

# Moving Towards Sustainable Materials Use:

Insights from Strategic use of Models

**Prof. Randolph Kirchain**

Materials Systems Laboratory  
Department of Materials Science & Engineering and  
Engineering Systems Division

Research Question

How can we make  
More Sustainable  
Materials & Materials  
Processing  
Decisions?

# What is Sustainable Development?

## Classic Definition

---

- *“Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs”*

(The World Commission on Environment and Development, United Nations, 1987)

Key Questions:

**What?**

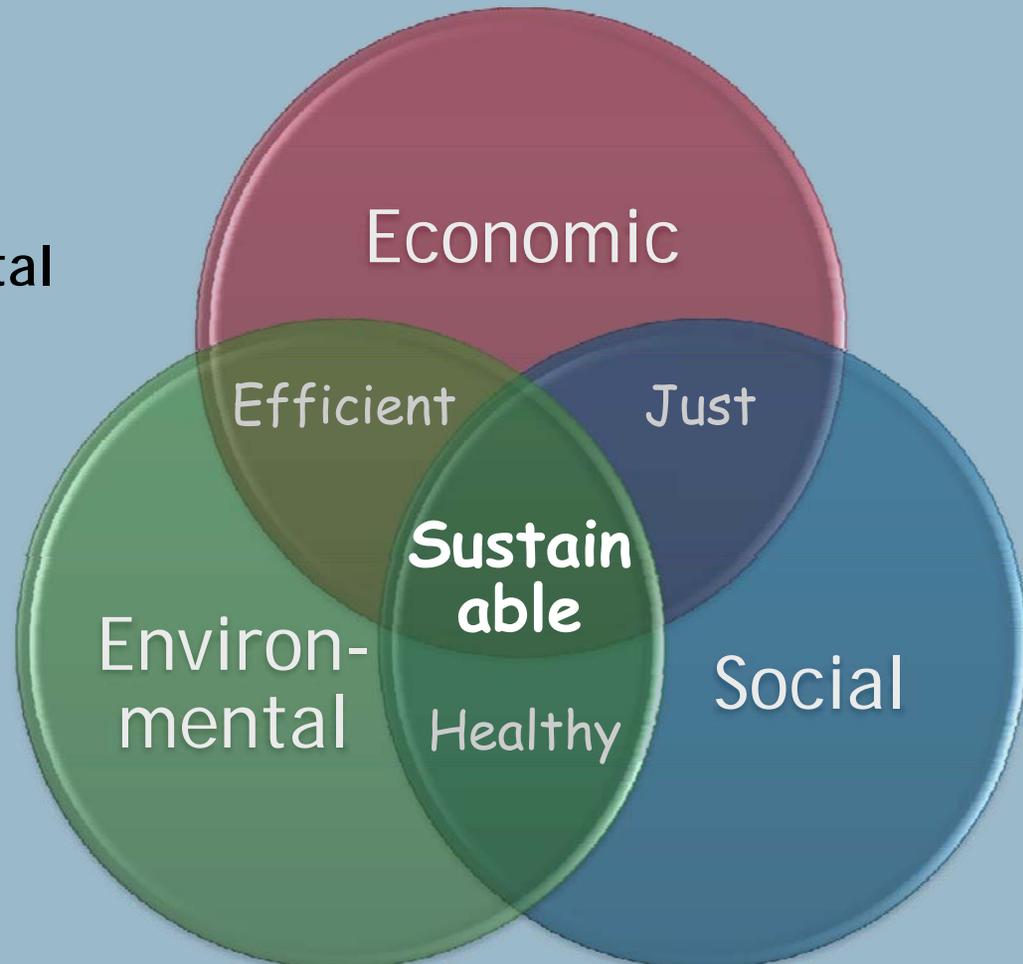
**... to Sustain?**

**... to Develop?**

# What is to be Sustained?:

## Broadly Accepted Elements of Sustainability

- Economic
  - Human Capital
  - Human-made Capital
- Environment
  - Natural Capital
- Social
  - Social Capital



Adapted from <http://www.state.nj.us/dep/dsr/sustainable-state/what-is.htm>

Sustainability is an interesting  
concept, but ...

Why Do We Care?

# How do design / technology decisions effect the environment?

# How do Technology Decisions Affect the Environment?

- Direct
  - Manufacturing burden
    - Consumption of energy
    - Emissions to the environment
  - Concentration in the environment
    - Most materials still eventually in up in landfills
    - Toxicity for some materials
  - Availability
- Indirect
  - Performance of the products which they create
    - Energy Efficiency
    - Recyclability

# Why care about technology's impacts today?

## (1) Societal Perspective

### a) Strain on the natural world

# Observable Strain on the Natural World

**Habitat Loss**

**Toxics  
Concentration**

Clip art of global warming removed due to copyright restrictions.

