Integration of Sustainability into Early Design

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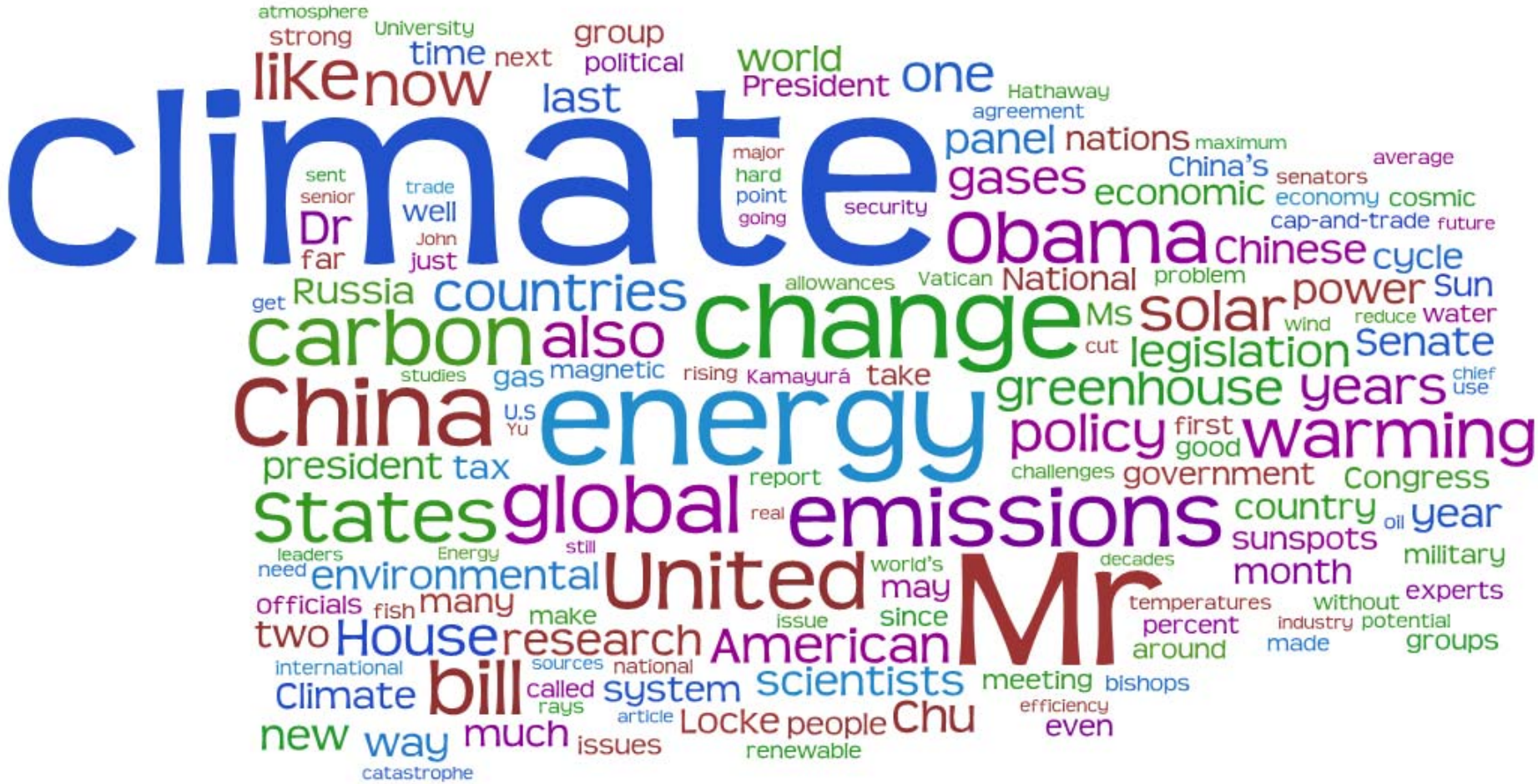
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Background

- An Overview of Sustainable Product Realization for the Life Cycle
  - Fu Zhao, Jun Ki-Choi, John Sutherland, Carol Handwerker and Karthik Ramani (NIST Indo-U.S. Workshop): review paper.
- Position is related to the paper:
  - **Srikanth Devanathan, Pranav Koushik, Fu Zhao, Karthik Ramani,** ASME, International Manufacturing Science and Engineering Conference, MSEC2009, October 4-7, 2009, West Lafayette, Indiana, USA. **MSEC2009- 84356**

Existing scenario

Conceptual Design

- Identify essential problem
- Develop concept variants
- Develop preliminary layout and form design
- Refine and evaluate technical and economic criteria

