Sustainable Manufacturing Research at Multiple Levels

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Outline

- Definitions & perspectives
- Lessons learned
- Process and product examples & cases
- Metrics

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Sustainability: Common Definition

"development that meets the needs of the present generation without compromising the needs of future generations."

United Nations' World Commission on Environment and Development in their report "Our Common Future", 1987

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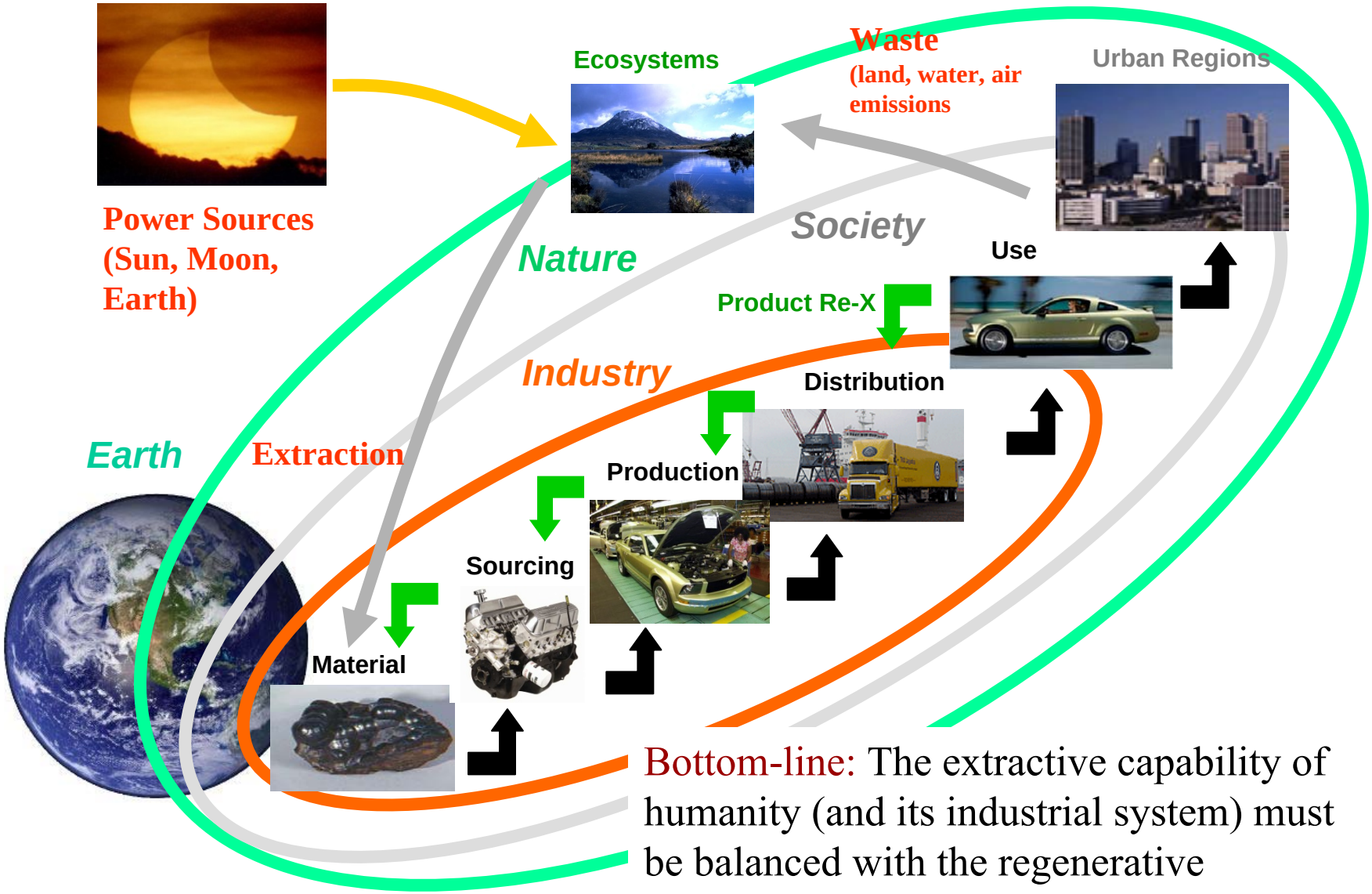
Sustainability: Working within the Physical Limits



Bottom-line: The extractive capability of humanity (and its industrial system) must be balanced with the regenerative capacity of the Earth.

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Sustainability's "Triple Bottom Line"

Sustainability is defined in three dimensions:

- Environmental
  - Destroying our resources will hurt us long term
  - Some materials already getting scarce
- Financial
  - Being bankrupt helps nobody
- Social
  - Quality of Life should go up
  - Workforce education and retention

"Green Economy"

Goal is to have win-win-win technologies and solutions

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Systems View is Needed

Conclusion from NSF Environmentally Benign Manufacturing study:

- Each region (US, Europe, and Japan) has different approaches to developing an environmentally benign manufacturing strategy.
- Each region has different drivers.
- There was no evidence that the EBM problem is solvable by a "silver bullet" technology.
- **Key finding: Japanese and Europeans view EBM as a systems problem, and have put in place various aspects of a systems solutions.**

- **Final Report**: *Environmentally Benign Manufacturing*. WTEC Panel Report, Baltimore, MD, Loyola College, 2001.
- **Online**: http://itri.loyola.edu/ebm/ebm.pdf

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Assessing Products & Processes

Some lessons learned over the years

- Assessment approach (top down, bottom up, accuracy level, etc.) and data requirements depend on the question to be answered
- Data is everywhere and nowhere, and never reconciled
- Legacy systems are a fact of life
- Location and time matter (where and when)
- System boundaries changes can fudge the numbers
- Expect the unexpected
- Verify! (prediction ≠ reality)
- Transparent modeling is crucial (for cont. improvement/use)
- Need for model base instead of database
- Start simple with best and/or worst case scenarios
- Best solutions invariably require change of system boundary

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Integrated Economic & Environmental Performance Monitoring

Challenge:

What is the "gas mileage" of a company? Can we construct a dashboard for a (production) facility providing financial and environmental read-outs akin to a car dashboard?

Sector:

Consumer goods (carpet tiles)

Partner company:

Interface, Inc.

INTERFACE

Solution:

✓Activity-Based Costing was extended to create integrated multi-dimensional financial and environmental assessments

✓Facility & process data was integrated using process sensors

✓A web-based "dashboard" for data acquisition and monitoring of financial and environmental performance of unit-processes was created and piloted.

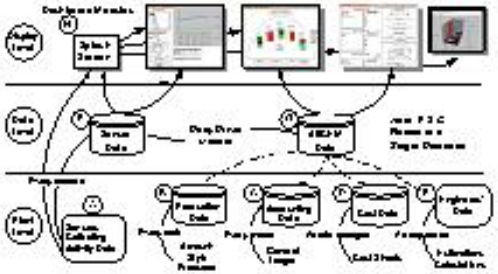
Outcome/Impact:

✓"EcoDash" was tested at Interface Flooring Systems

✓Allowed for detailed investigation of product and process performance over specific time periods.

✓Commercialization potential was explored.

✓Findings led to internal reorganization of facility.



