Sustainable Product and Process Design

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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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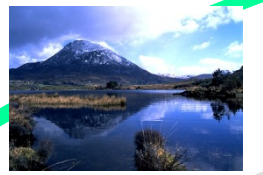
Sustainability: Physical and Biological Limits

Power Sources (Sun, Moon, Earth)

Ecosystems



Waste (land, water, air emissions

Urban Regions

Nature

Society

Use

Product Re-X

Industry

Distribution

Earth

Extraction

Production

Sourcing

Material

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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Grand Challenge: Need for a Systems Approach

Observations from 2001 National Science Foundation sponsored global study on Environmentally Benign Manufacturing:

- There was no evidence that the environmental problems from our production systems are solvable by a "silver bullet" technology.
- There is a need for **systems-based solutions**
  - which requires a comprehensive systems approach
  - where scientists, engineers, managers, economists, entrepreneurs, policy-makers, and other stakeholders all work together to
    - address environmental issues in product realization and
    - achieve economic growth while protecting the environment.

Sustainability is a complex, multi-disciplinary problem that needs cross-cutting approaches in order to achieve true impact.

- **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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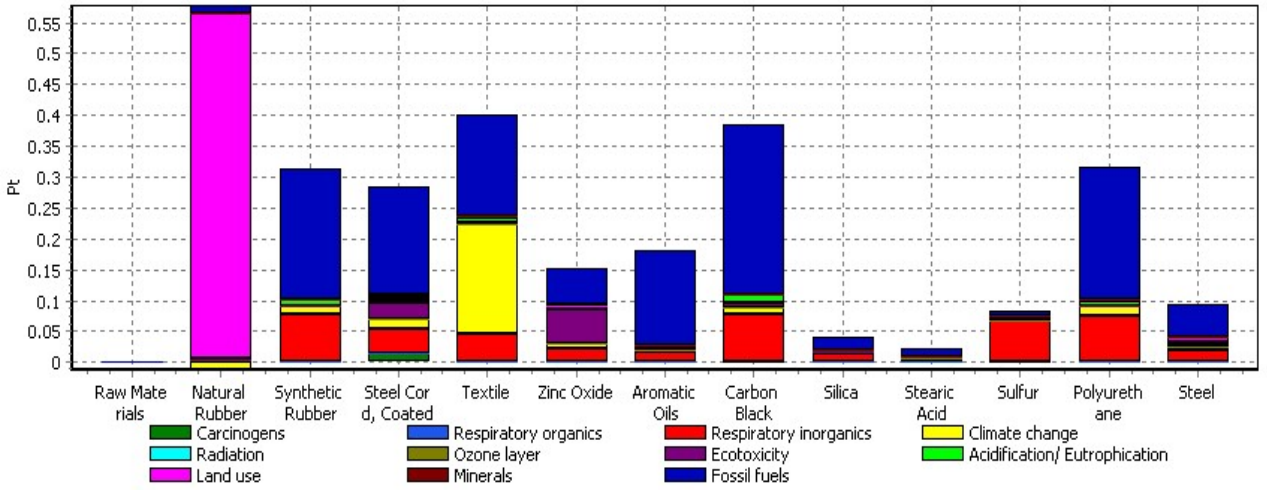
LCA Example: Natural vs Synthetic Rubber Design Dilemma