Detailed Design

- Finalize details
- Complete detailed drawings
- Generate production documents

Manufacturing Planning

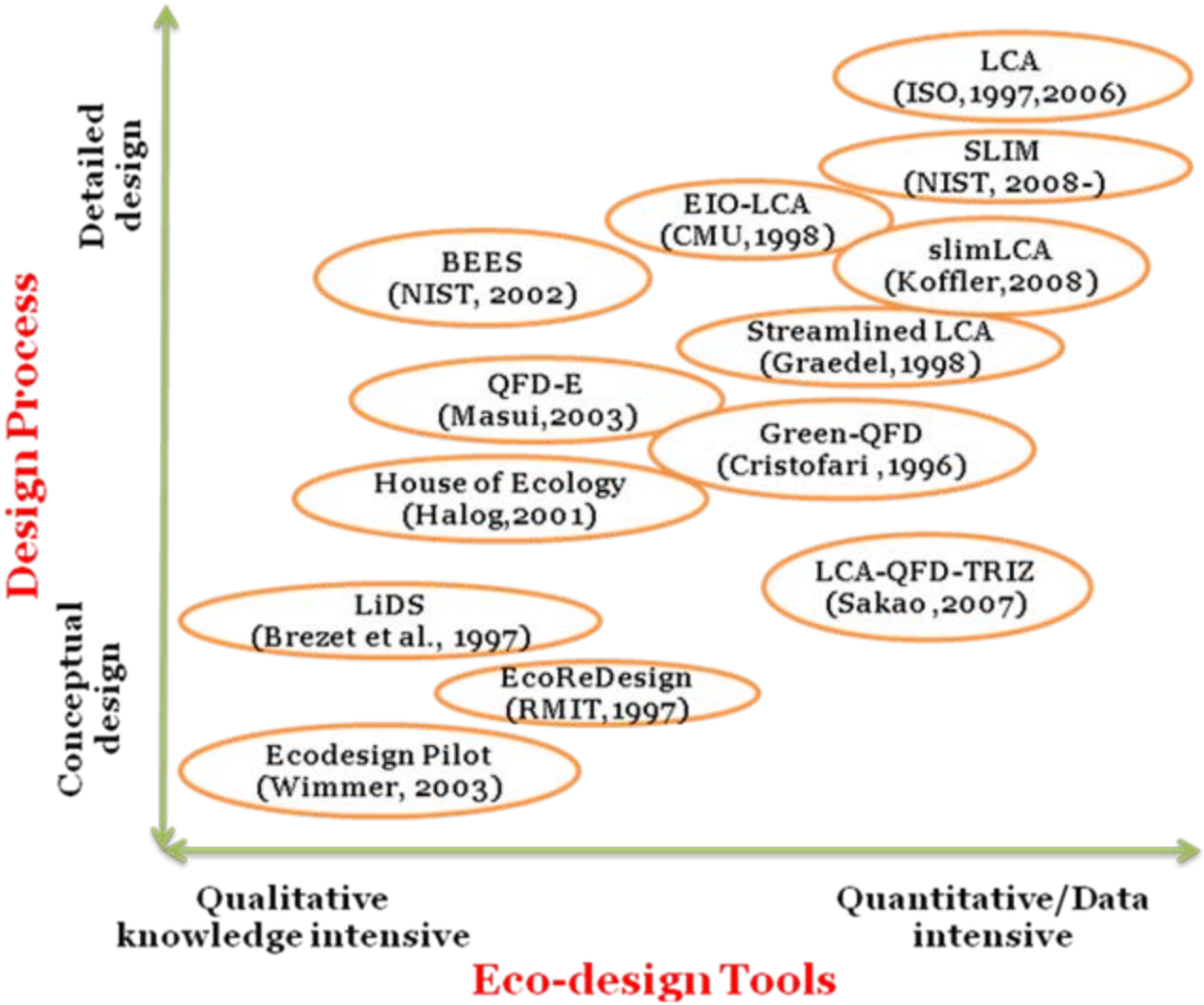
- Source parts
- Identify best manufacturing process plan

Lifecycle Assessment (LCA)

- Perform detailed lifecycle analysis of each component, assembly and final product
- **Currently an after-thought!**

"*…the wrong choice of concept in a given design situation can rarely, if ever, be recouped by brilliant detail design!*" – Pugh, 1991

A Map of Eco-Design Tools



Motivation

- Currently environmental impact is analyzed *after* all the important product decisions are made.
- Early design accounts for 70% of the environmental impact!
- Yet, there are no ways for assessing environmental impact in early design.
- This, we believe will ease environmental pressures on manufacturing.

