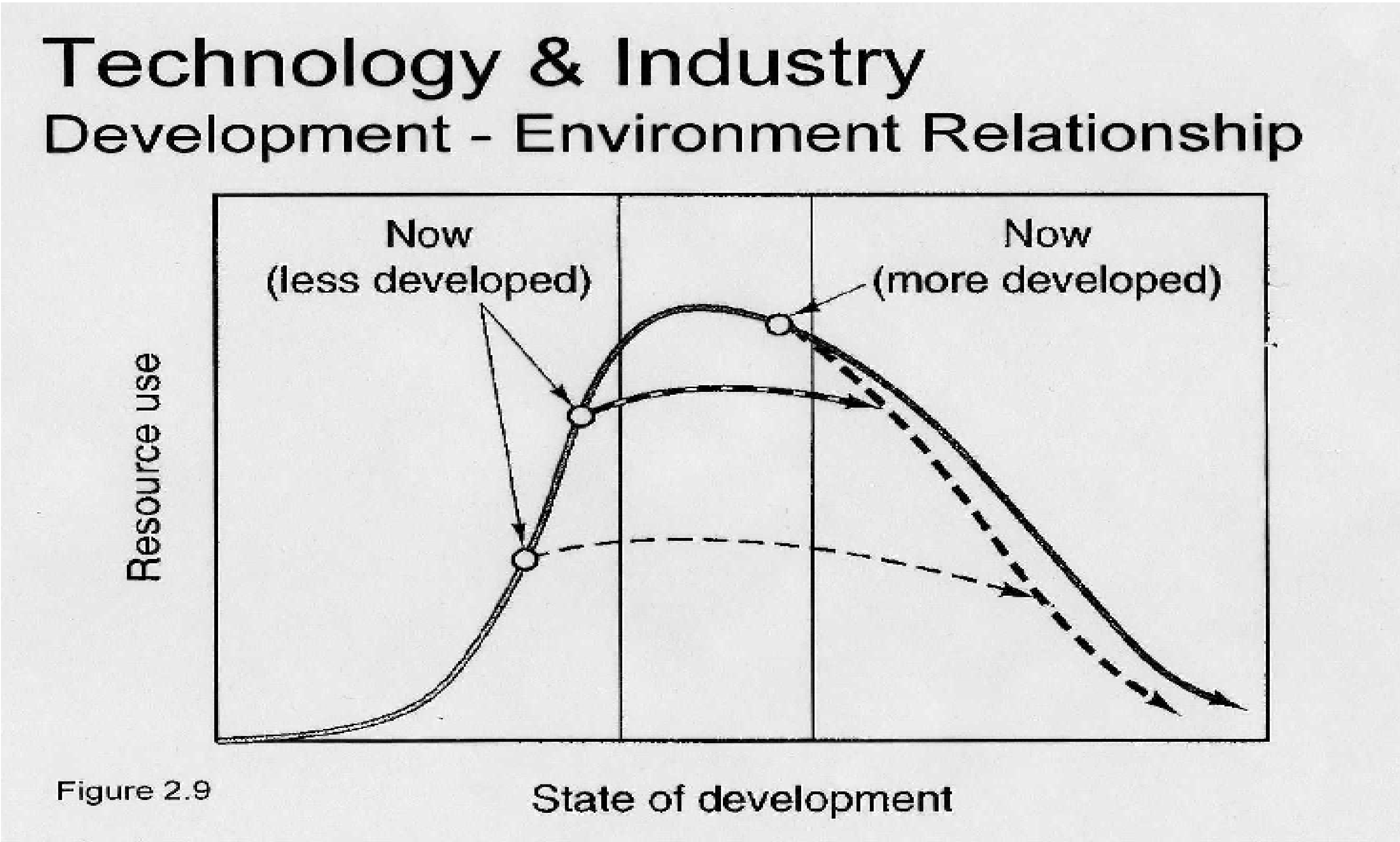
Figure 1.5 The typical life cycle of the relationship between the state of technological development of society and its resulting environmental impact.

Graedel and Allenby, Industrial Ecology, 1995

Population

- → The challenge: How to increase quality of life while minimizing detrimental effects to human health, the environment and the biosphere.
- → The solution: Engineers through sustainable design can contribute in very real terms to enhancing prosperity both in the developed and developing world.