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

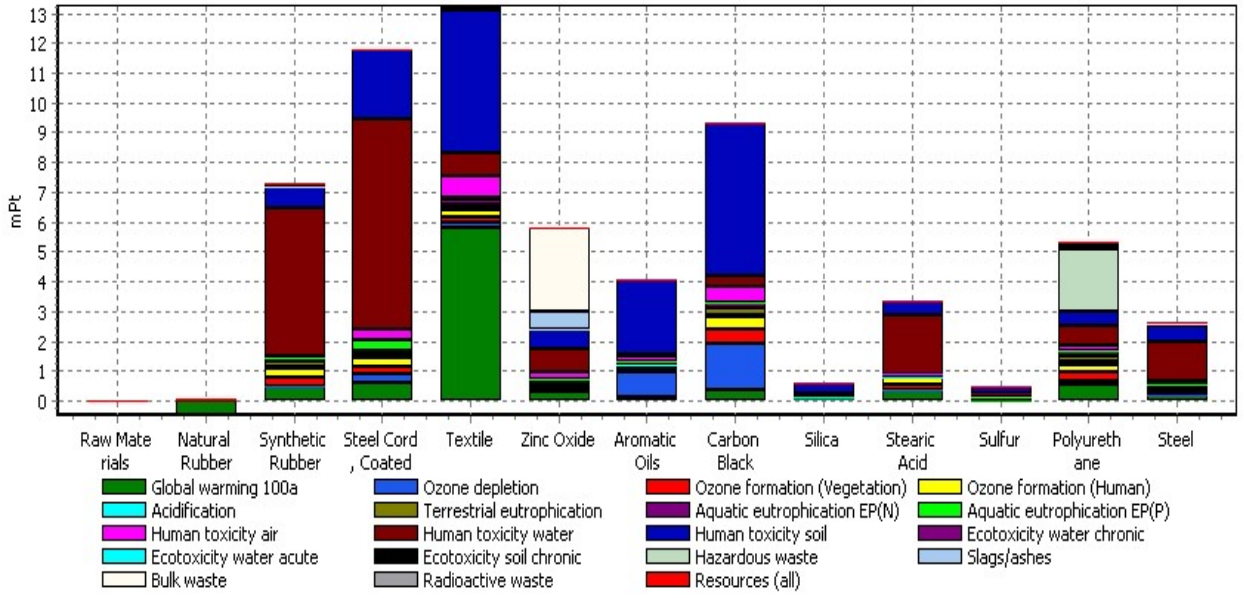
- ***What now?***
- ***It depends…***

TWEEL ® LCA

Bras, B. and Cobert, A., "Life-Cycle Environmental Impact of Michelin Tweel® Tire for Passenger Vehicle", SAE International Journal of Passenger Cars – Mechanical Systems, June, Vol. 4, No.1, pp. 32-43, 2011



Analyzing 1 kg 'Raw Materials'; Method: Eco-indicator 99 (E) V2.05 / Europe EI 99 E/E / single score



Analyzing 1 kg 'Raw Materials'; Method: EDIP 2003 V1.00 / Default / single score

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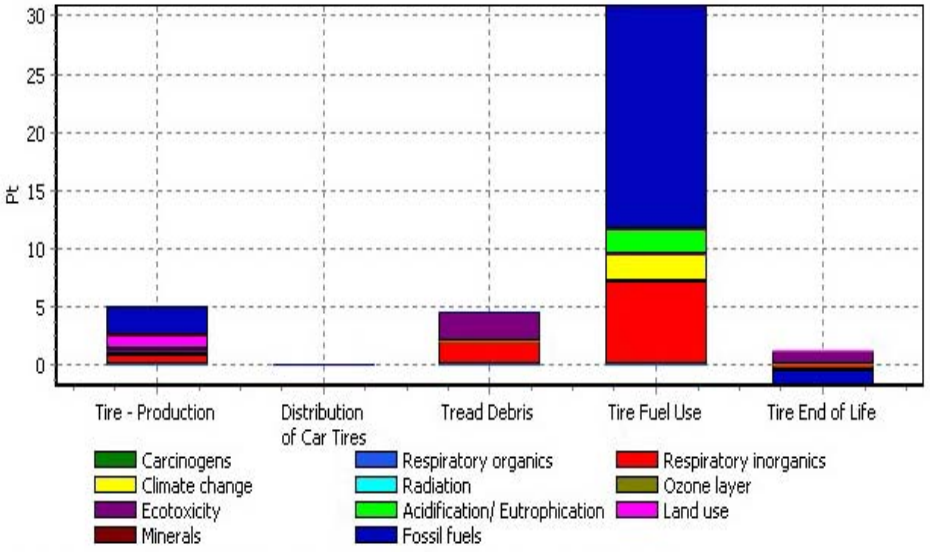
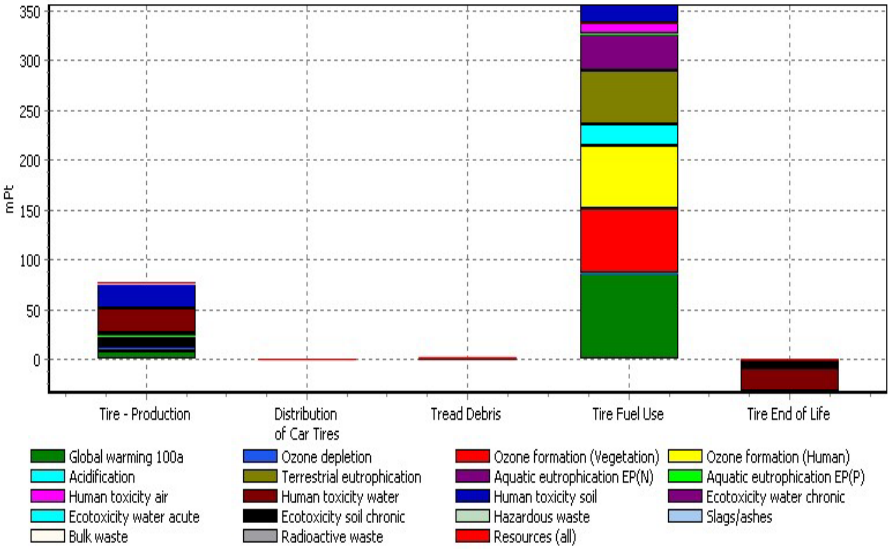
A better way forward