**Resource  
Degradation**

**Global  
Climate Change**

# Why care about technology's impacts today?

(1) Societal Perspective

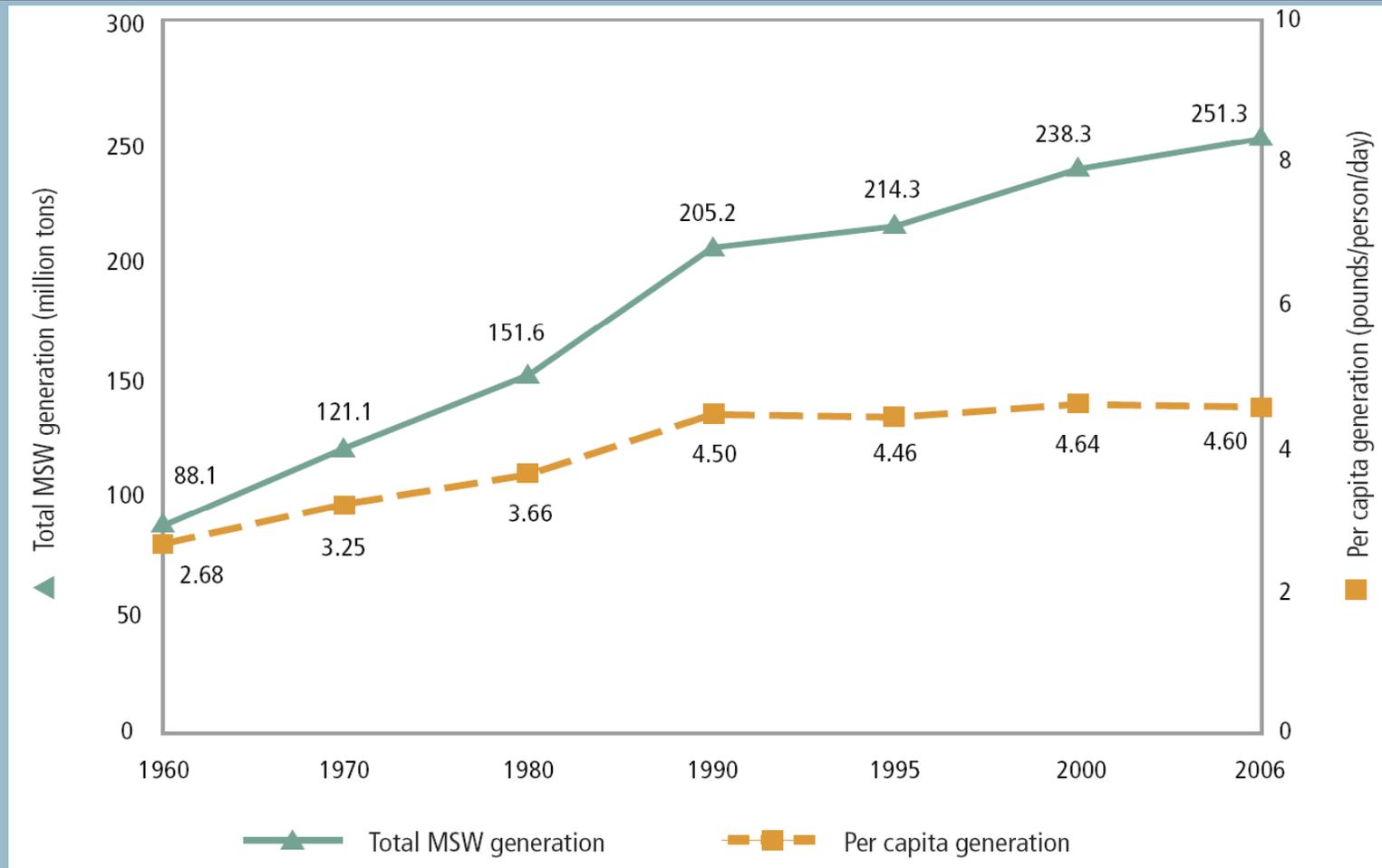
b) Materials Consumption  
is massive & growing rapidly

# Observable Strain on Natural World

Is this *really* a problem?

How much do  
**YOU**  
consume per day?

# How Much Do You Throw Out per Day? Municipal Solid Waste in the US



Municipal Solid Waste in the United States: 2007 Facts and Figures. Office of Solid Waste, US EPA

# Observable Strain on Natural World

Is this *really* a problem?

How much do  
**YOU**  
consume per day?

# Consumption has Skyrocketed in the Past Century

Total Inflow > 80 kgs / person / day

Image removed due to copyright restrictions.

Please see Fig. 26 in Ayres, Robert U., Leslie W. Ayres, and Benjamin Warr. "Is the U.S. Economy Dematerializing?"

Chapter 3 in Janssen, Marco, and Jeroen C. J. M. van den Bergh. *Economics of Industrial Ecology*. Cambridge, MA: MIT Press, 2005. ISBN: 9780262220712.

Total Inflow Associated with US Economy:  
fuels, metals, construction, chemicals & biomass

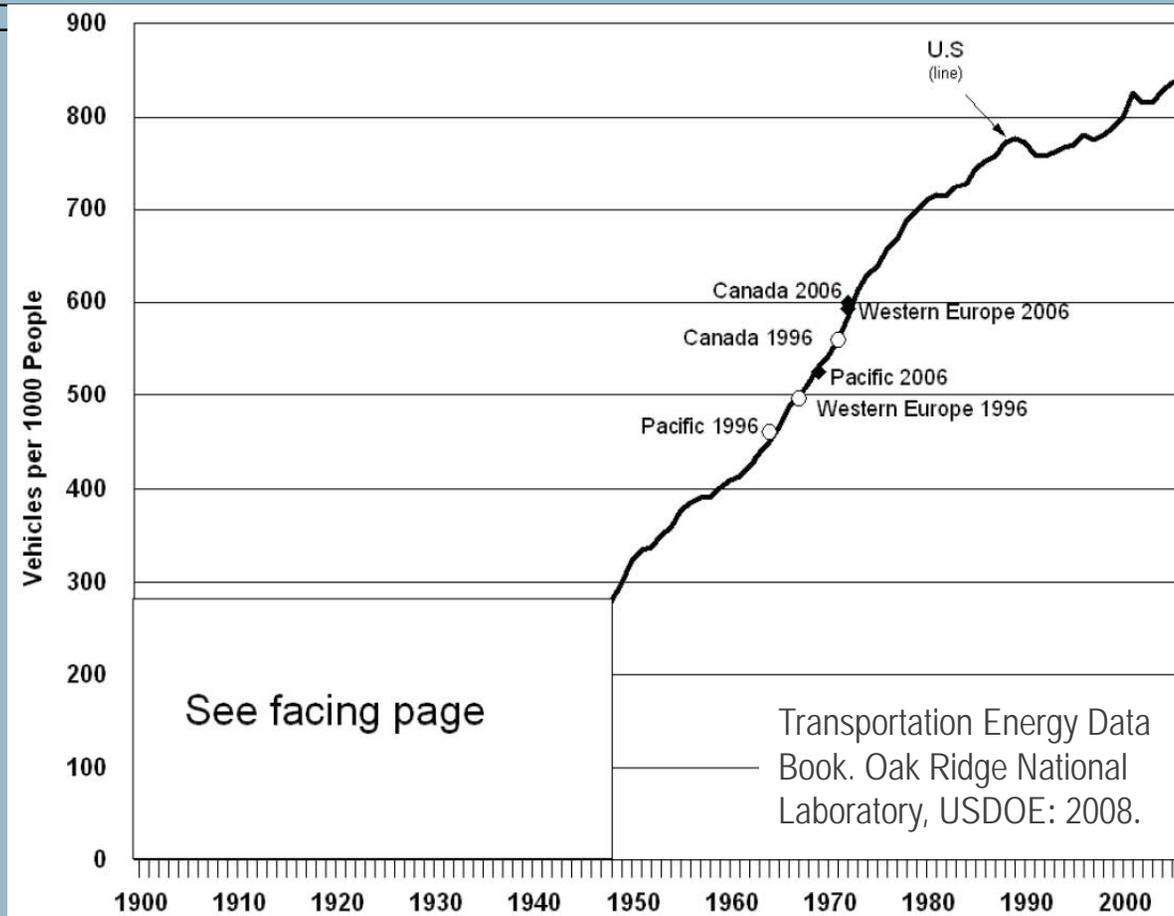
Ayres, Ayres, & Moore, "Is the US Economy Dematerializing?" 2006