Green Engineering:
The How of Sustainability



Graedel and Allenby, Industrial Ecology, 1995

What is Green Engineering?

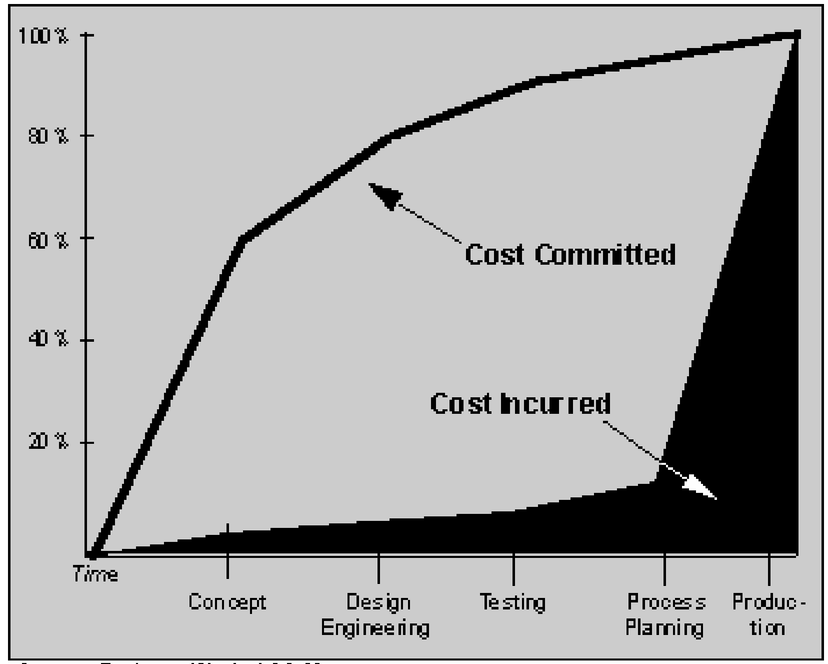
- → Design, discovery, and implementation
- → Molecules, products, processes, systems
- → Maximize Inherency
- → Maximize mass, energy, time, and space efficiency

Goals of Principles of Green Engineering

- → Principles of DESIGN
- → Apply across scales of design
  - → **Molecular architecture to construct chemical compounds**
  - → **Product architecture to create a cell phone**
  - → **Urban architecture to build a city**