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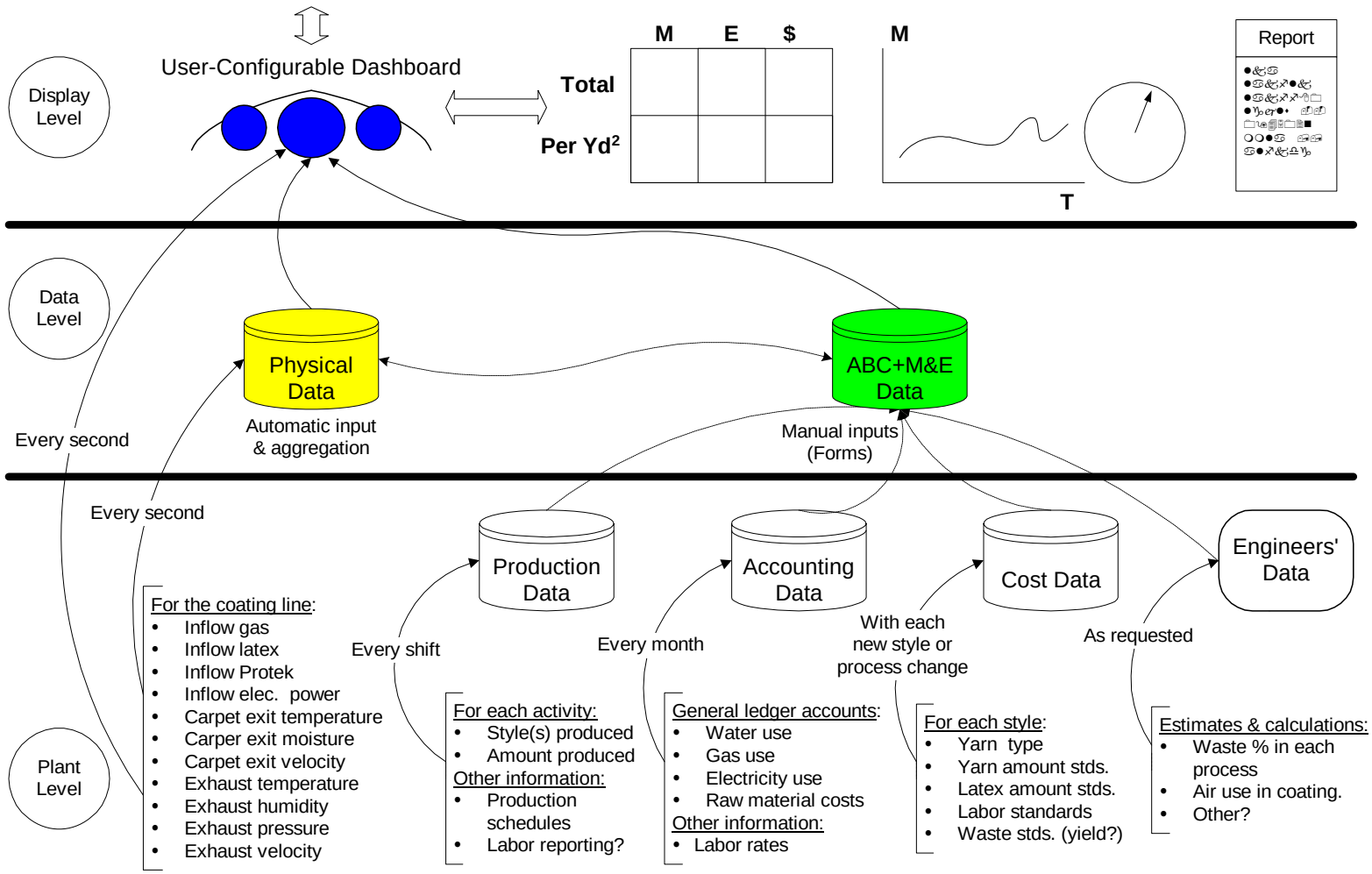
ABCEM EcoDash Pilot Implementation

Resources
1. Resource consumed (all, nylon, latex, air, water, gas...)
2. Level of inclusion (plant, process)
3. Normalized by (all products, specific product)
4. Time period (year, half, quarter, month, week, shift, hour...)

Objects
1. All products
2. Specific products

Indicators
1. Efficiency
2. Effectiveness

Information
1. Sensors
2. Constants
3. Drivers
4. Reports



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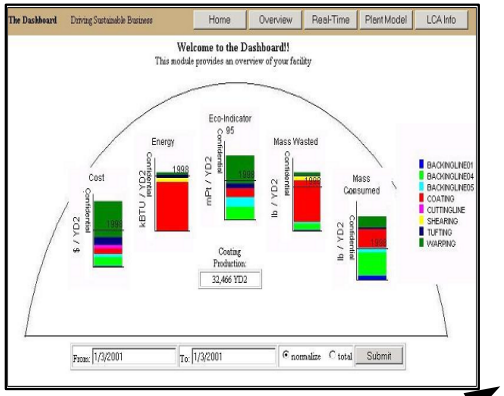
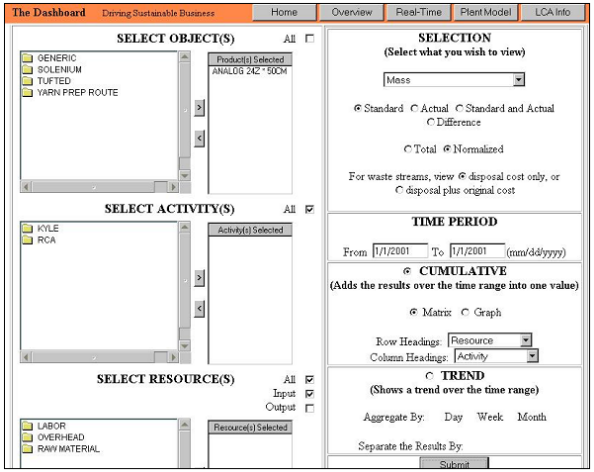
EcoDash Module Overview

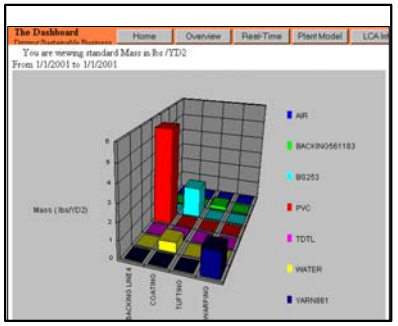
Plant Performance Overview



ABCEM Consumption Tracking Module

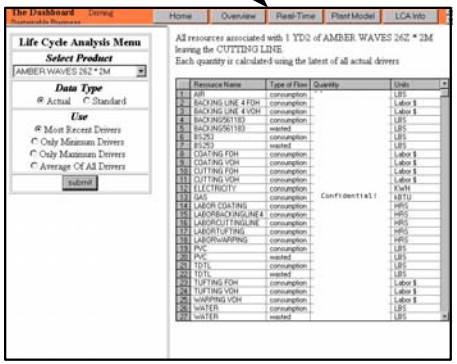


ABCEM Consumption Tracking Results

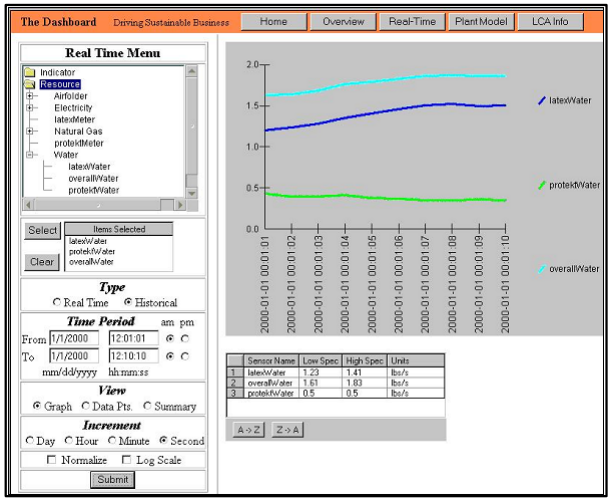


Login Screen → Module Selection Screen

LCA Module



Sensor History Module



INTERFACE

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Findings

- Companies have inconsistent (poor) financial systems
  - Erodes our basic assumption and hypothesis
- Model building effort extensive
- Real time data acquisition can be an overkill
- Employee turnover and short attention spans cause significant implementation hurdles
- Results are not always what you expected
- Even the best recommendations can be ignored
- Organizationally, many barriers exist…

Our Conclusion (then):

Focus on capital investment and strategic decisions rather than operational issues

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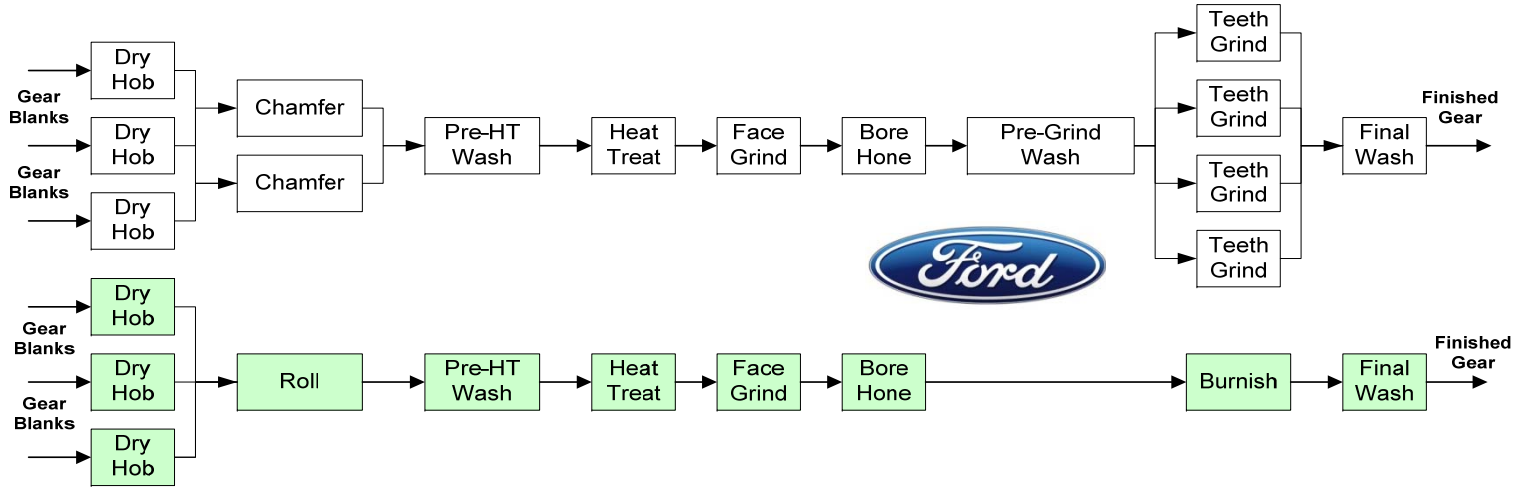
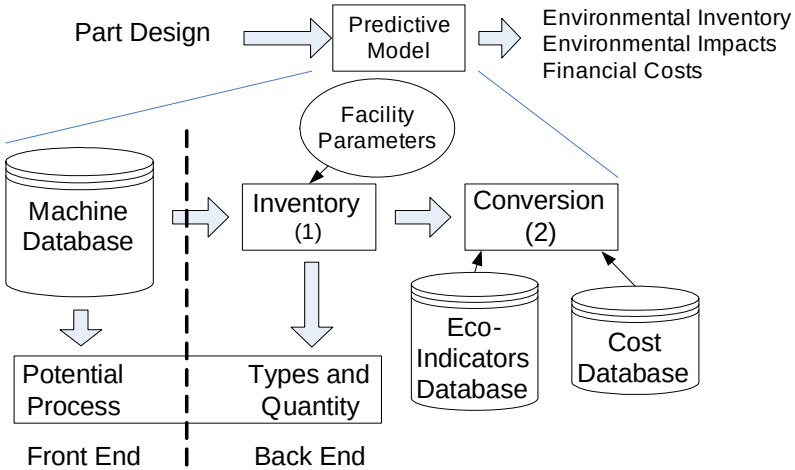
The Simple Version: Assessing Processes using Spreadsheets