Its NOT just about US anymore!

---

How much does (*will*)  
Rest of World  
consume?

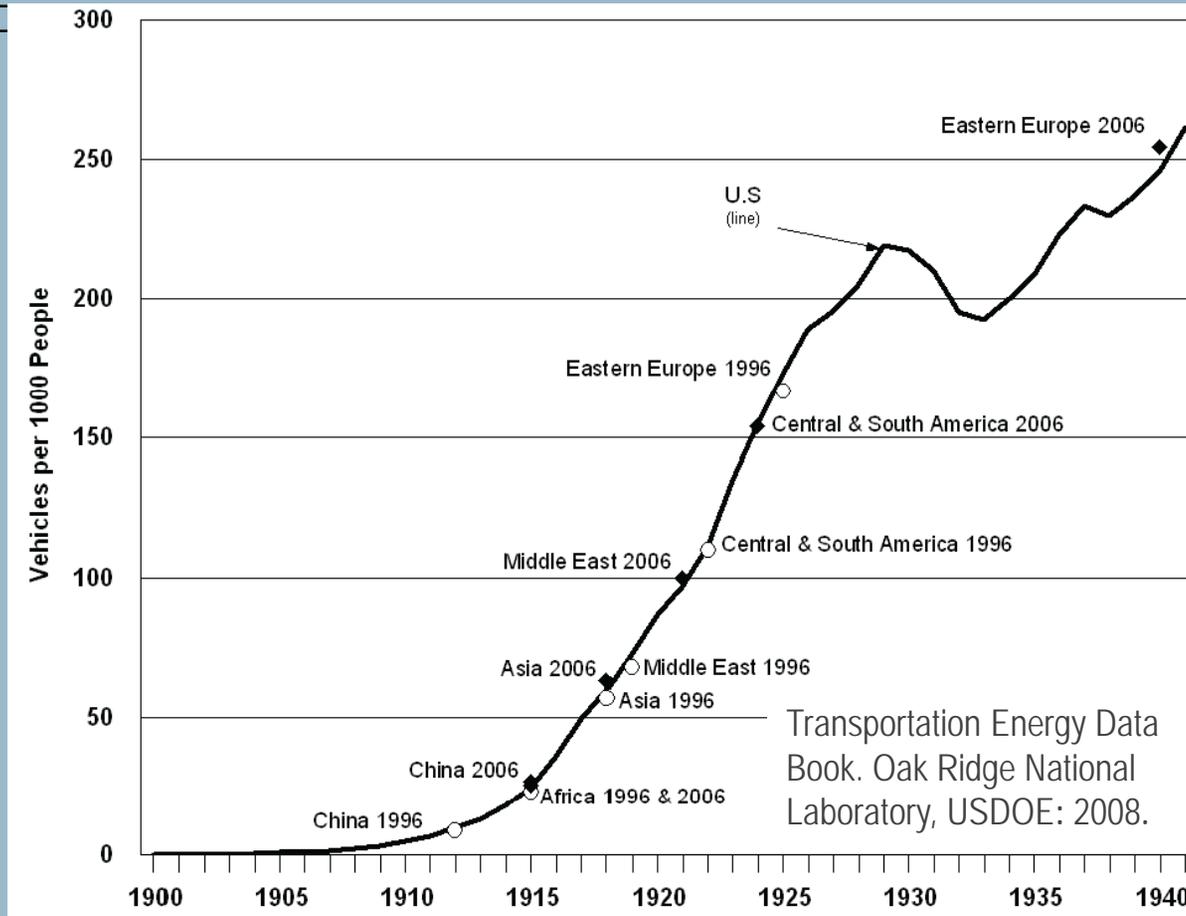
# Differences in Consumption: The Example of Automobiles



Line - US Vehicles per capita over time

Points - Vehicles per capita in a specific region

# Differences in Consumption: The Example of Automobiles



Line - US Vehicles per capita over time

Points - Vehicles per capita in a specific region

# Why care about technology's impacts today?

## (2) Private/Firm Perspective

The business climate is changing  
(aka Show me the Money!)

## Brand Image

Major firms have realized that highlighting environment / carbon is good for the bottom line

Please see:

Maestri, Nicole. "[Wal-Mart Index to Rate Products' Environmental Impact](#)." Reuters, July 15, 2009.  
Advertising for [Timberland Earthkeepers](#) and [Apple MacBook](#)  
[Procter & Gamble Sustainability Report](#).

**What used to be only niche differentiator will likely soon become a barrier to entry**

Okay, so designers &  
technology decision-makers  
should care...

What do we do about it?