Impacts of Design Decisions

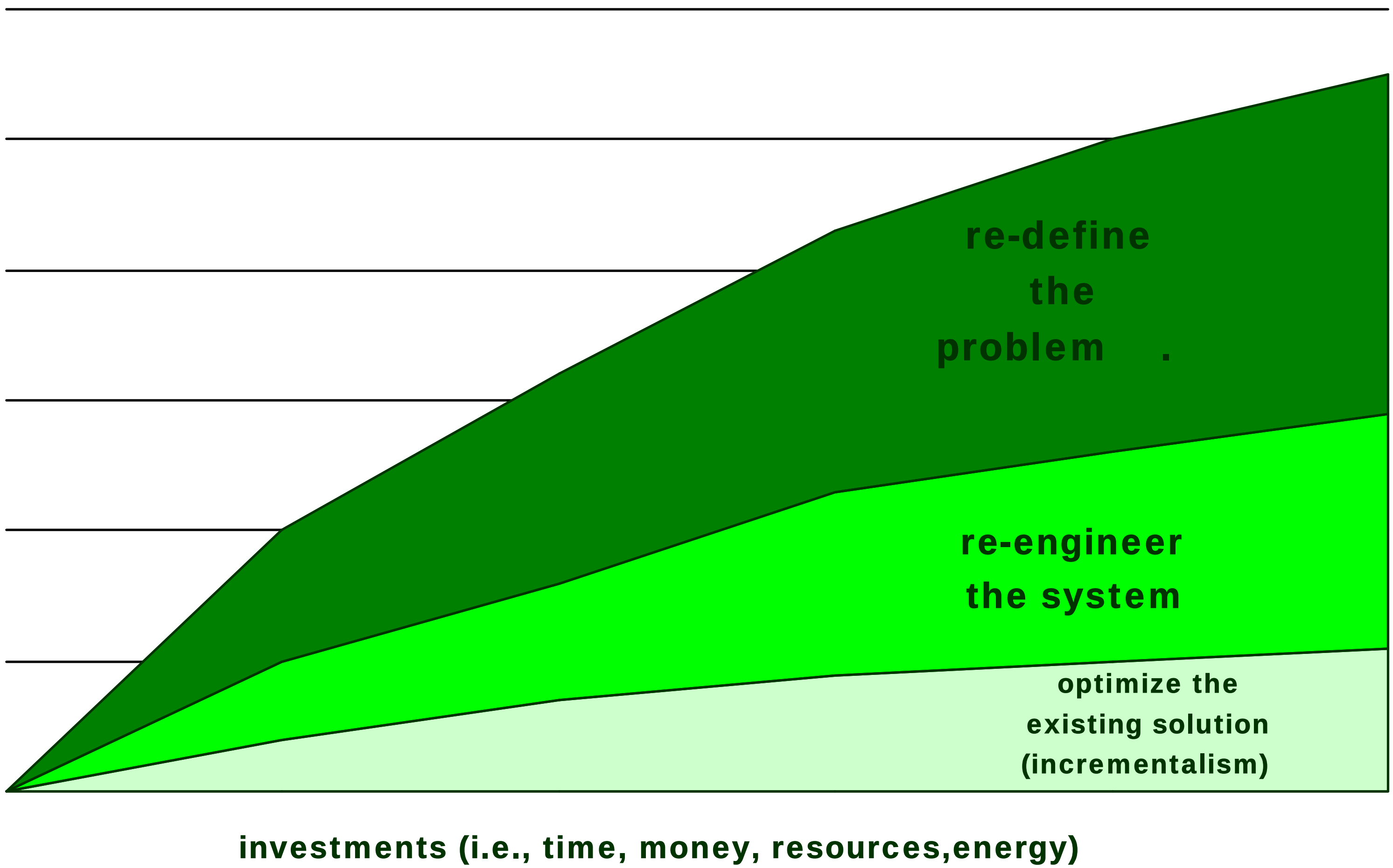
- For a typical product, 70% of the cost of development, manufacture and use is determined in its design phase.
- Integrating environmental considerations into the upfront product design can
  - **increase efficiency**
  - **reduce waste of materials and energy**
  - **reduce costs**



Source: *Business Week 4-30-90*

Not just how you design but <u>what</u> you design

Schematic of potential benefits vs. investments



Goals of Principles of Green Engineering

- Principles of DESIGN
- Framework
  - **Applicable**
  - **Effective**
  - **Appropriate**
- Apply across disciplines
  - **Chemical, Civil, Environmental, Mechanical, Systems…**

How were the Principles of Green Engineering developed?

- Identify examples of successful engineering that moves towards sustainability
  - **various disciplines**
  - **various scales**
- Elucidate the underlying principle(s) embedded in the examples.
- See if the embedded principles are applicable across scales and across disciplines
  - **even if not generally realized**

How to think about Principles of Green Engineering?

- Not Rules, commandments, or natural laws.
- Can be viewed as performance parameters
- Need to be optimized
  - **Synergies**
  - **Trade-offs**
- Need to be applied in context
  - **Vary with innovation, creativity**
  - **Vary with culture, society**
- Often synergistic with traditional design metrics.
  - **Quality**
  - **Safety**
  - **Cost effective**

Fundamental Issues in applying the Principles

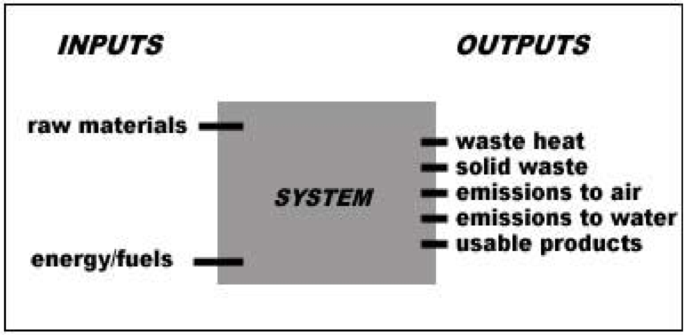
→ Inherency

Inherently benign

- → Circumstantial
  - Use
  - Exposure
  - Handling
  - Treatment
  - Protection
  - Recycling
  - Costly
- → Inherent
  - Molecular design for reduced toxicity
  - Reduced ability to manifest hazard
  - Intrinsic safety from accidents or terrorism
  - Increased potential profitability
  - Cannot fail