		Hard Finish	Green Finish	units
Main	Environmental SPS	313.140	146.789	mpt / part
	Financial Cost	2.083	0.919	$ / part
Inventory	Water Use	3.940	3.138	gal / part
	Landfill Waste	0.000	0.000	lb / part
	Recyclable Material	0.287	0.284	lb / part
	Special Waste	0.401	0.000	lb / part
	Energy	10.091	4.850	kWh / part
	CO2	13.482	6.480	lb / part

- Design affects manufacturing process & technology decisions
- Tighter tolerances require different process technologies with different impacts

Learning: Spreadsheet used by Ford for manufacturing technology selection

Not used by design engineers

Some “black box” issues still remain

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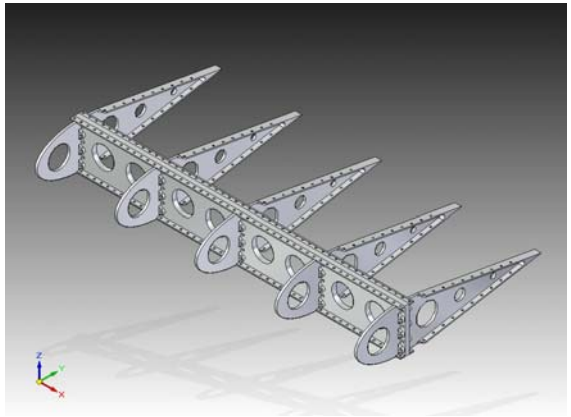
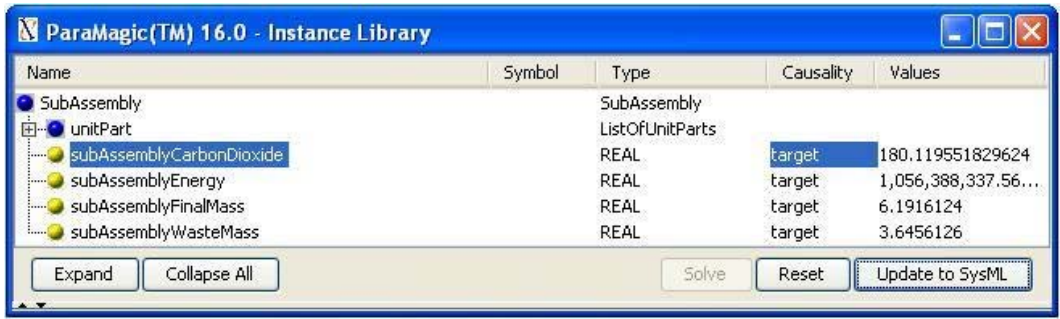
Now: Back to ABC with Boeing

- Need:
  - Decision support in choosing best (sustainable) course of action in material, technology, manufacturing process selection & designs while minimizing information gathering and leveraging and even supporting other design & manufacturing assessments

VAUGHN SWIER PHOTO

- Approach:
  - Use an Activity Based "Costing" approach
  - Build on existing Systems Modeling Language (SysML) work
  - Investigate issues of concern (for Boeing)





ParaMagic(TM) 16.0 - Instance Library

Name	Symbol	Type	Causality	Values
SubAssembly		SubAssembly		
unitPart		ListOfUnitParts		
subAssemblyCarbonDioxide		REAL	target	180.119551829624
subAssemblyEnergy		REAL	target	1,056,388,337.56...
subAssemblyFinalMass		REAL	target	6.1916124
subAssemblyWasteMass		REAL	target	3.6456126

Expand | Collapse All | Solve | Reset | Update to SysML

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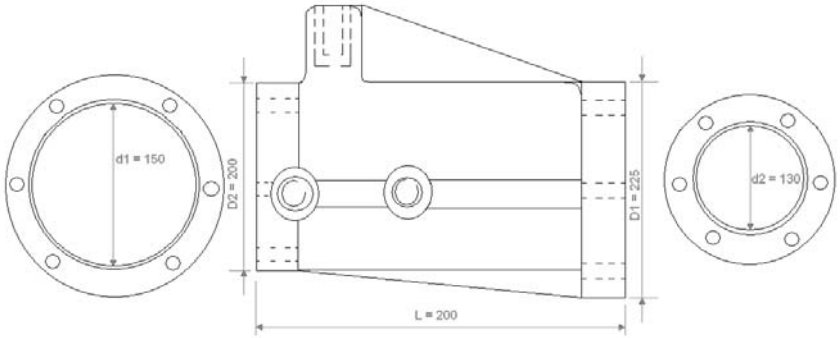
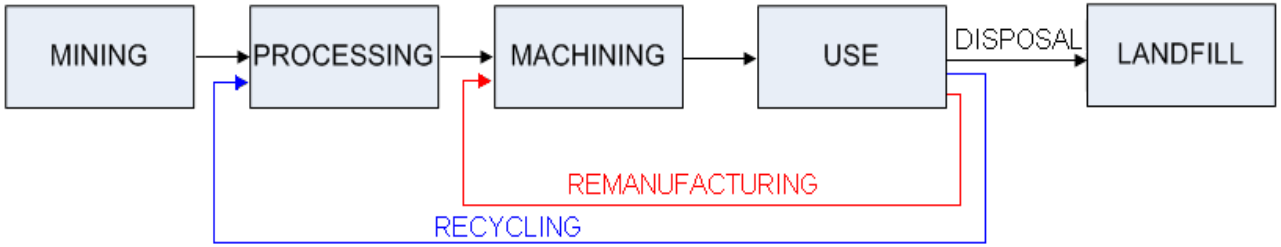
Why Life-Cycle Perspective is Needed

Consider the Life-Cycle of an Aluminum Transfer Casing with different End-of-Life (EOL) Scenarios