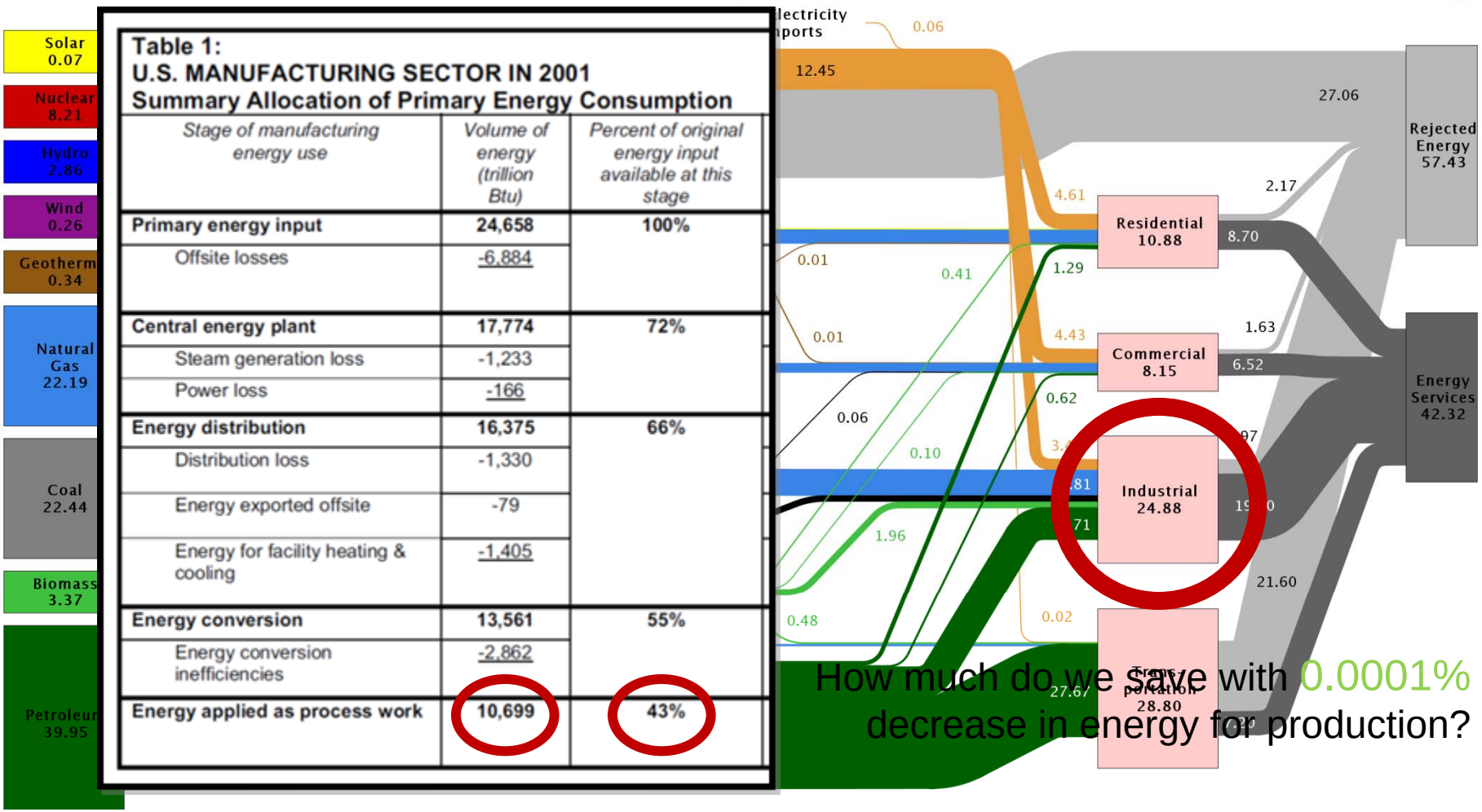
US Energy Flow

Estimated U.S. Energy Use in 2006: ~99.8 Quads

Lawrence Livermore National Laboratory

Table 1:
U.S. MANUFACTURING SECTOR IN 2001
Summary Allocation of Primary Energy Consumption

Stage of manufacturing energy use	*Volume of energy (trillion Btu)*	*Percent of original energy input available at this stage*
Primary energy input	**24,658**	**100%**
Offsite losses	-6,884	
Central energy plant	**17,774**	**72%**
Steam generation loss	-1,233	
Power loss	-166	
Energy distribution	**16,375**	**66%**
Distribution loss	-1,330	
Energy exported offsite	-79	
Energy for facility heating & cooling	-1,405	
Energy conversion	**13,561**	**55%**
Energy conversion inefficiencies	-2,862	
Energy applied as process work	**10,699**	**43%**



How much do we save with 0.0001% decrease in energy for production?