Industrial Ecology:  
A Perspective & Strategy

# How Can We Affect This?

- Human Behavior
  - Change patterns of consumption
    - Waste less
- Change the rules
  - Dematerialization
    - Get the same function from less material
  - Materials substitution
    - Apply less harmful materials
  - Waste Mining - Reuse, Recycle
    - Find ways to make use of streams currently wasted

Irrespective of the strategy, method needed to evaluate performance

# Finding Sustainable Materials & Processes:

## Product Footprint

# Question: Which strategies should be pursued to improve sustainability?

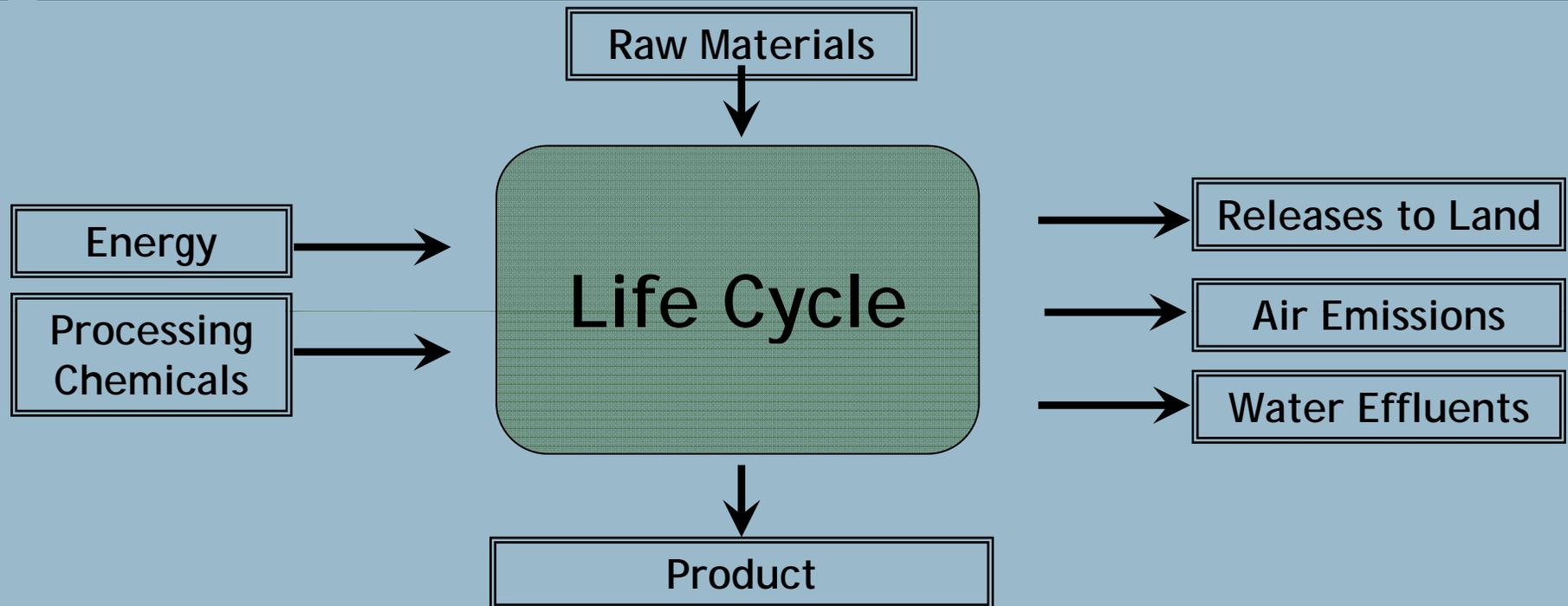
- Engineers have identified many strategies that could improve sustainability
  - Implement more efficient process
  - Substitute materials in product
  - Select nearby supplier
  - Change package from PVC to cardboard
  - Redesign product
- Each costs money to implement
- Which would have the most impact?
  - Cannot just look it up. Let's try modeling...

# What is an engineering model?

- 11 : a description or analogy used to help visualize something (as an atom) that cannot be directly observed
- 12 : a system of postulates, data, and inferences presented as a mathematical description of an entity or state of affairs

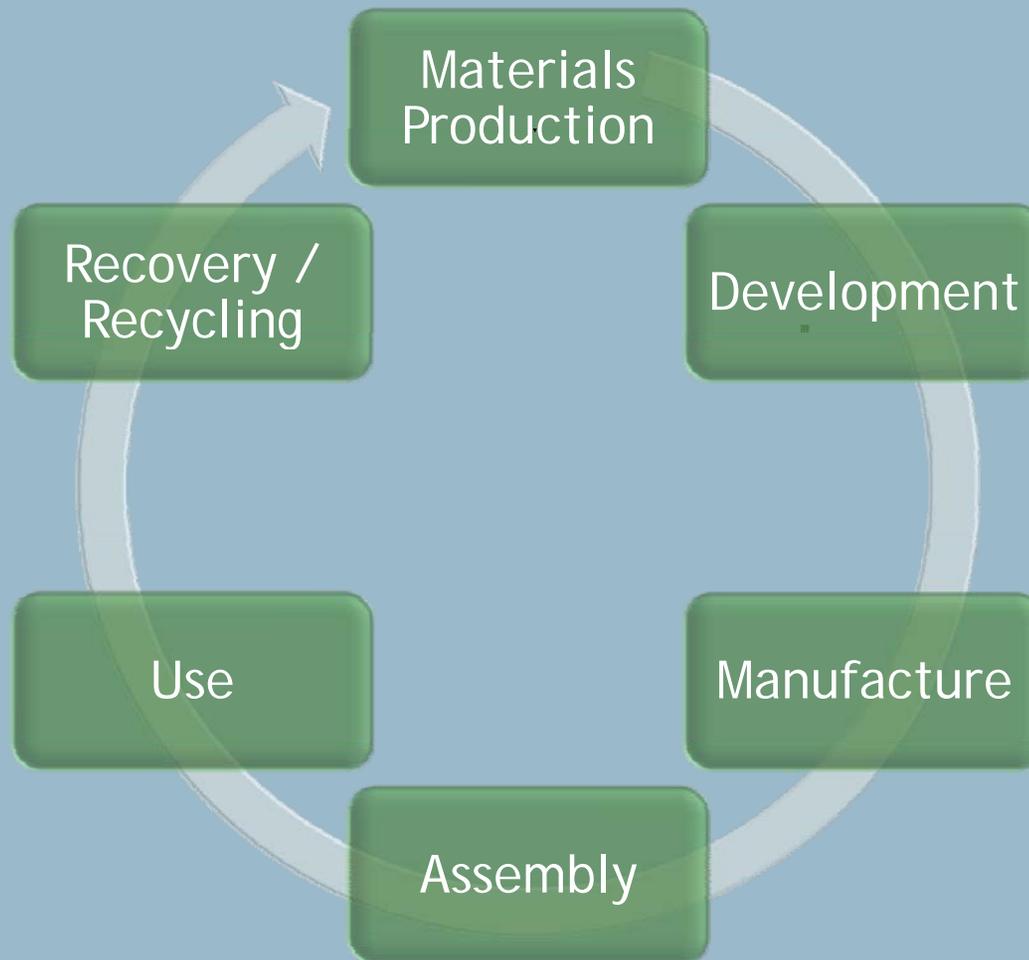
What is the purpose of creating such models?