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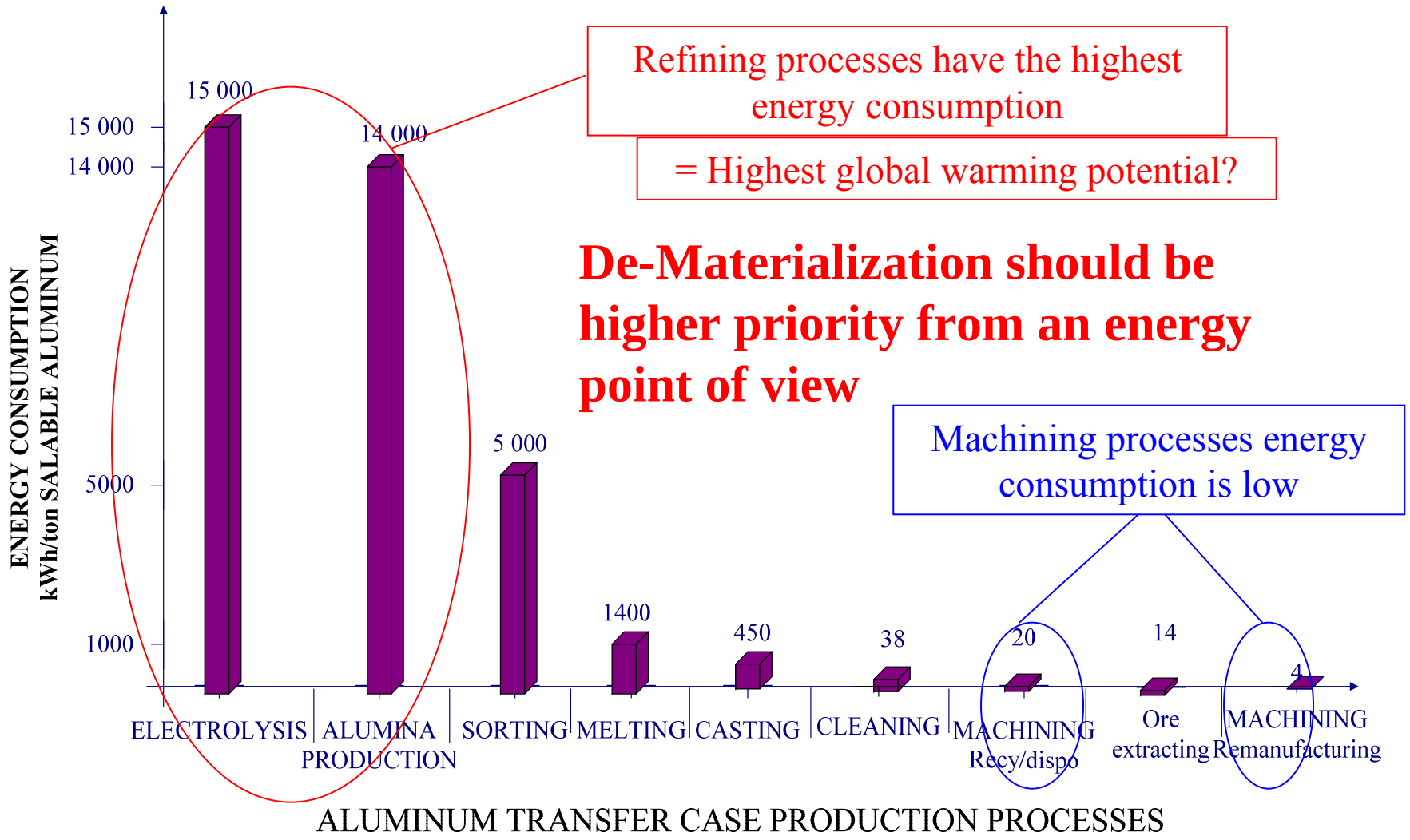
Does manufacturing matter?



ALUMINUM TRANSFER CASE PRODUCTION PROCESSES

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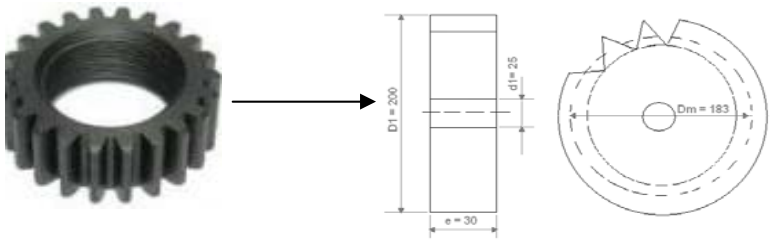
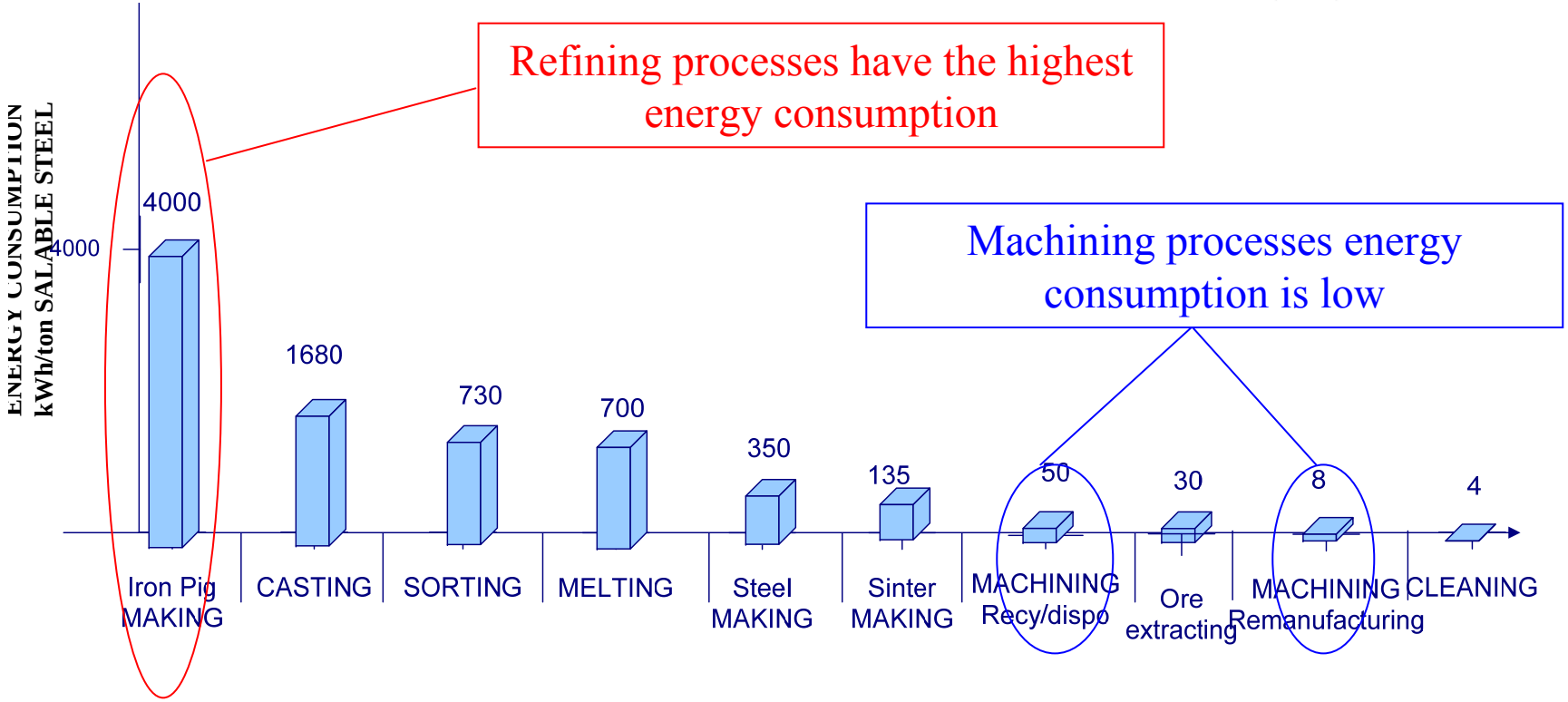
Steel Processing Energy Consumption

De-Materialization again will result in higher gains from an energy pint of view





STEEL PRODUCTION PROCESSES

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Energy Consumption in Manufacturing Sectors

Consumption of Energy (Site Energy) for All Purposes (First Use) for Selected Industries, 1998 and 2002 (Trillion Btu)

- **Manufacturing process energy savings are small when majority is embodied in upfront material production/refining**

		MECS Survey Years	
NAICS	**Subsector and Industry**	**1998**	**2002**
311	Food	1,044	1,123
312	Beverage and Tobacco Products	108	105
313	Textile Mills	256	207
314	Textile Product Mills	50	60
315	Apparel	48	30
316	Leather and Allied Products	8	7
321	Wood Products	509	377
322	Paper	2,747	2,363
323	Printing and Related Support	98	98
324	Petroleum and Coal Products	7,320	6,799
325	Chemicals	6,064	6,465
326	Plastics and Rubber Products	328	351
327	Nonmetallic Mineral Products	979	1,059
331	Primary Metals	2,560	2,120
332	Fabricated Metal Products	445	388
333	Machinery	217	177
334	Computer and Electronic Products	205	201
335	Electrical Equip., Appliances, and Components	143	172
336	Transportation Equipment	492	429
337	Furniture and Related Products	88	64
339	Miscellaneous	89	71
	Manufacturing	23,796	22,666

Source: Energy Information Administration, Form EIA-846, Manufacturing Energy Consumption Surveys, 1998 and 2002, http://www.eia.doe.gov/emeu/efficiency/mecs_trend_9802/mecs9802_table1a.html