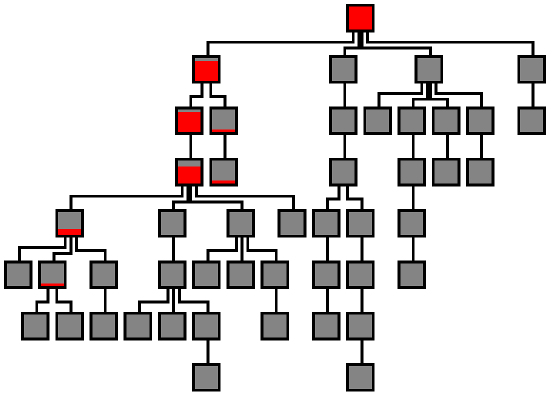
Fundamental Issues in applying the Principles

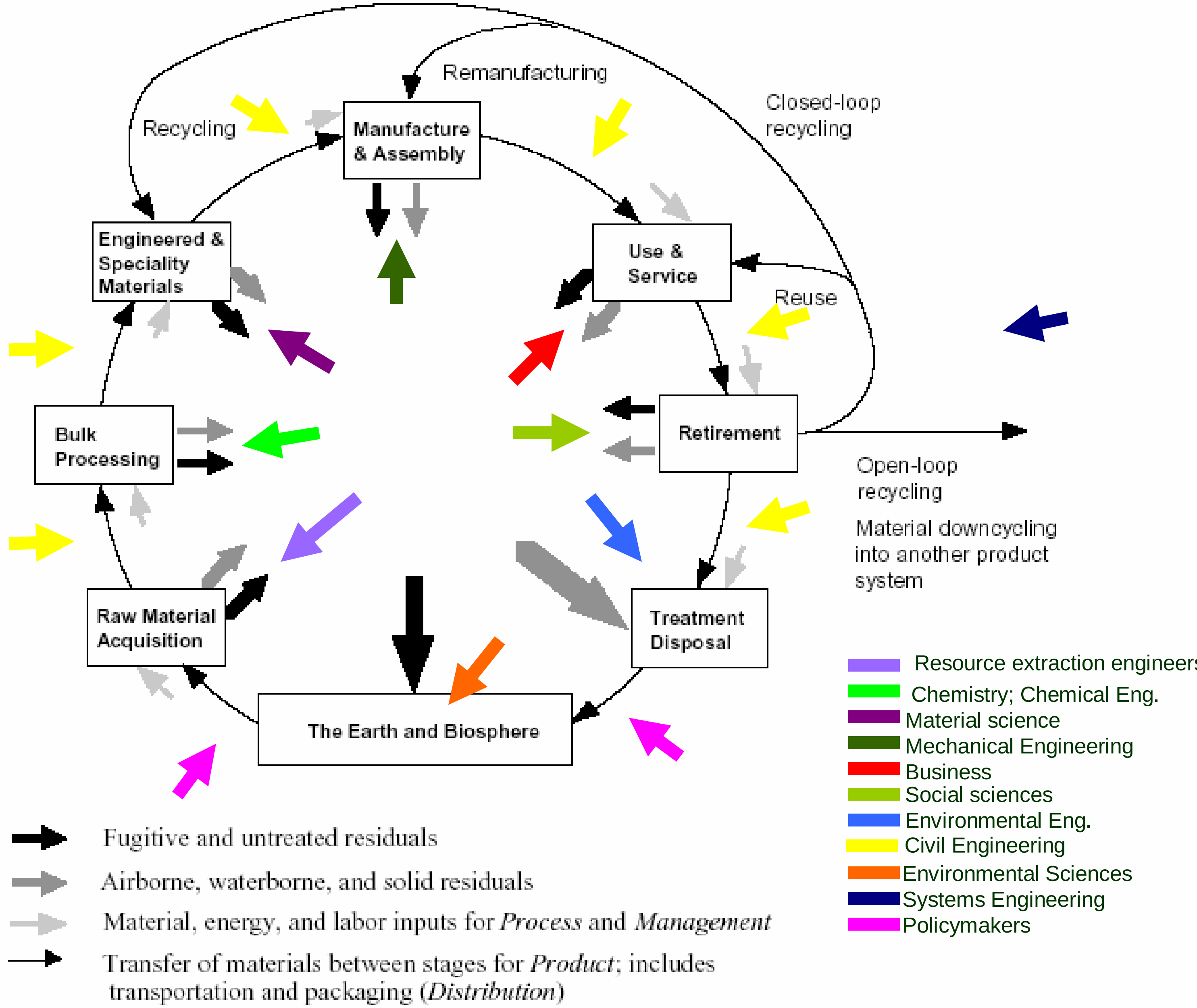
- → Inherency



- → Life cycle foundation across all principles.