# Life Cycle Assessment: Basic Concept



- Quantify inflows and outflows
- Characterize how in & outflows “change the world”

# Life Cycle Assessment: Basic Concept



# Study Goal

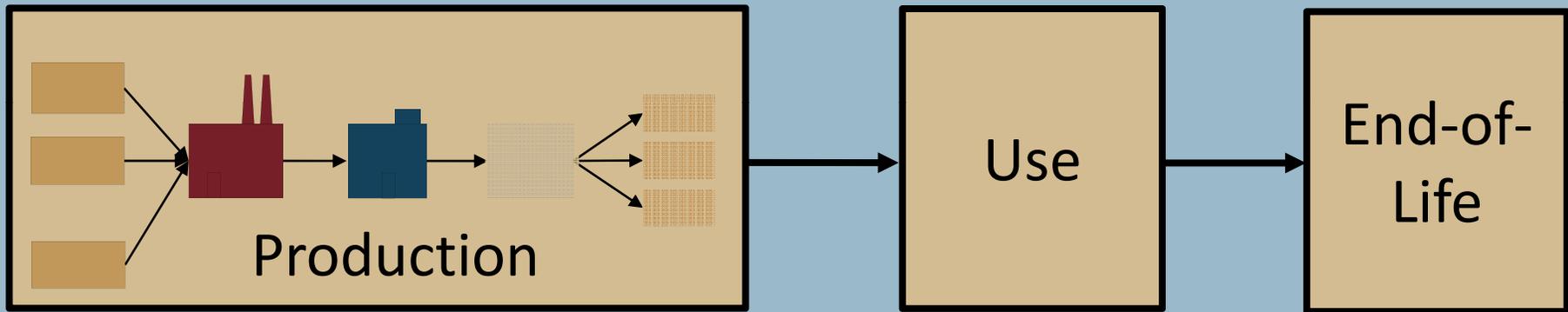
---

- Study Goal:  
*Characterize the environmental life-cycle impact of common consumer product to*
  - *understand the primary drivers of environmental impact and*
  - *identify strategies to reduce environmental impact.*
- Functional Unit:  
one product

# Question: Which strategies should be pursued to improve sustainability?

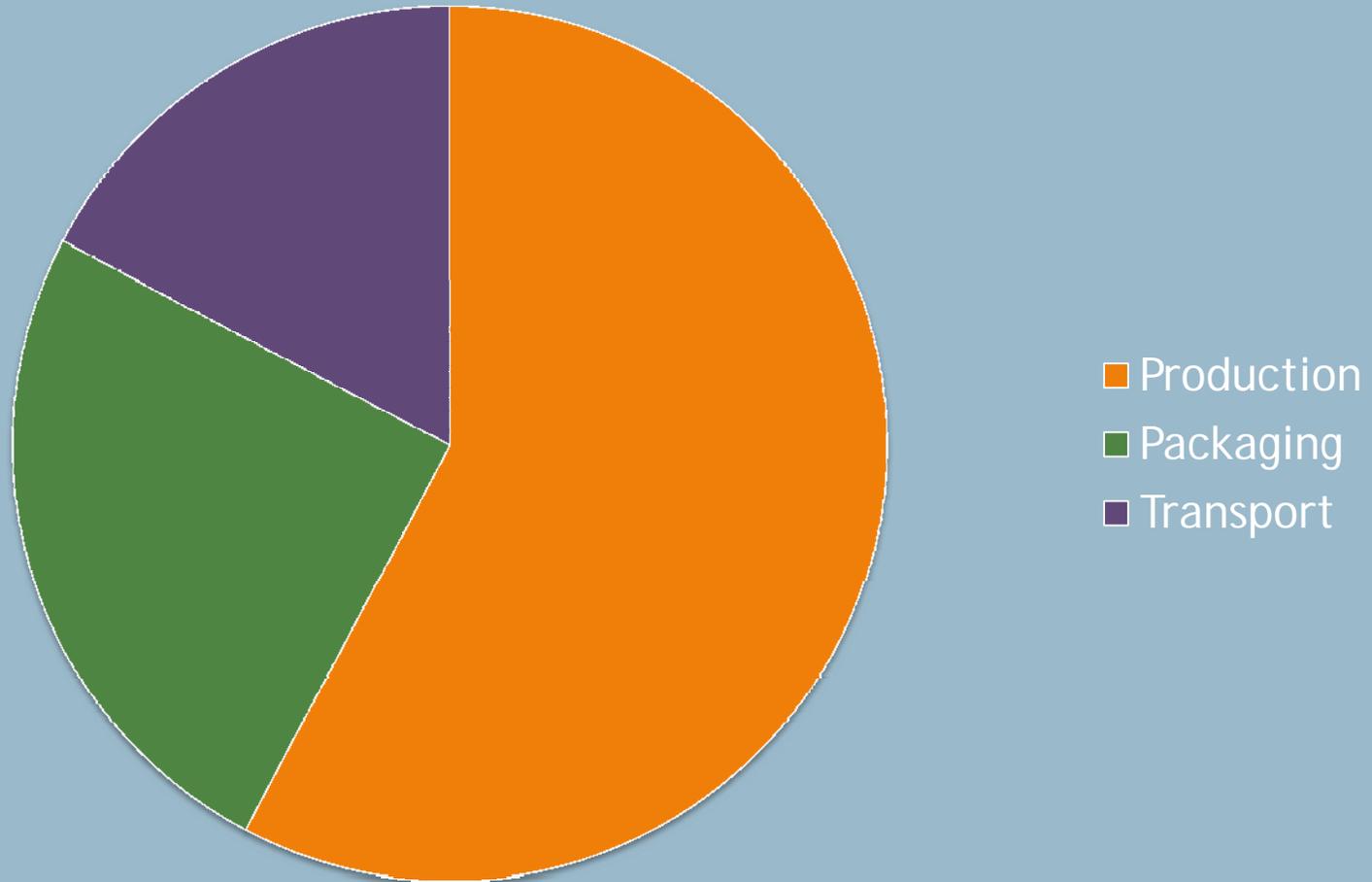
- Engineers have identified many strategies that could improve sustainability
  - Implement more efficient process
  - Substitute materials in product
  - Select nearby supplier
  - Change package from PVC to cardboard
  - Redesign product
- Each costs money to implement
- Which would have the most impact?