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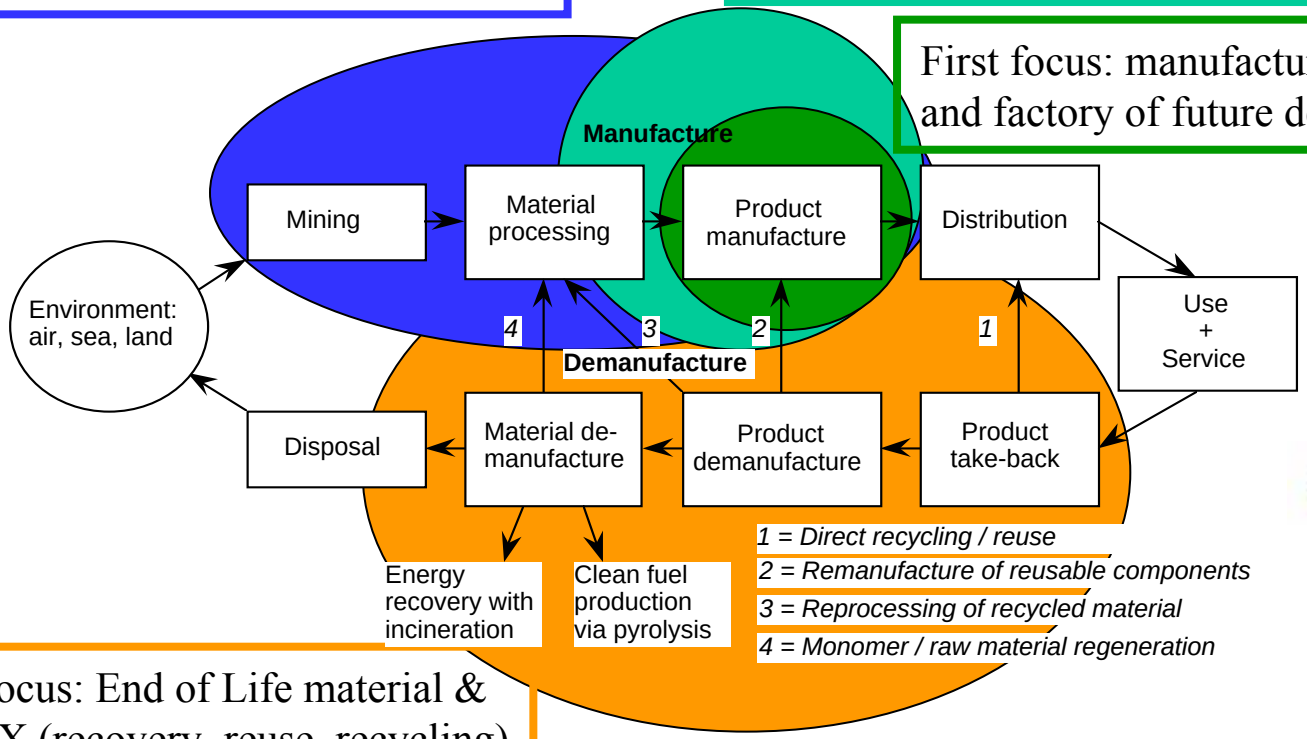
Evolution of Thinking: From Manufacturing to Covering the Life Cycle

- Impact is made in different stages of life-cycle

Third focus: include material & part sourcing/supplier selection

Second focus: product design decisions that affect manufacturing processes

First focus: manufacturing processes and factory of future design



Fourth focus: End of Life material & parts re-X (recovery, reuse, recycling)

Schematic of Product Life-Cycle (Bras, 1997)

Bras, B. (1997). "Incorporating Environmental Issues in Product Realization." United Nations Industry and Environment **20**(1-2): 7-13.

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A Simple Question…

- *What is better for the environment*: Digital pictures or conventional pictures?

- Typical (correct) answer: *"It depends…"*
- Why answer is not clear cut….
  - Digital camera avoids chemicals in film developing.
  - However, digital cameras require electronics and computers that need energy and contribute to greenhouse gasses.

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It gets more complicated…

- **Consumer has many different options**
- **What is the environmental performance of product <u>systems</u>?**

Imaging Scenarios	ABBR	Capture	Processing	Output
Film Capture to Retail Print	FC/R	Film	Retail	Retail
Film Capture to Wholesale Print	FC/W	Film	Wholesale	Wholesale
Digital Capture to CRT Retail Print	DC/CR	Digital	PC/CRT	Retail
Digital Capture to LCD Retail Print	DC/LR	Digital	PC/LCD	Retail
Digital Capture to CRT Wholesale Print	DC/CW	Digital	PC/CRT	Wholesale
Digital Capture to LCD Wholesale Print	DC/LW	Digital	PC/LCD	Wholesale
Digital Capture to CRT Inkjet Print	DC/CI	Digital	PC/CRT	PC / CRT Inkjet
Digital Capture to LCD Inkjet Print	DC/LI	Digital	PC/LCD	PC / LCD Inkjet
Digital Capture to Display CRT	DC/CD	Digital	PC/CRT	PC / CRT Display
Digital Capture to Display LCD	DC/LD	Digital	PC/LCD	PC / LCD Display

Companies make strategic product and processes technology decisions and need to know the environmental issues associated with *different product systems, strategies, and use scenarios.*

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LCA Results

Scenario	ABBR	Greenhouse Emission kg CO_2 eq. / kg CO_2 eq.	Water Use m^3 / m^3	Waste Generation kg / kg	Energy Use MJ / MJ
Film Capture to Retail Print	FC/R	**1**	0.0075	0.0992	0.9801
Film Capture to Wholesale Print	FC/W	0.6127	**0.0064**	**0.0714**	0.6508
Digital Capture to CRT Retail Print	DC/CR	0.6770	0.2053	0.2512	0.7945
Digital Capture to LCD Retail Print	DC/LR	0.6409	0.0595	0.2281	0.6786
Digital Capture to CRT Wholesale Print	DC/CW	0.4673	0.2053	0.2494	0.6193
Digital Capture to LCD Wholesale Print	DC/LW	**0.2085**	0.0547	0.2034	**0.2235**
Digital Capture to CRT Inkjet Print	DC/CI	0.3122	0.1976	**1**	0.4606
Digital Capture to LCD Inkjet Print	DC/LI	0.2798	0.0670	0.9794	0.3567
Digital Capture to Display CRT	DC/CD	0.5145	**1**	0.3388	**1**
Digital Capture to Display LCD	DC/LD	0.3337	0.2709	0.1724	0.4203

Best and worst are indicated in each column

Outcome/Impact:

- No clear winning or high risk scenario
- Supported business decision to go "digital"
- Digital technologies offer more choice and flexibility, resulting in a much wider range of potential impact
- Influence of consumer during use phase can significantly influence environmental burden
- ***Providing <u>services</u> (wholesale printing, Ofoto) instead of products (PC printers) is better (in this case)***

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CAD & LCA

- Basic "cradle to gate" environmental assessments early in (cad) design process can (easily) be done
- Implementation barriers are data sources (availability, uniformity, transparency, etc.), priority, and skilled engineers (incl. students)
- Manufacturing and use phase data has high(er) levels of uncertainty and ambiguity
  - Time span and locations matter

See also:

Kalyan-Seshu, U.-S. and Bras, B., "Integrating DFX Tools With Computer-Aided Design Systems", Paper no. 98DETC/DAC-5593, ASME Design Automation Conference, Proceedings **1998 ASME Design Engineering Technical Conferences** and Computers in Engineering Conference, Atlanta, Georgia, September 14-17, 12 pp., 1998.

Kalyanasundaram, V. and Bras, B., "Software Tool for evaluation of environmental indicators using cad models early in the design cycle", Proceedings of the ASME 2009 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference, IDETC/CIE 2009, August 30 - September 2, 2009, San Diego, California, USA

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Example Data Schema: Restricted Substances

Schema

Include data from industry standards such as the Global Automotive Declarable Substance List (GADSL) for the automotive industry, Joint Industry Guide (JIG for the electronics industry or legislative requirements

ENV_REGULATIONS

Substance_Category	Threshold

SUBSTANCE_CATEGORIZATION

CAS Number	Substance_Category

Follows Automotive Industry Action Group End of Life Vehicle standards

MATL_COMPOSITION

Material_ID	Substance_CAS_Number	Substance_perc

Materials contain multiple substances in different amounts (percentages)