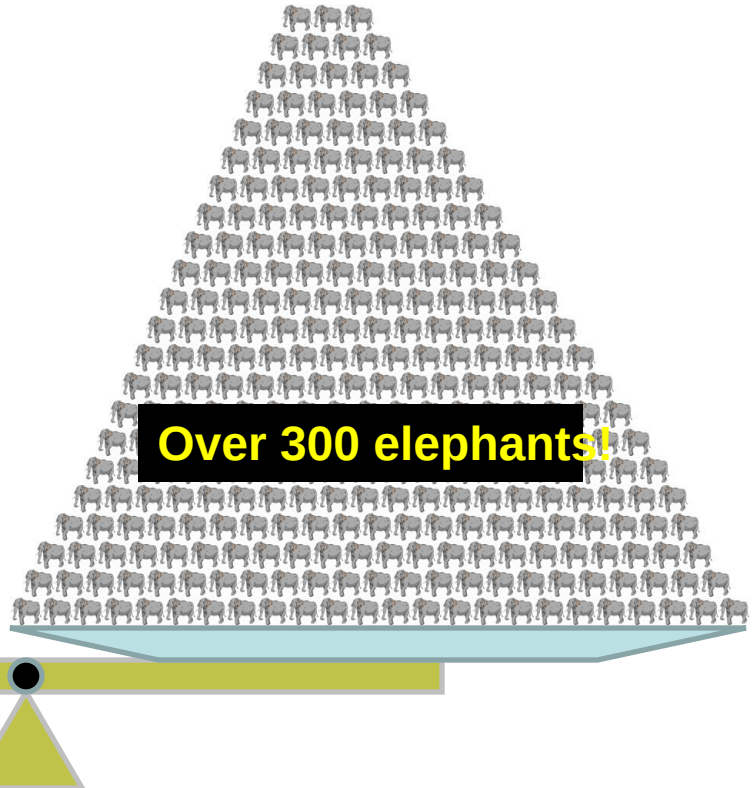
process work - the conversion of raw materials and intermediates into final products

calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

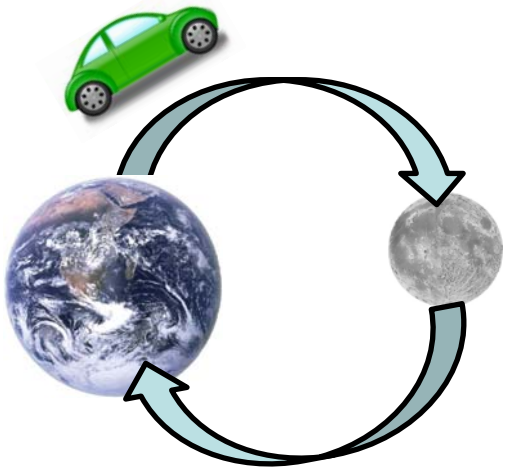
For a **0.0001%** improvement in energy efficiency in production:

10.699 billion btu of energy	→	**3.1359 million KWh**
34.7 KWh per gallon of unleaded gasoline →		**90,371 gallons of gas**
Based on a 20 mpg vehicle	→	**Over 1.8 million mi**
Carbon Footprint of US Grid (0.6 kg/KWh) →		**1881.54 metric tons**

1881.54 metric tons annually



4 round trips to the moon!