# System Boundary: Lifecycle



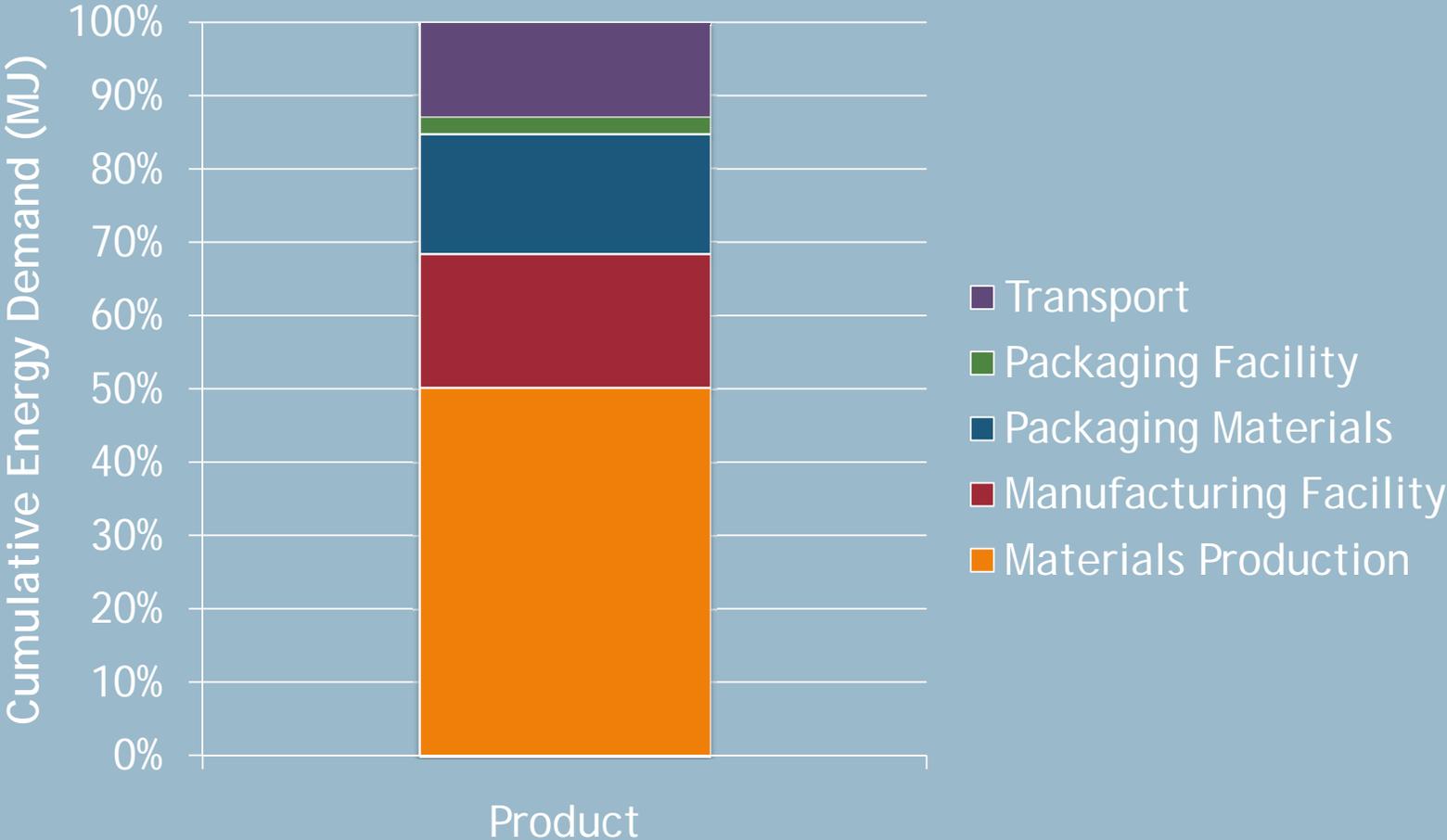
# Impacts in Product Production

## Cumulative Energy Demand



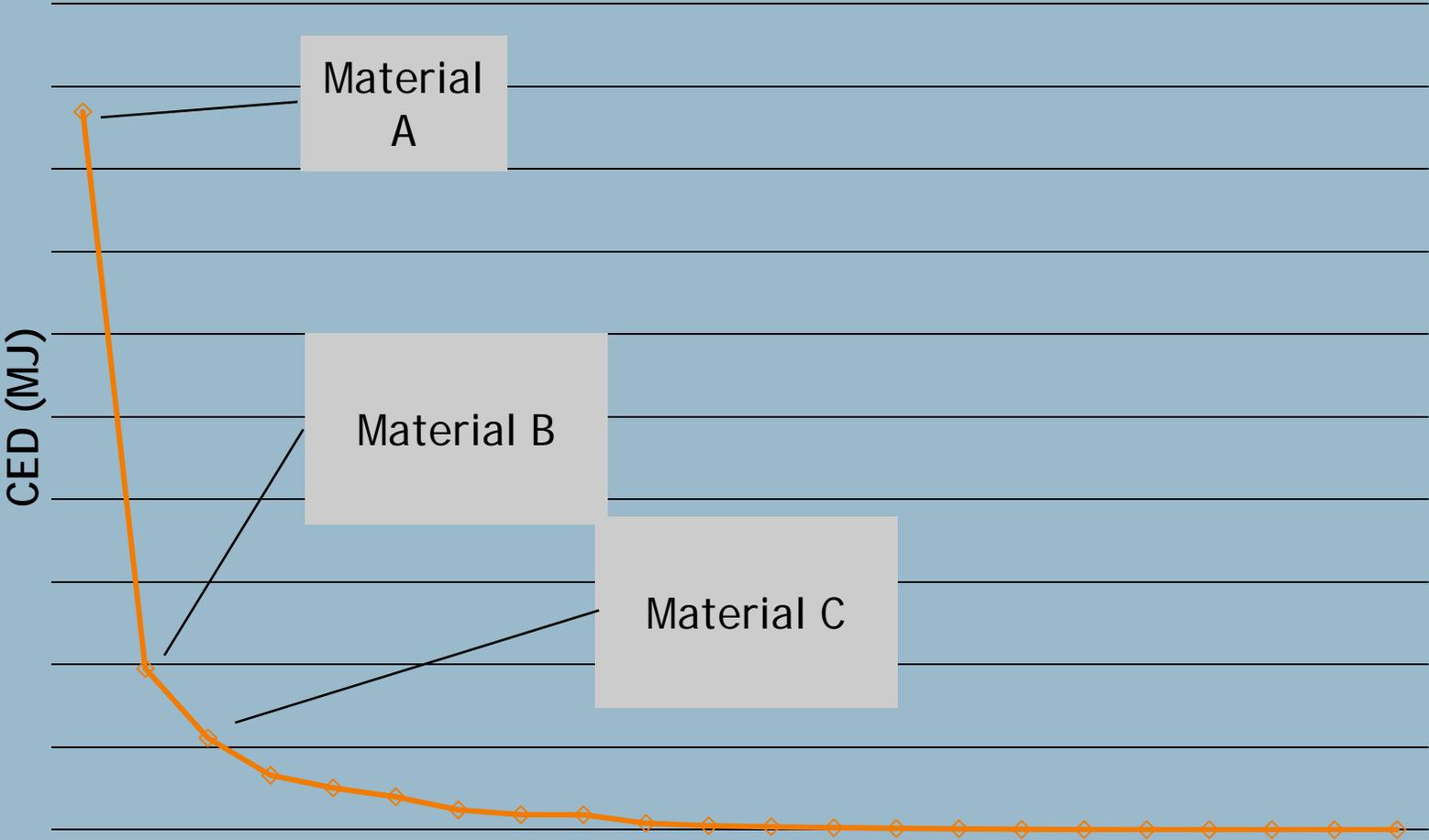
# Impacts in Product Production

## Cumulative Energy Demand



# Impacts from Materials Production

## Cumulative Energy Demand



What else could be done?



Massachusetts Institute of Technology  
Department of Materials Science & Engineering  
Engineering Systems Division