PART_INFO

Part ID	Part_No	Material_ID	Part_Mass

CAD

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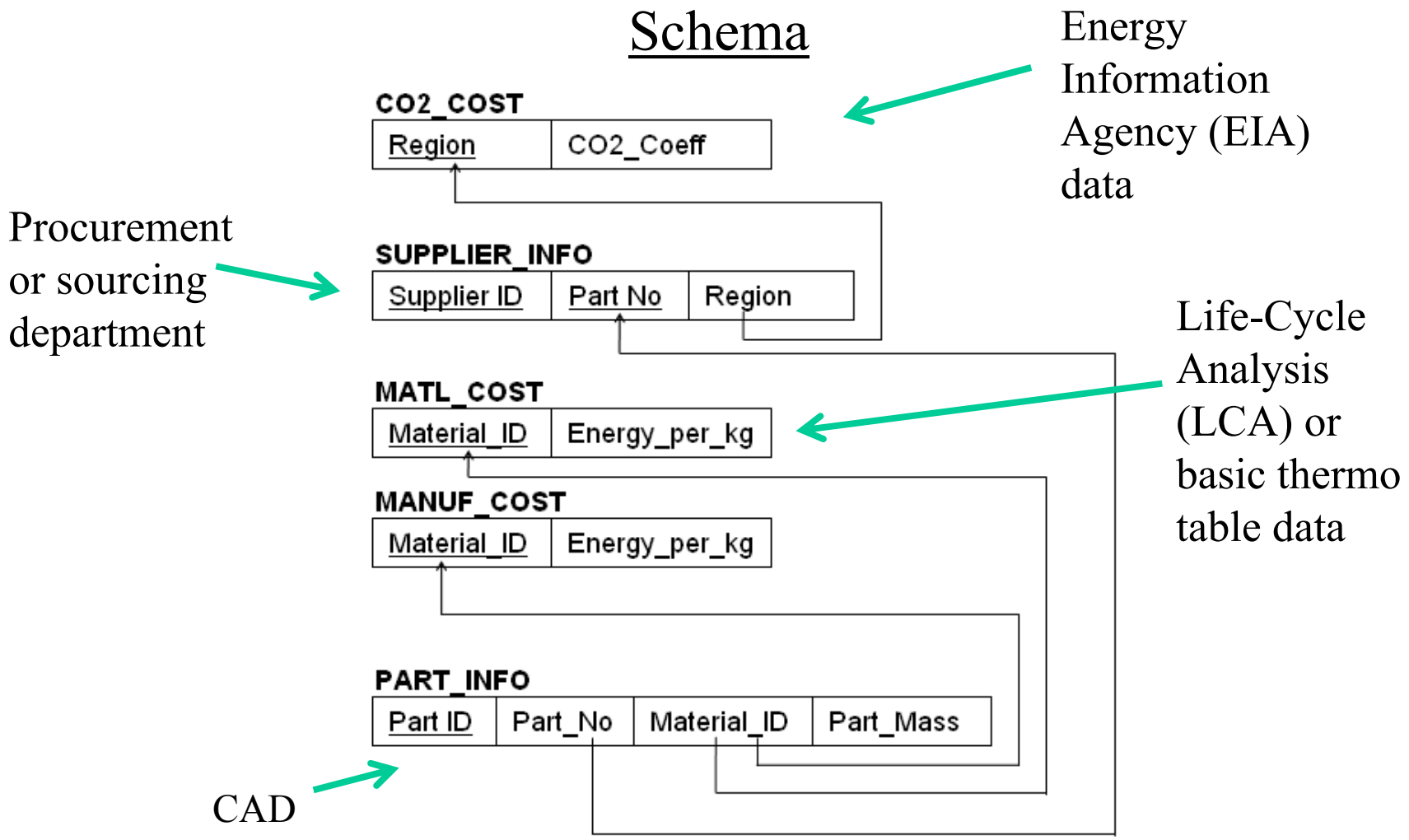
Cradle to Gate CO_2 Cost



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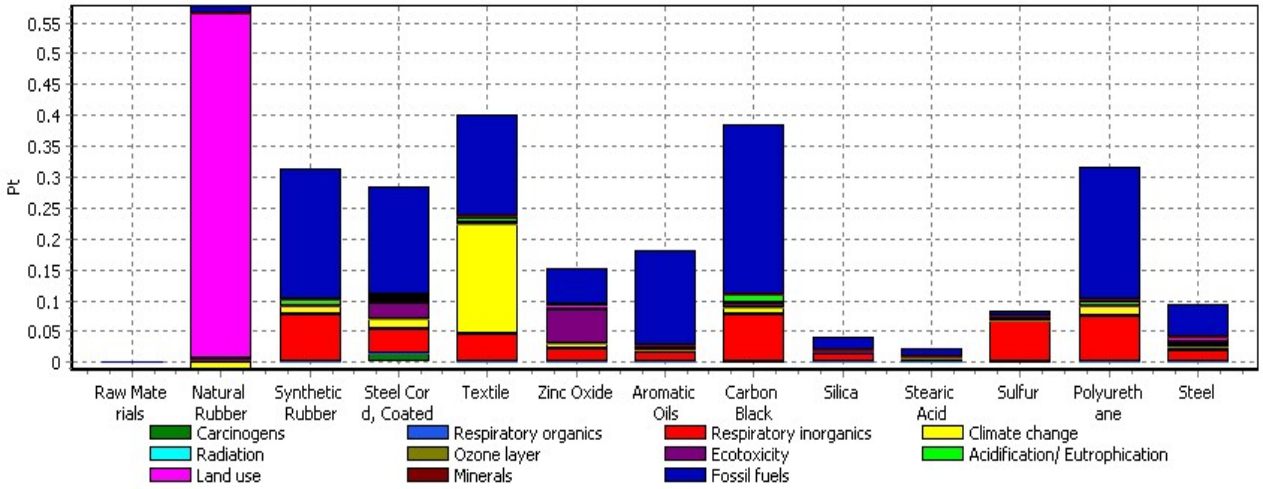
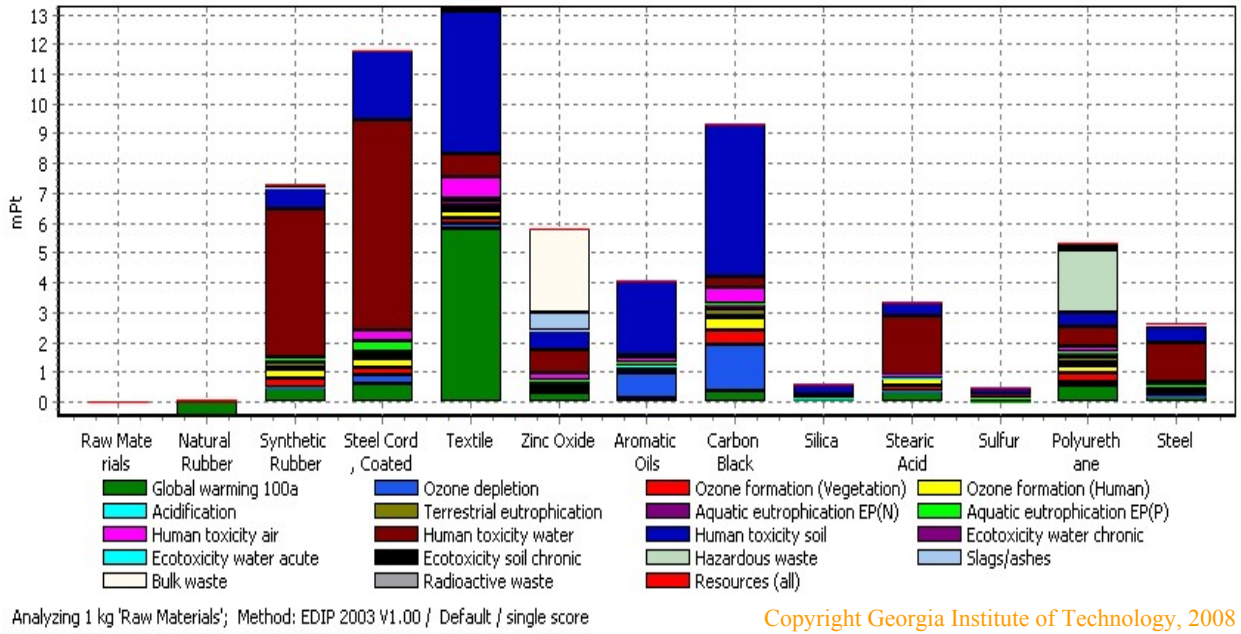
Natural vs Synthetic Rubber Design Dilemma

- Impact of production of 1 kg of raw material – EcoIndicator99 versus EDIP 2003



- ***What now?***



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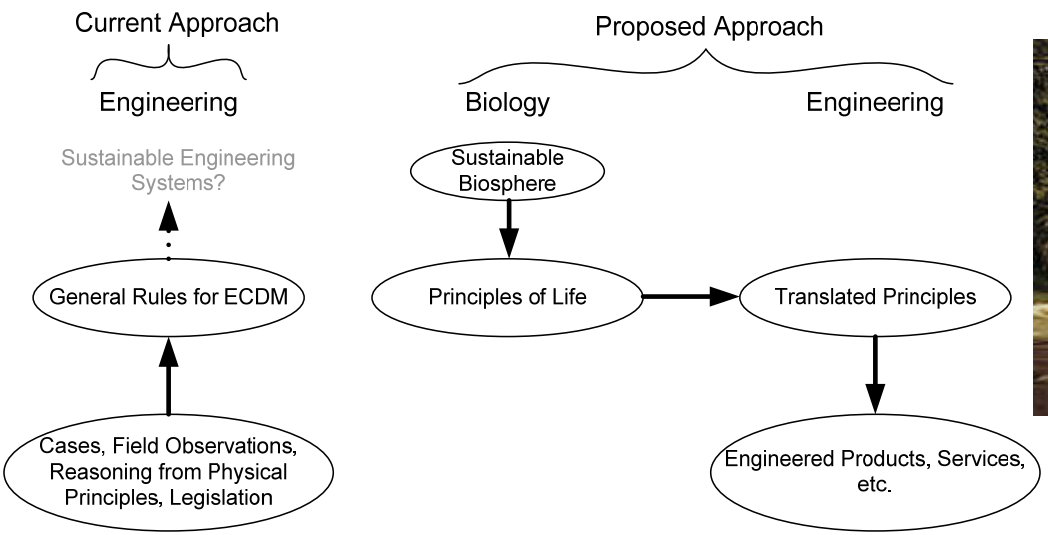
Bio-Inspired Metrics and Guidelines