- → Holistic or so-called “systems thinking” should be applied to avoid the unintended consequence of doing the wrong things, but doing them very well.





Source: Gregory A. Keoleian and Dan Menerey, *Life Cycle Design Guidance Manual* (Cincinnati: U.S. EPA Risk Reduction Engineering Lab, 1993), 14.

FIGURE 7: THE PRODUCT LIFE CYCLE SYSTEM

The 12 Principles of Green Engineering

1. Green Chemistry
2. Prevention rather than treatment.
3. Design for separation.
4. Maximize mass, energy, space, and time efficiency.
5. “Out-pulled” rather than “input-pushed”.
6. View complexity as an investment.
7. Durability rather than immortality.
8. Need rather than excess.
9. Minimize material diversity.
10. Integrate local material and energy flows.
11. Design for commercial “afterlife”.
12. Renewable and readily available.

Anastas and Zimmerman, Environmental Science and Technology, March 1, 2003

Advancing Sustainability

- Science and technology is fundamental and essential
- Global dialogue based on integrating the best and most appropriate knowledge, methodologies, techniques, principles and practices
    - Developing nations typically have a long history of practical innovation and successful application of indigenous knowledge systems
        - **Science and Technology**
        - **Economics and Commerce**
        - **Governance**

Science and Technology

- Pharmaceuticals
  - **Over 120 pharmaceutical plant-derived products and 75% were discovered by examining the use of plant species in traditional medicine**
  - **Shaman Pharmaceuticals pioneered a novel approach to drug discovery while maintaining a commitment of reciprocity to the indigenous cultures.**
  - **Shaman has brought two products into clinical trial within 24 months of identification through indigenous knowledge.**
    - Compare to most major pharmaceutical companies where 1,000,000 relevant substances are screened for each new medicine, the associated cost is $897 million, and the typical time to trial is 4.5 years (DiMasi, 2003)

Science and Technology

- Water Supply and Treatment
  - **Rain water harvesting**
  - **Natural coagulants**
- Cooling technologies
  - **Evaporative**

Science and Technology

- → Passive Solar Design



- → Waste to energy
  - → **Biogas**
- → Building Materials
  - → **Adobe**
  - → **Rammed earth**
  - → **Straw**

Commerce and Governance

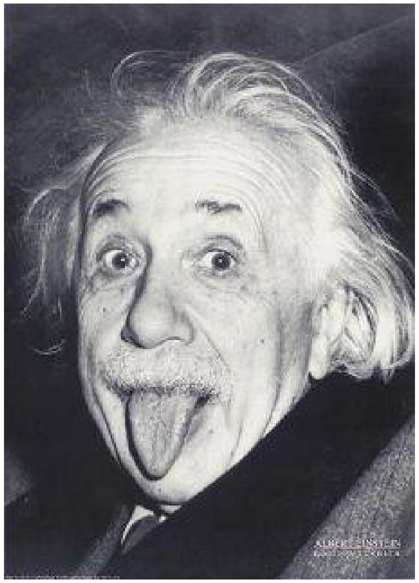
- → Microfinancing
- → Cooperative businesses
- → Local economic development strategies
- → Natural system valuation
- → Quality of life indicators

Addressing sustainability challenges through S&T

- → Within the currently industrialized nations as well as those developing nations whose path to development will be most consequential for the environment and society
- → Essential that these design principles be incorporated systematically in the next generation of products, processes, and systems.
- → Consider and utilize both a high level understanding of complex systems as well as an incorporation of simple elegance found in millennia of experience and tradition.

Science, technology, and policy - looking ahead...

- Historical
  - Medicines
  - Space exploration
  - Computing
- Future
  - Essential to any path forward



"Problems cannot be solved at the same level of awareness that created them."