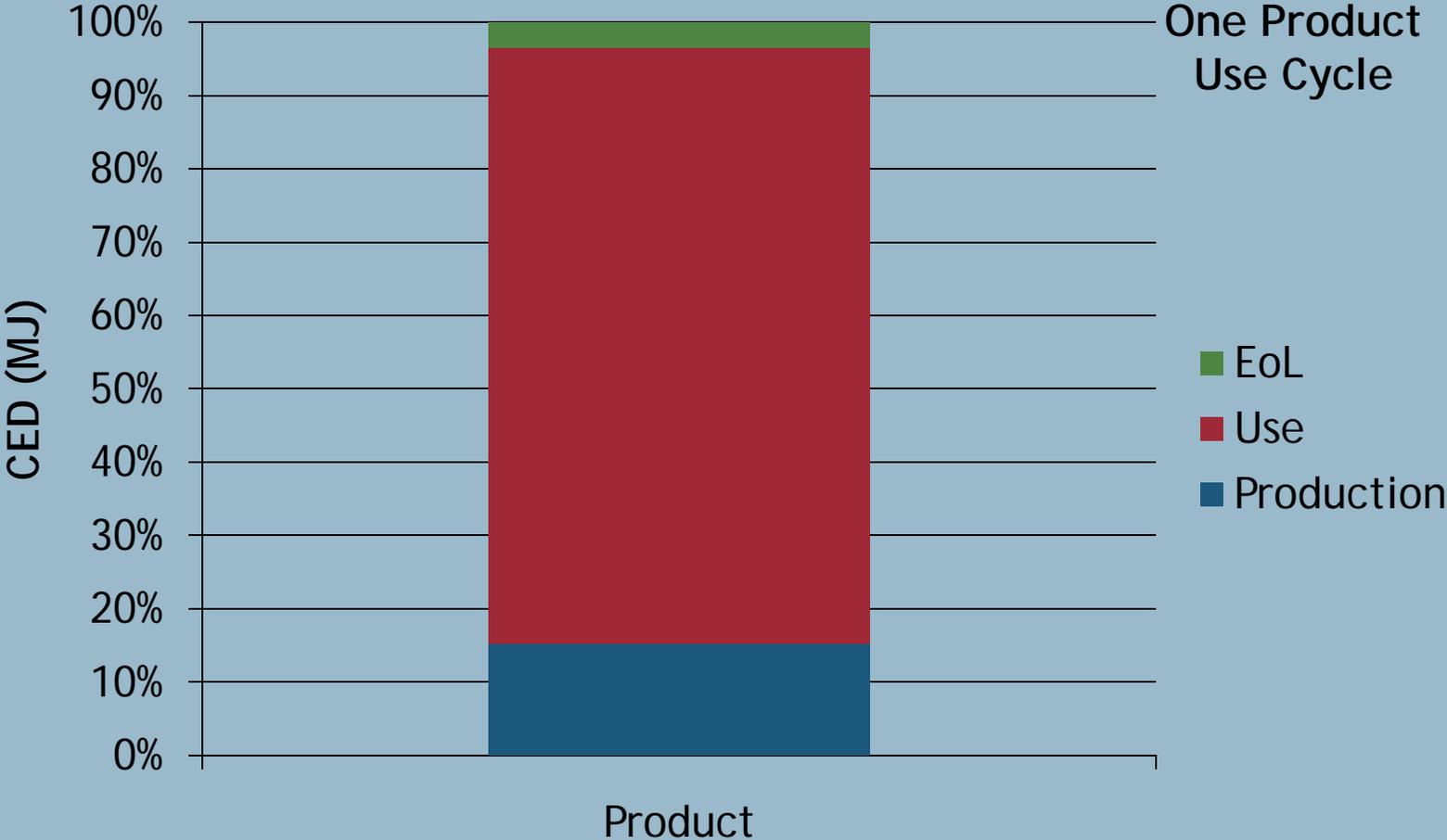
**MSL**

**Materials Systems Laboratory**

Slide 38

# Complete Life Cycle: One Use Cycle

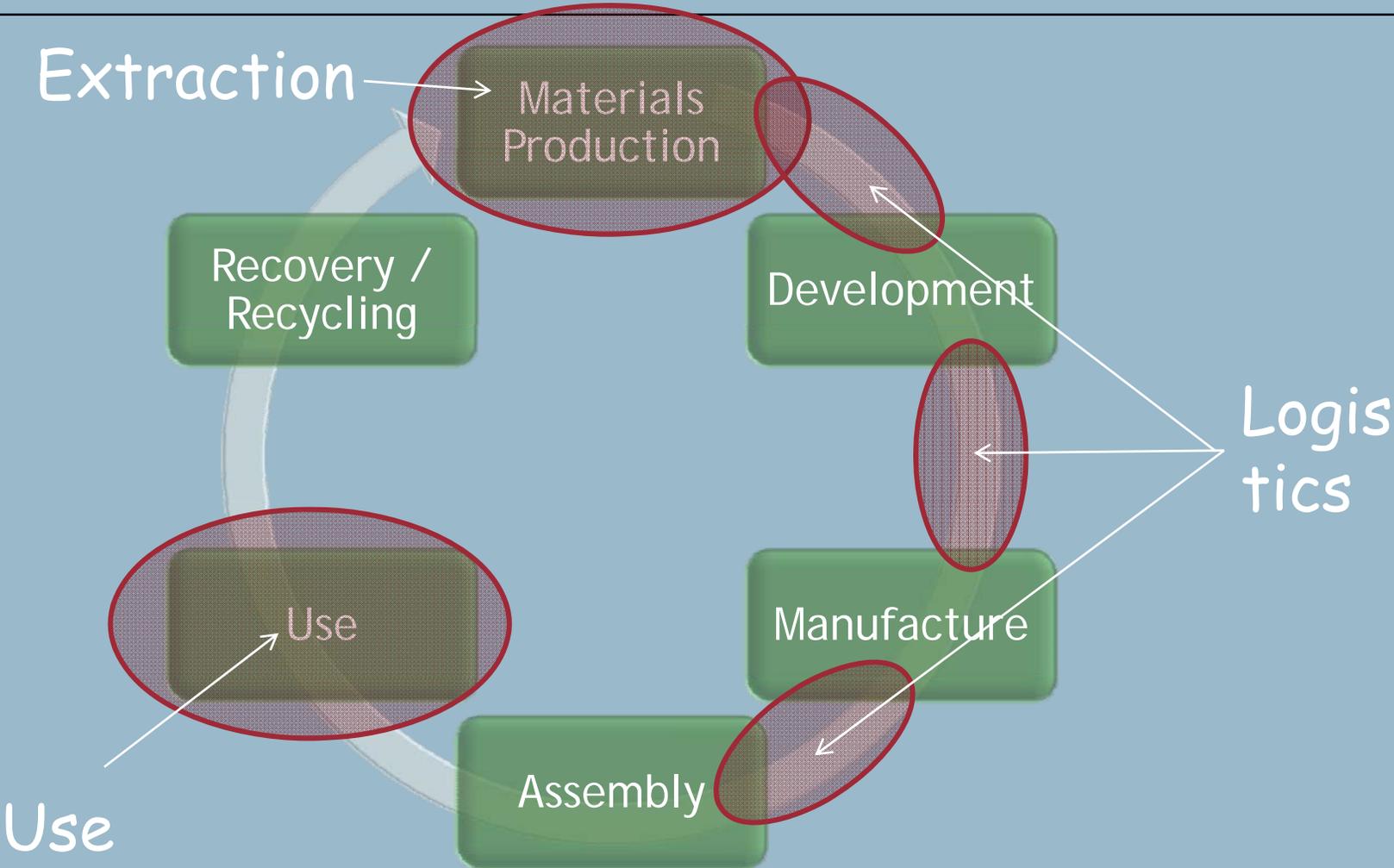
Use phase dominates



# Clear Strategic Opportunities

- In supply-chain
  - Materials production    Particularly, Materials A, B & C
    - Use a new supplier
    - Use recycled materials
    - Use a new material
- In house
  - Manufacturing facility
- Transport, packaging are smaller impacts for this product, but could be improved
- EOL is negligible
- Redesign to improve use phase would be revolutionary

# Common LC Hotspots



# Evaluating Sustainability:

## Issues to Consider for Solar Cells

---

- **Economic**
  - Costs to produce
  - Costs to use
  - Costs to dispose
- **Environmental**
  - Resource use
  - Effluents / Emissions
    - Supply-chain & Production
    - Use
    - Disposal
    - Avoided
  - End-of-life recovery

MIT OpenCourseWare  
<http://ocw.mit.edu>

3.003 Principles of Engineering Practice  
Spring 2010

For information about citing these materials or our Terms of Use, visit: <http://ocw.mit.edu/terms>.