Does it matter…

Tire – EI99



Tire – EDIP 2003



- Land use discussion is irrelevant in the context of overall tire LCA results
- Discussion *IS* relevant in context of corporate choices and local impacts

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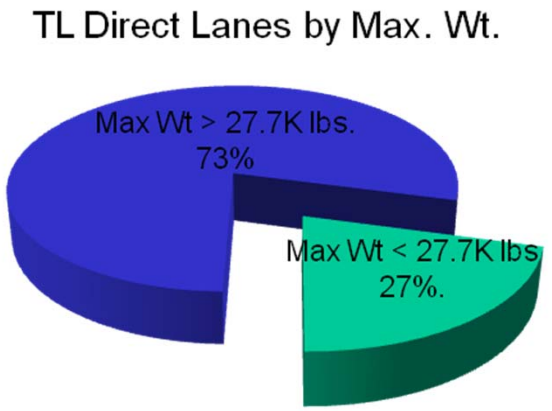
A better way forward

Does it REALLY Matter…

- Many systems are over-engineered
- Appropriate technology and sound engineering can go a long way towards sustainability
- Switching from Class 8 High Duty Diesel trucks to Ford F750 can provide significant savings.
- Ideas were triggered by quest for fuel savings.

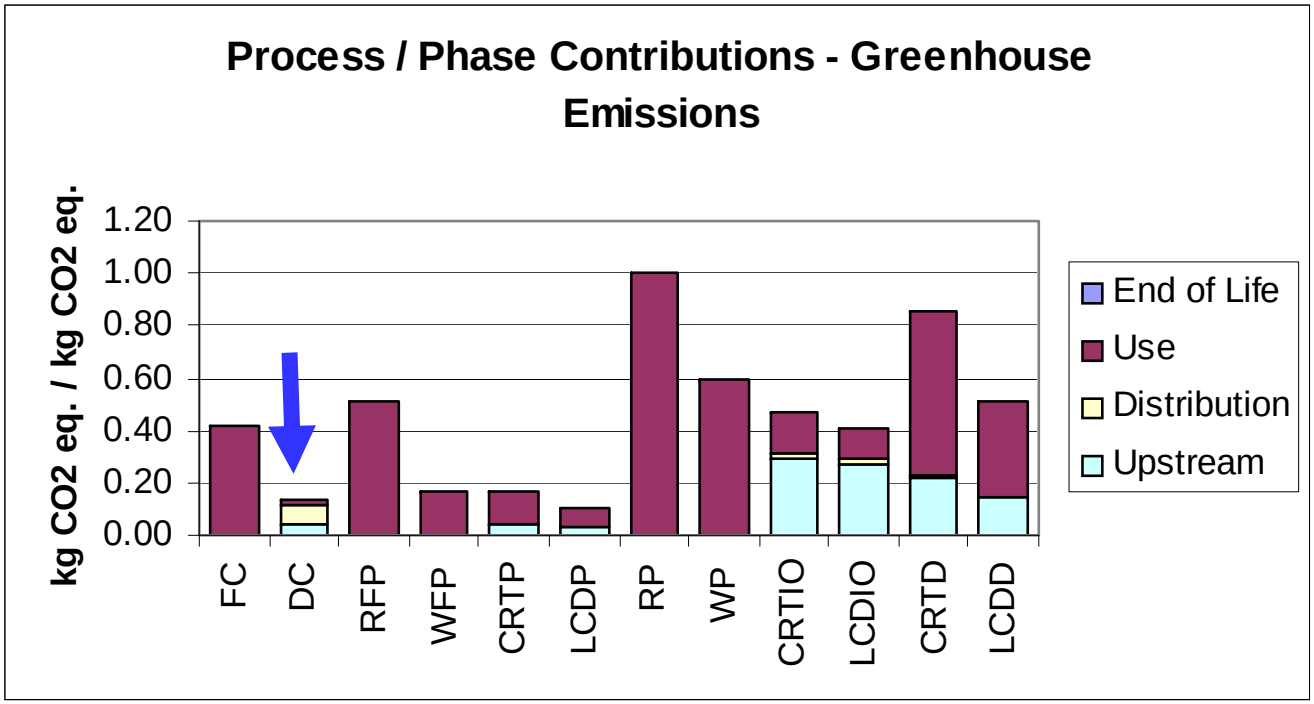


Tire rolling resistance is meaningless compared to selecting appropriate vehicle

	Ford F-450/550	Class 6 Ford F-650	Class 7 Ford F-750	Class 8 (Freightliner Day Cab)
MSRP (New)	$42,295/$45,240	$54,167	$55,448	$140,000
Price w/ Incentives	$33,750/$36,463	$43,334	$44,358	$87,000
Curb Wt.	17,950 – 19,000 lbs. (GVWR)	9,300 lbs.	9,300 lbs.	16,000 lbs.
Gross Combined Wt. Rating	24,000 – 33,000 lbs.	50,000 lbs.	50,000 lbs.	80,000+
Towing Wt.	24,800 lbs.	40,700 lbs.	40,700 lbs.	57,000 lbs.
Max Payload	16,800 lbs.	27,700 lbs.	27,700 lbs.	44,000 lbs.
Output	325-362 hp	325 hp	325 hp	410-550 hp