The Solution is within **PRODUCT DESIGN**

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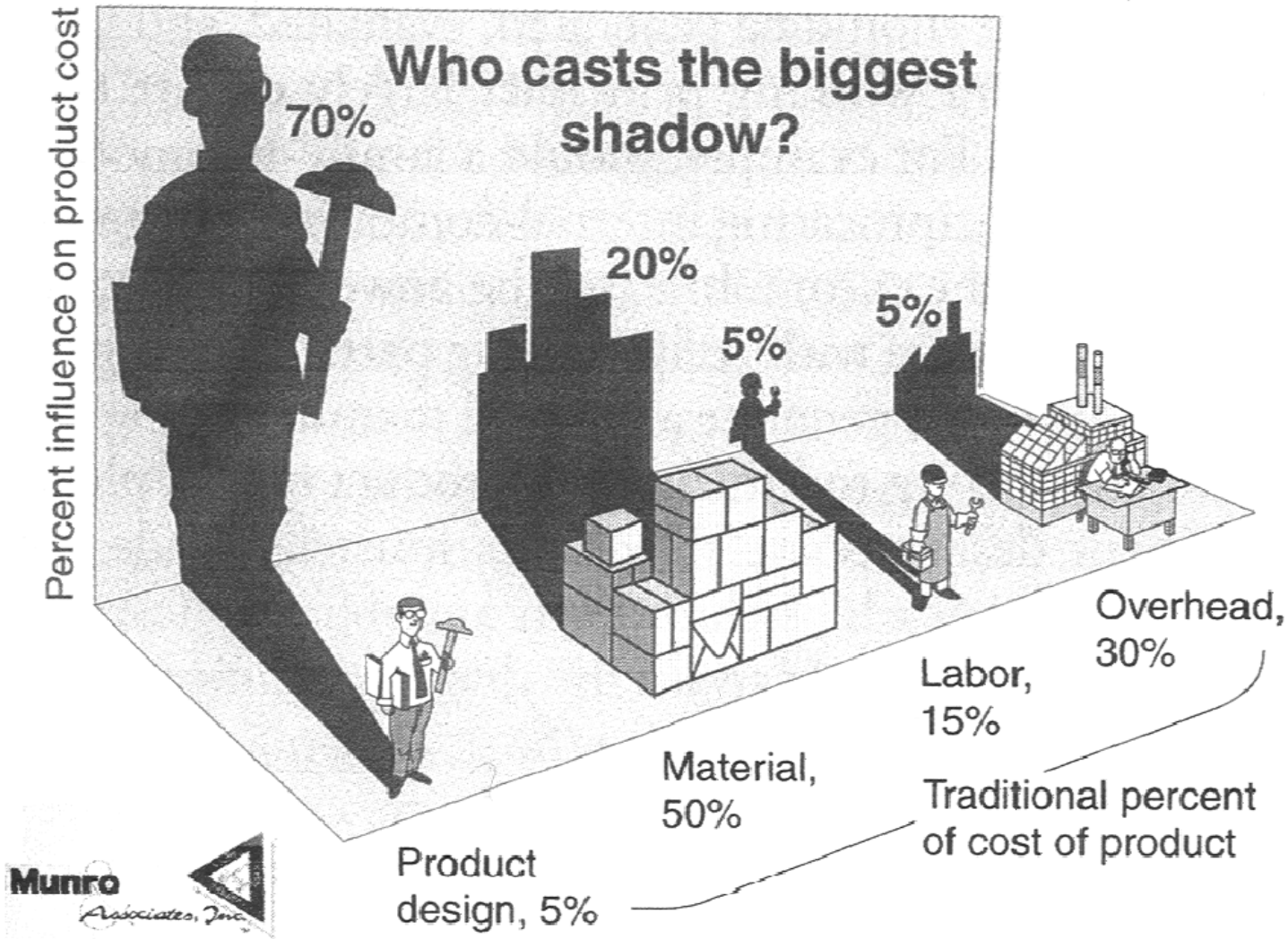
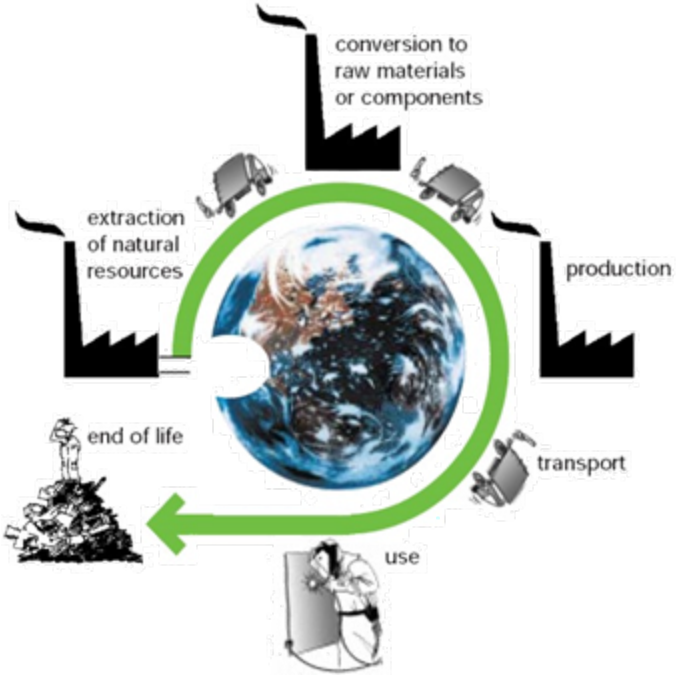


*Business for Social Responsibility and IDEO (2008)

Lifecycle Assessment (LCA)