Going beyond the metric conundrum:

- Nature has been sustainable for a long time.
- What can we learn from past & present biological systems?
  - Including extinct systems…
- Can we derive design guidelines from Nature that will result in inherently sustainable engineered systems



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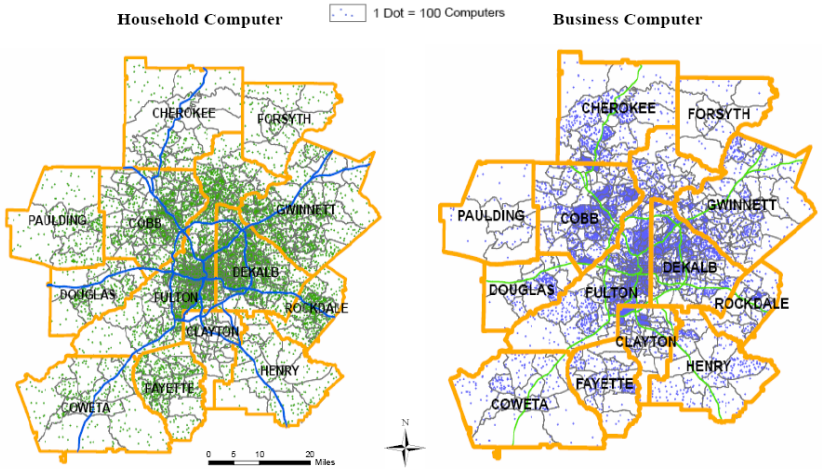
Socio-Economics Benefits from Regional Product & Material Re-X

Urban Region (Atlanta)

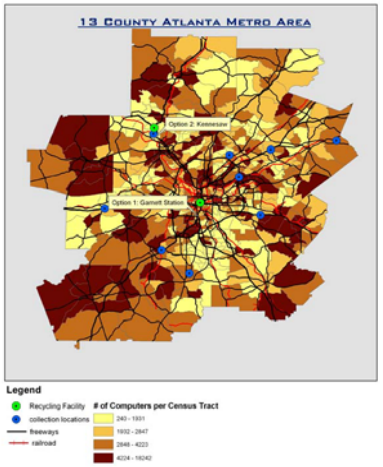
Products



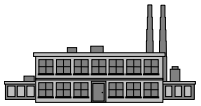
Source: Computer stocks are estimated using population and employment information provided by Atlanta Regional Commission (ARC) and computer use information in the Current Population Survey (CPS) September 2001 Supplement Survey.

Product Inventory Estimate (PIE) models

Recycling facility locations



Where will future (sustainable) manufacturers get their materials from?

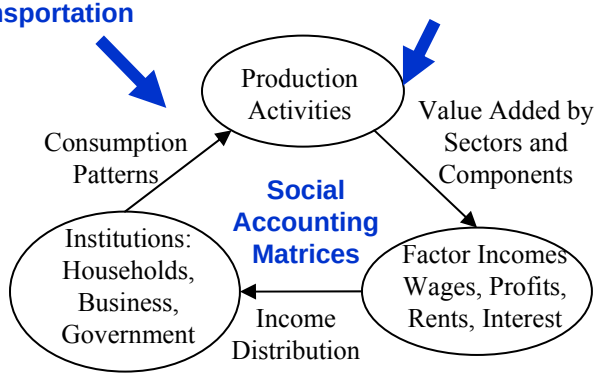


Re-X Facility/Process

Transportation

Environmental impact

Could material reclamation create new manufacturing activities in distressed areas and be an economic development strategy promoting urban sustainability?



Need for understanding of material blending, new products, and re-X processing technologies, etc.

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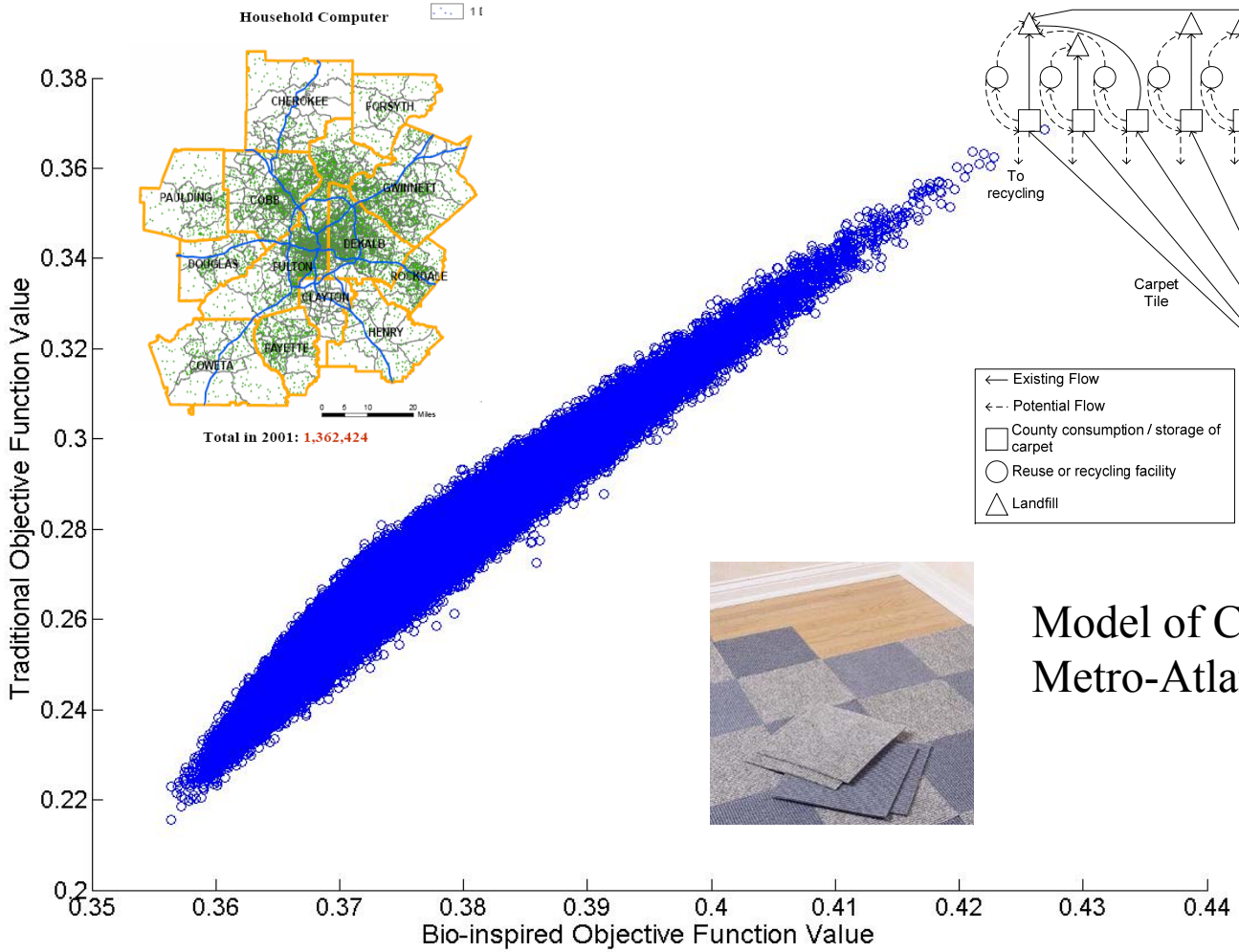
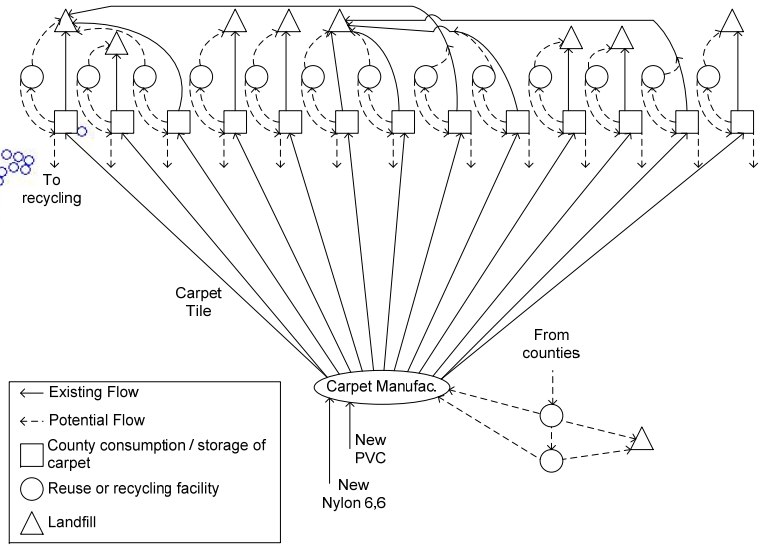
Engineering and City Planning joint MUSES Project CMMI-0628190