REALLY? GHG Emissions for Imaging Systems

- GHG emissions for various imaging capture and print options
- Distribution has only real impact in DC (Digital Camera)
- **Use phase dominates!**



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

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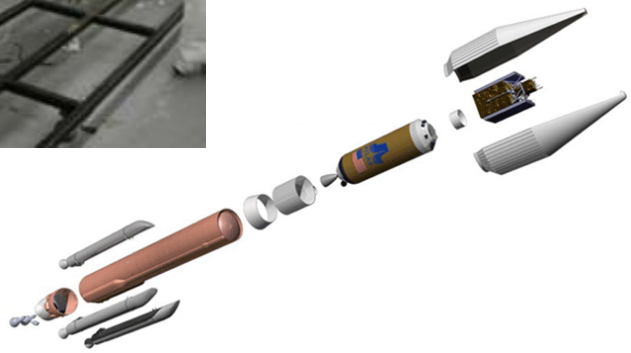
Improving Use Phase with Carbon Fibers

- CF used for "light-weighting"
  - **Lighter vehicle = less fuel = lower environmental burdens**
- BUT: Carbon fibers have energy intensive manufacturing processes with many emissions
  - Key problem: Disagreement in published data (100-600 MJ/kg)
- ***What if life cycle is not use phase dominated?***
  - *Rocket systems take months to manufacture and minutes to use*
  - *Does material or propellant selection dominate?*
- *What is the return on "energy" investment for rockets?*

Traditional Systems

Exotic Systems



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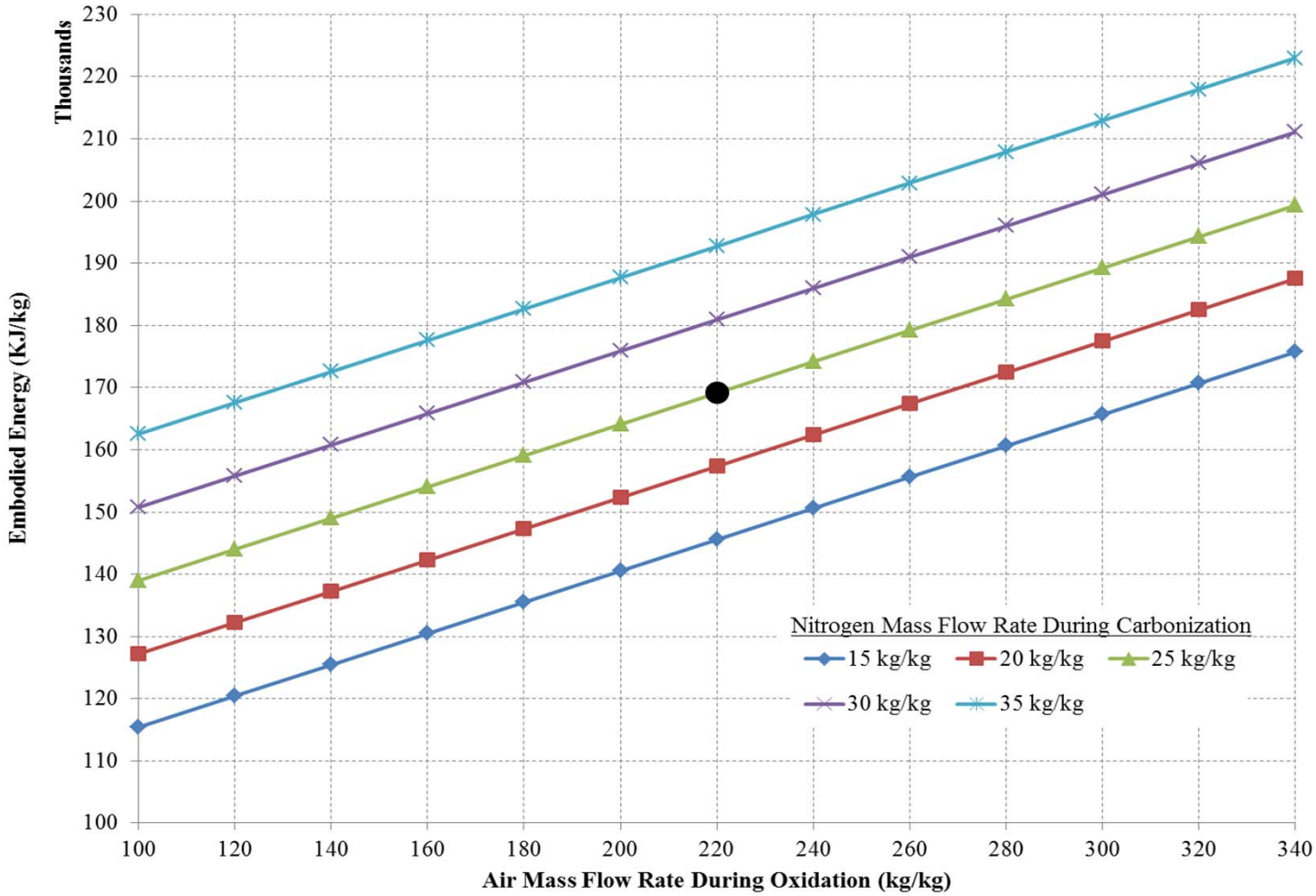
Variability in CF Embodied Energy