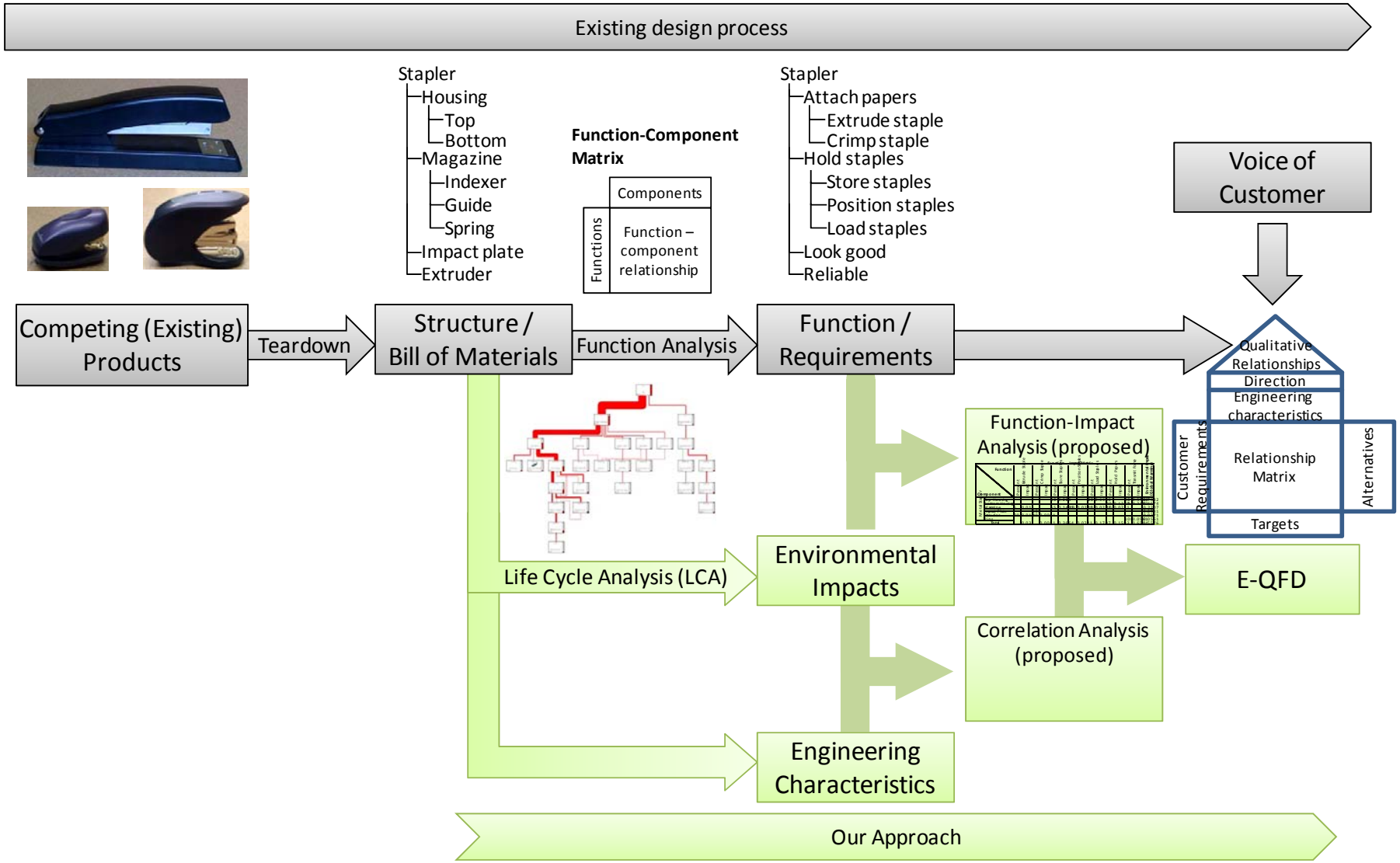
- LCA addresses the environmental aspects and potential impacts throughout a product's life cycle.
- LCA requires detailed and complete product information.
- Consequently, LCA is not suitable for early design.



Approach

1. Develop tools for estimating and modeling ecological impact *during* design, especially conceptual design:
   a. Understand that even new designs are combinations of existing ideas, concepts, parts and processes!
   b. Environmental impact depends on material and manufacturing process which in turn depends on the *structure* of the product.
   c. Provide a mechanism to trace environmental impact of existing products to *functions* and then interpolate to new design using the new **Function-Impact Matrix.**
2. Provide ways to extend environmental impact knowledge to subsequent decision making tools through the Working Knowledge Model.