Applying Ecology Metrics to Carpet Recycling





Model of Carpet Tile Flow in Metro-Atlanta Region

Traditional cost-based and bio-inspired ecological community metrics-based objective function values for 100,000 randomly generated designs

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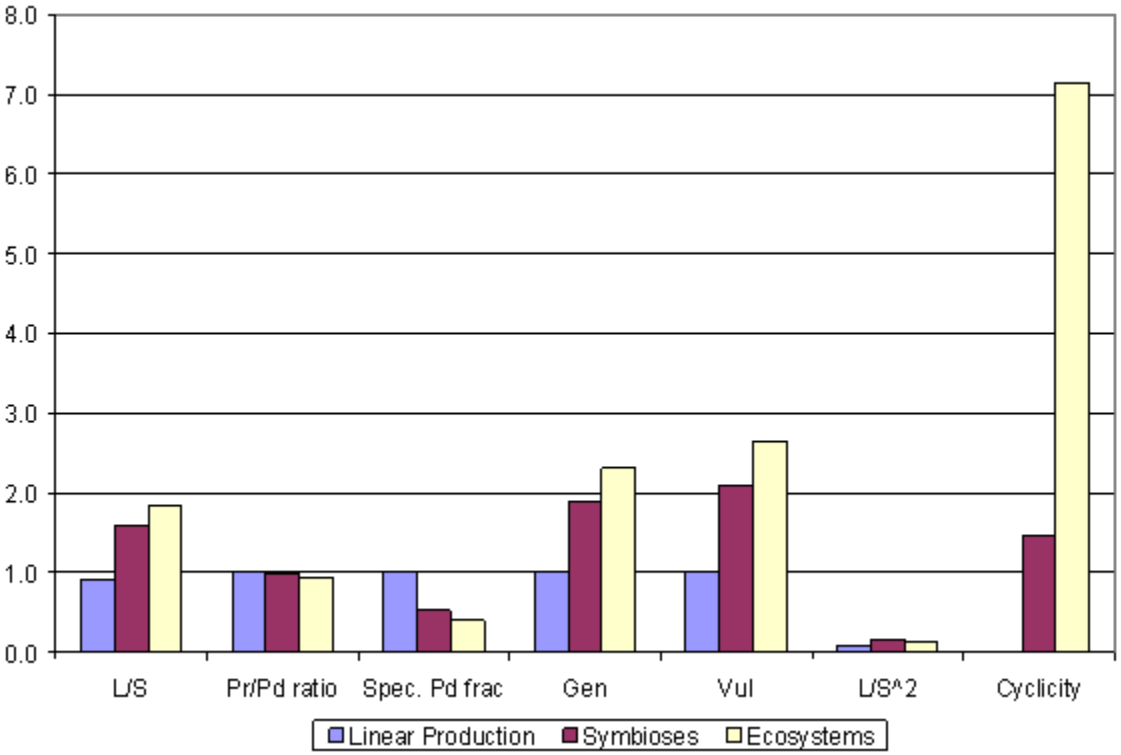
How industrial ecosystems rank



Average ecological structural metrics for a linear production chain, industrial symbioses (n=29) and ecosystems (n=40)

- Industrial symbioses have greater resource efficiency and less waste compared with linear counterparts
- Statistically, industrial symbiosis and food web structures cannot plausibly be grouped with food webs.
- Symbioses represent middle ground
- Worth exploring result of patterning closed industrial material flows after those found in nature

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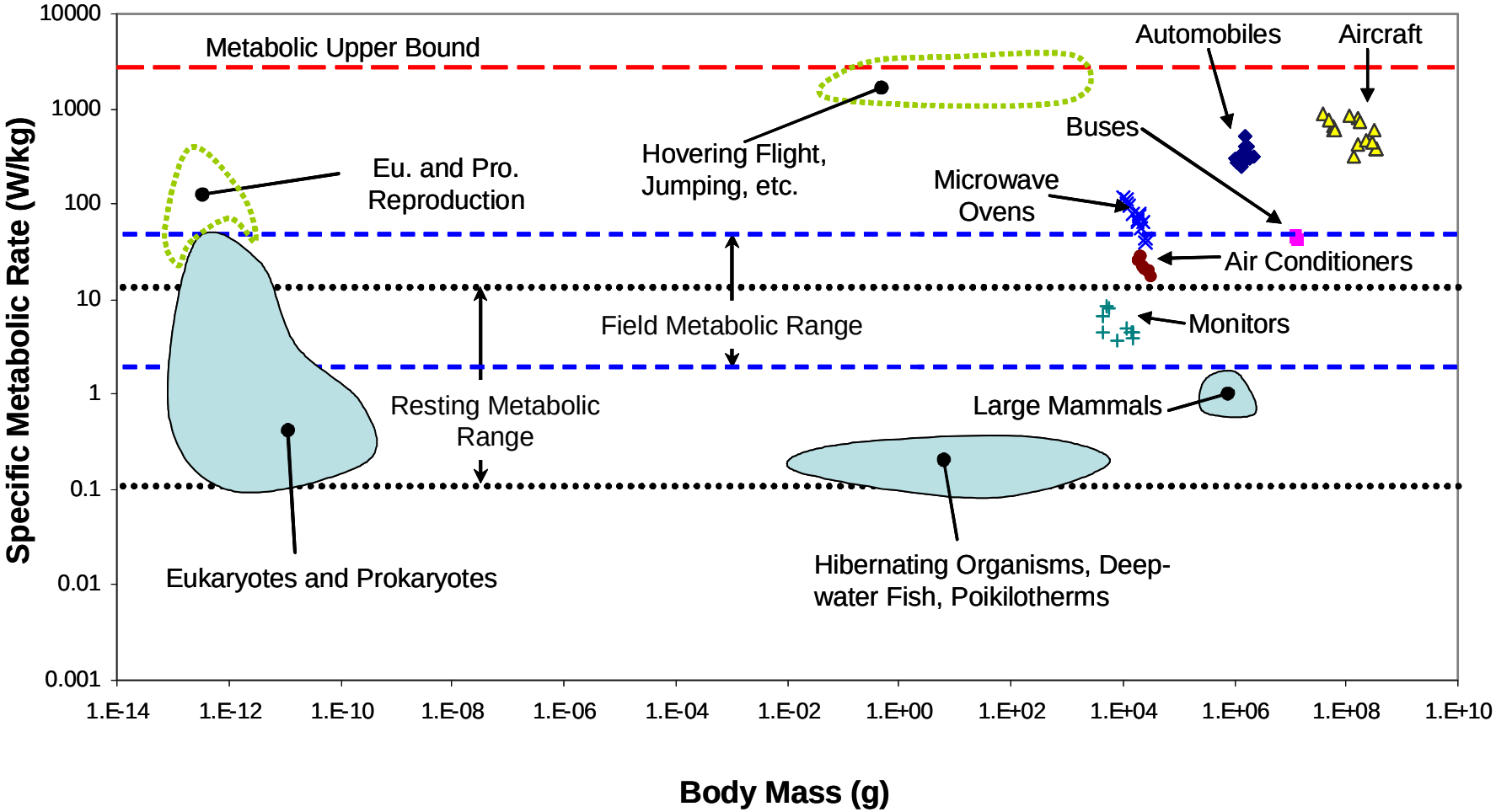
Specific Energy Consumption of Organisms & Devices: A Fundamental Limit for Sustainability?



Reap, J., Bras, B., "Exploring the Limits to Sustainable Energy Consumption for Organisms and Devices", Journal of Sustainable Manufacturing, Vol. 1, No. 1-2, pp.

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Limits of Engineering

- **Be aware of "systems solutions" beyond engineering as well as "unintended consequences" (e.g., rebound effects)**

For example:

- Localities matter in sustainability
  - Relocating a manufacturing facility to a locality with renewable power often has a larger carbon footprint effect than any process efficiency improvement

GA Power Plant Bowen (Cartersville):

- **CO2 emission: 0.9 kg/kWh**
- **H2O evaporation: 0.4 gallons/kWh**

South-East average (incl. Georgia):

- **CO2 emission: 0.6 kg/kWh**

- Social behavior has larger influence than engineering
  - Car pooling creates more fuel savings than all technologies combined
  - Rebound effect can kill any efficiency gains

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Finally…

Importance of Education

Thank You!

Questions?

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