Note variability in embodied energy depending on process conditions – **LCA databases do not include this**

Models are needed

Embodied energy as a function of

- air throughput during oxidation and
- nitrogen throughput during carbonization

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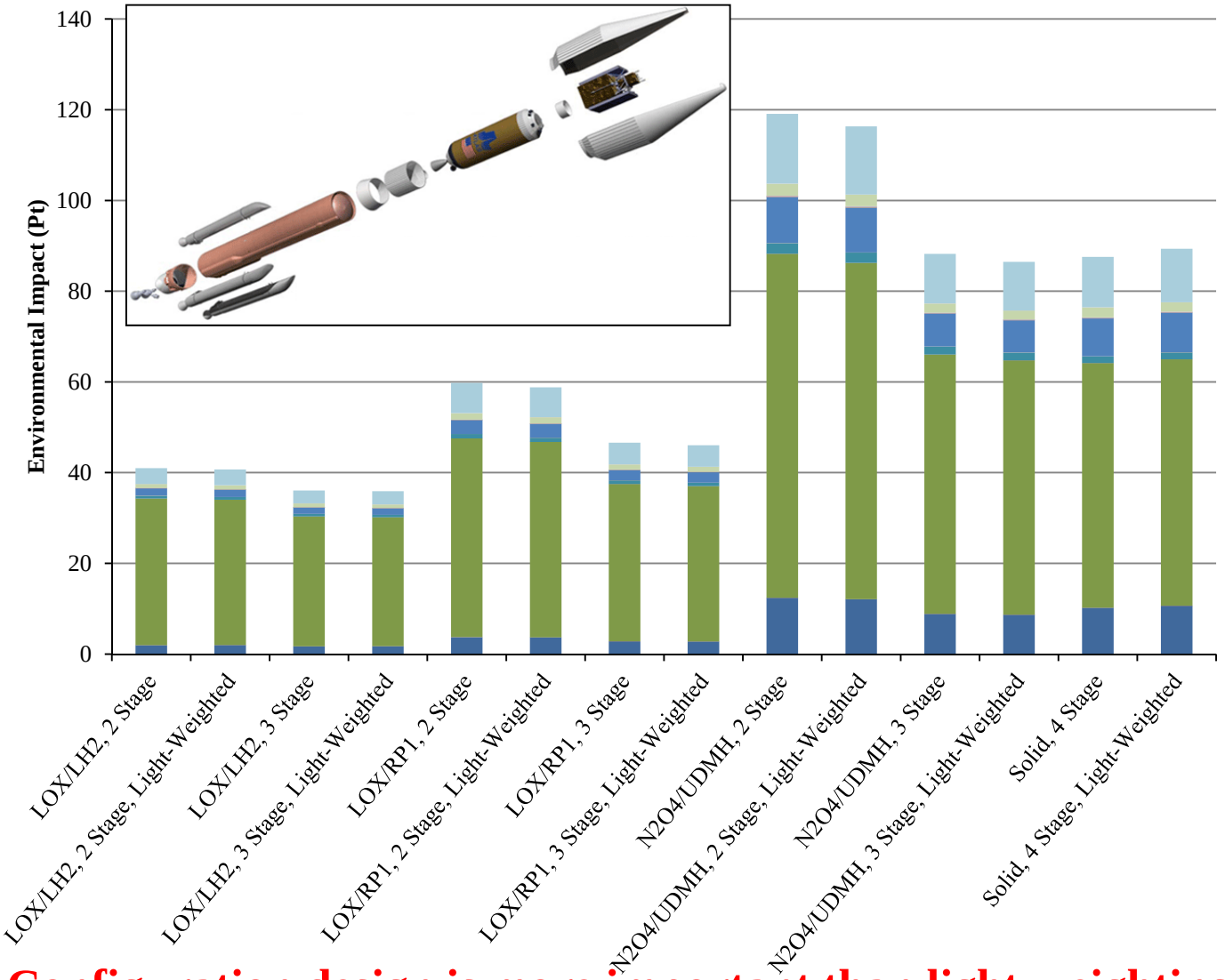
Rocket Science! Environmental Impact of Rockets