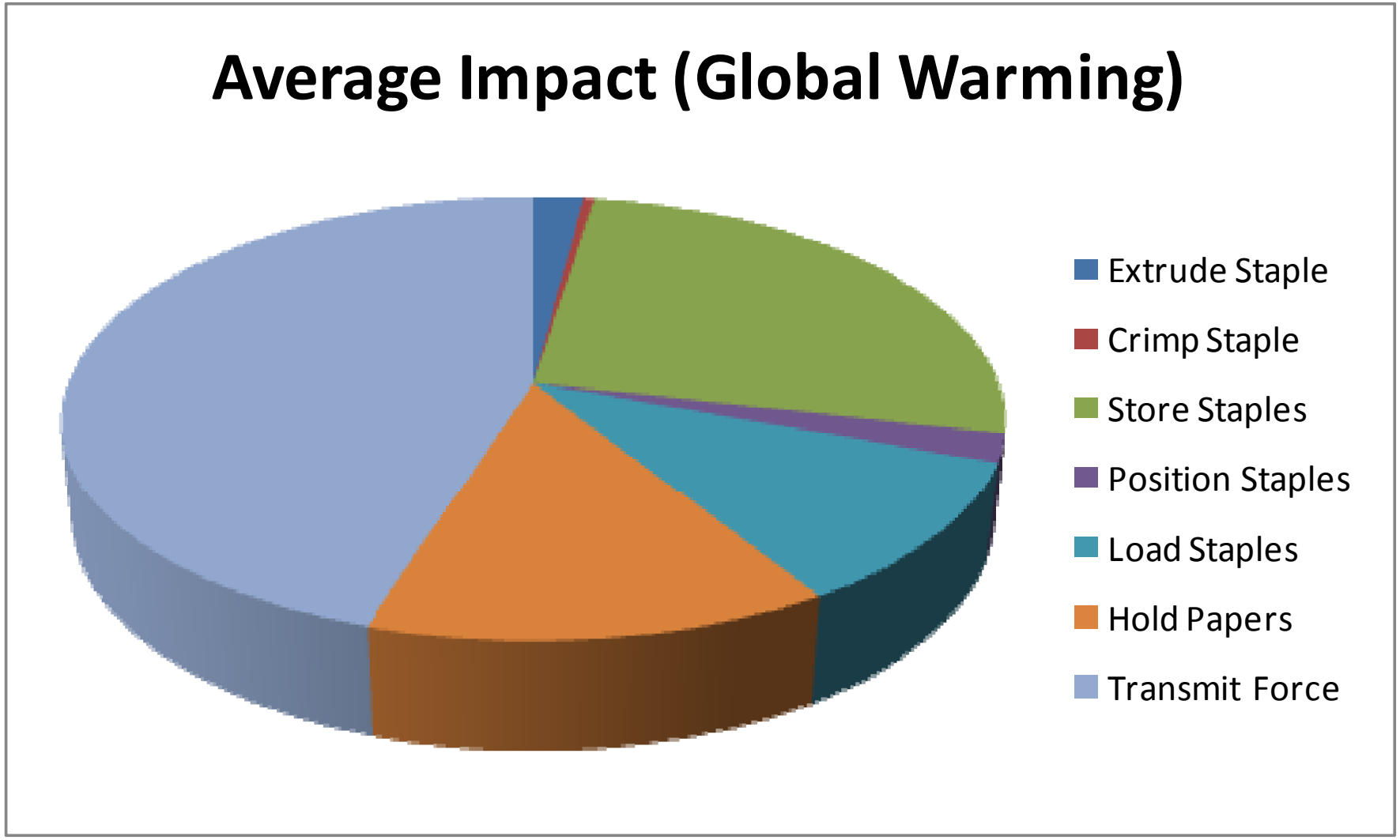
Integrating LCA and Visual Tools



The Function Impact Matrix

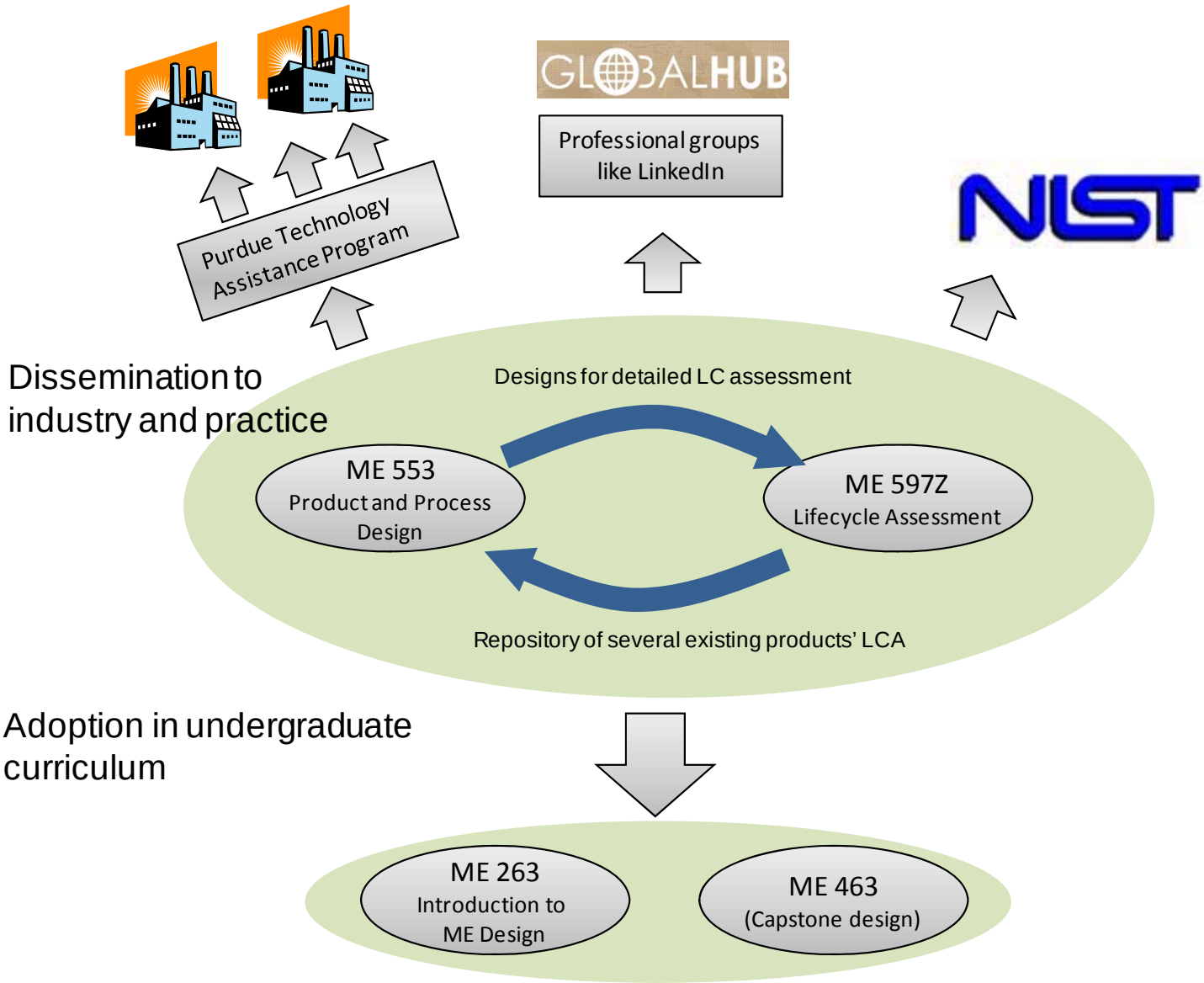
Function - Impact Matrix

Function / Component	Extrude Staple		Crimp Staple		Store Staples		Position Staples		Load Staples		Hold Papers		Transmit Force		**Environmental Impact (Global Warming)**
	Percent	Impact	Percent	Impact	Percent	Impact	Percent	Impact	Percent	Impact	Percent	Impact	Percent	Impact	
Top Housing					30	0.223			20	0.1486			50	0.3716	0.7432
Bottom Housing											30	0.1372	50	0.2287	0.4574
Magazine	5	0.011			65	0.1435	10	0.0221	10	0.0221	10	0.0221			0.2207
Impact Plate			100												0.0531
Extruder	70	0.019	30	0.0081											0.0271
Pins													100	0.0561	0.0561
Total		0.03		0.0081		0.3664		0.0221		0.1707		0.1593		0.6564	1.5576


Average Impact (Global Warming)
Extrude Staple
Crimp Staple
Store Staples
Position Staples
Load Staples
Hold Papers
Transmit Force

Enable Project-Based Learning of Eco-design: Method Development and Curriculum Reform

Zhao and Ramani (NSF EEC)



Jan-Ki Chei & Kartikk Ramani

A Quest for Sustainable Product Design

A Systematic Methodology for Integrated Assessment of Environmentally Benign and Economically Feasible Product Design

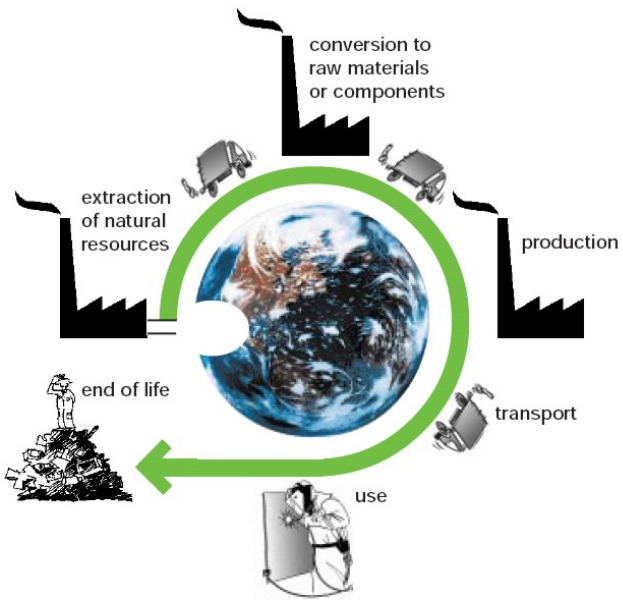
ASME Journal of Mechanical Design Special Issue on Sustainable Design

- The ASME Journal of Mechanical Design solicits submissions for a special issue on sustainable design, including design of devices, design theory, decision making methods, life cycle product design, market and regulatory factors, computer-aided sustainable engineering methods and models, metrics for sustainable design; uncertainty issues in evaluation of sustainable design, design and policy implications, cost, environmental and social impact. Relevant application areas include energy, water, buildings, industrial processes, and transportation. We will consider also a small number of high quality papers in sustainable engineering education including incorporation of sustainable design in engineering curricula.
- Special Issue Editors:

  Steven J. Skerlos, University of Michigan, skerlos@umich.edu

  Alexander H. Slocum, MIT, slocum@mit.edu

  Karthik Ramani, Purdue University, ramani@purdue.edu



Open Innovation Model

- Collaborations – University, Government, Industry
- Avoid duplication and sharing (build a community): ASME – Linked In …join us!
- Project-based learning and incorporation into design thinking
- Design thinking applies broadly to services and systems including energy/products
- Acknowledgement: NSF EEC 0935074 support

- “Designers are routinely faced with environmentally impactful decisions: do you design one pen to last a lifetime, or a solution that requires manufacturing a thousand that are disposable?
  - Ambidextrous
  - Stanford University Journal of Design
  - Fall 2008