Configuration design is more important than light-weighting

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Systems Design: Traditional Car + Home

- Car and Home only share the garage (and occupants)

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A little less traditional home…

- But still the same concept…

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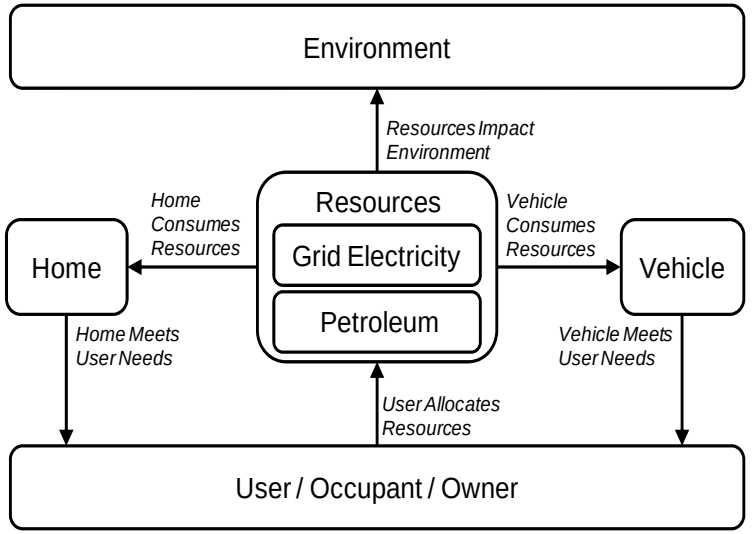
Home of the Future: Systems Connect

MyEnergiLifeStyle



Car and Home are connected. Literally.

Collaborative project between Engineering and Architecture

Lee et al., The Integrated Electric Lifestyle: The Economic and Environmental Benefits of an Efficient Home-Vehicle System, SAE Paper 2013-01-0495, SAE World Congress, April 16-18, Detroit, MI

Scenario Investigation

House location: San Jose, CA

Data came from various industrial partners and public domain sources

- Scenario 1: Baseline
  - Mid 1990's appliances
  - 2 Gasoline vehicles
  - Flat rate electricity
- No Electric Vehicle
  - Scenario 2: Add 5 kW-rated PV system (to South roof)
  - Scenario 3: Replace Vintage appliances with New
  - Scenario 4: Add Smart Control (TOU)
- Electric Vehicle Included (replace 1 Gasoline Vehicle)
  - Scenario 5: Add 5 kW-rated PV system
  - Scenario 6: Replace Vintage appliances with New
  - Scenario 7: Add Smart Control (TOU)

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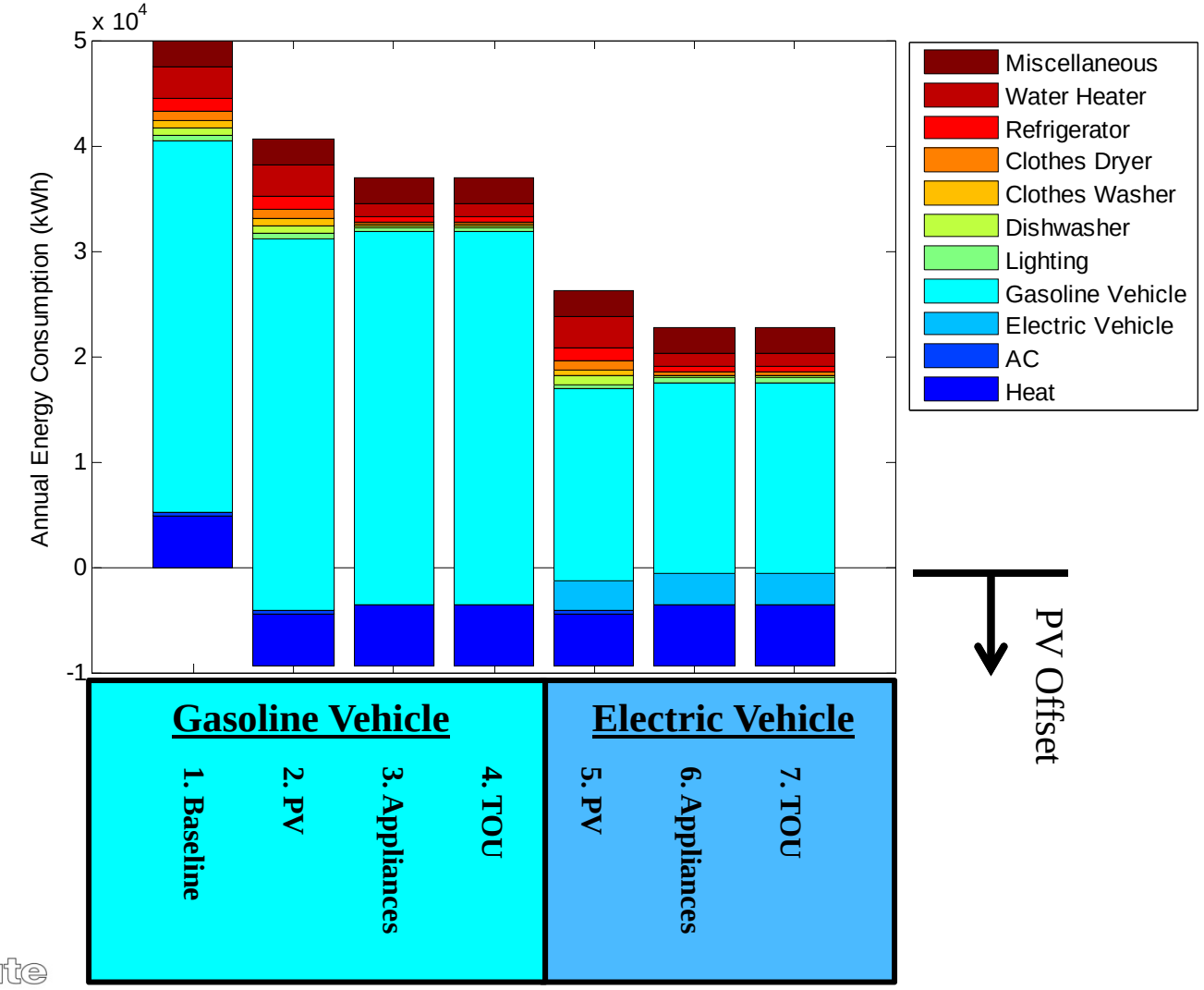
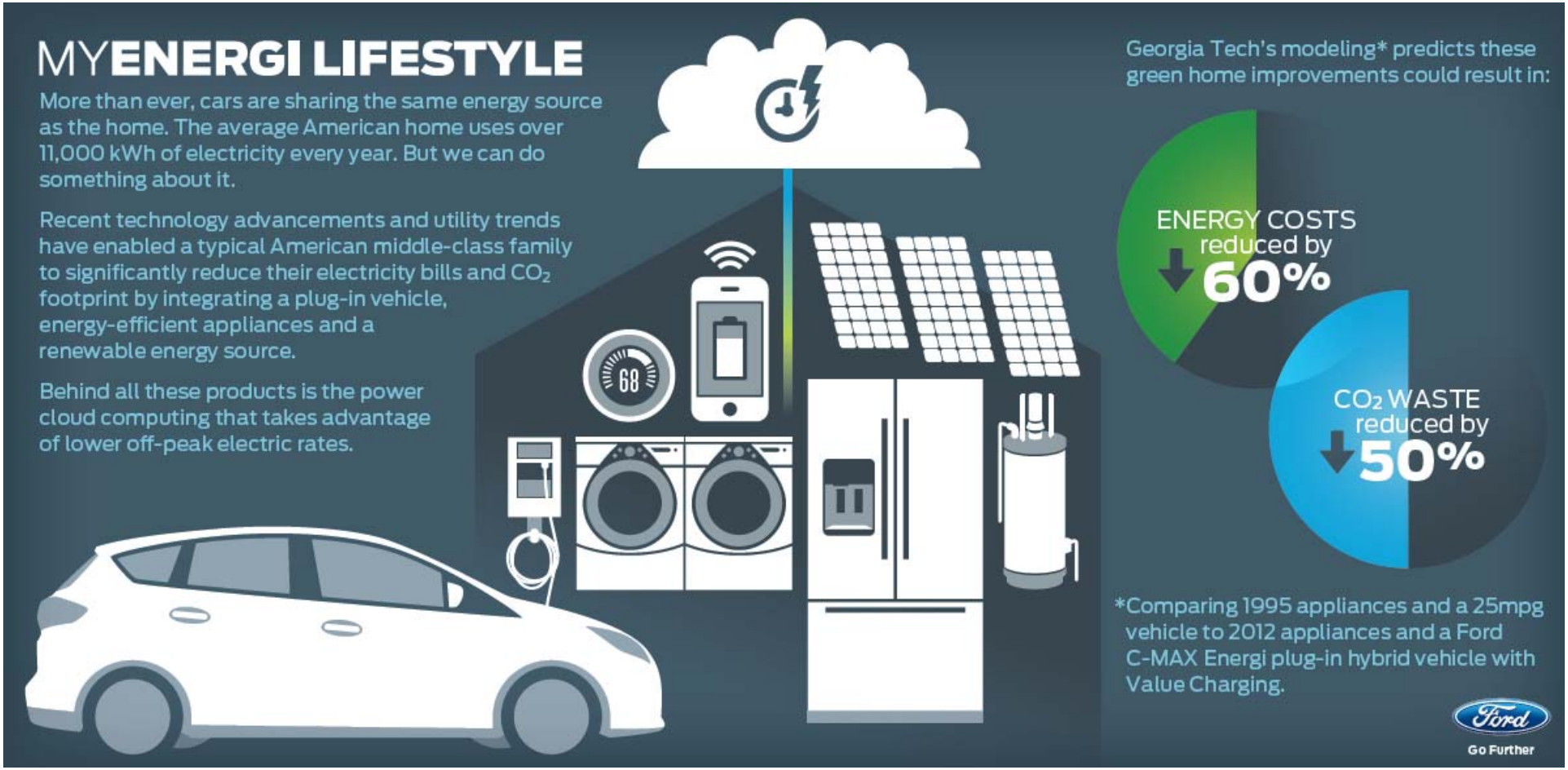
Annual Energy Consumption (kWh)

*Including energy in gasoline and electricity



MyEnergi Lifestyle – New Collaborations, New Business



Ford
SUNPOWER
Whirlpool CORPORATION
EATON Powering Business Worldwide
Infineon
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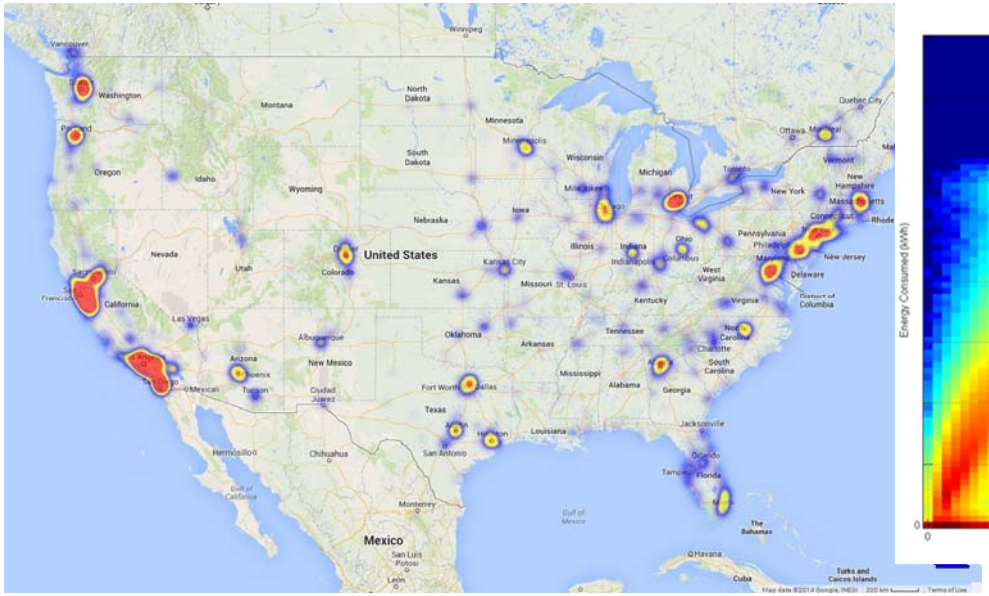
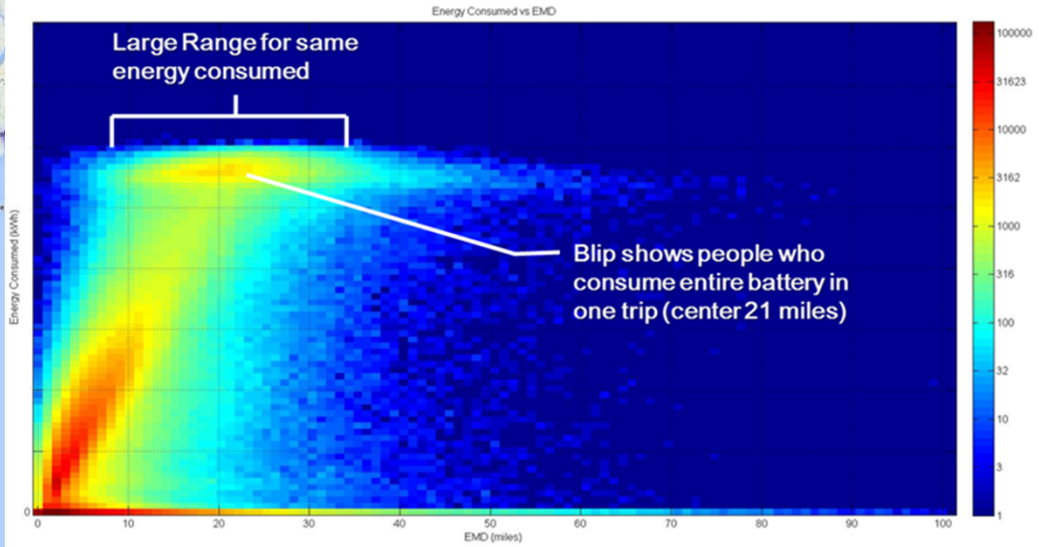
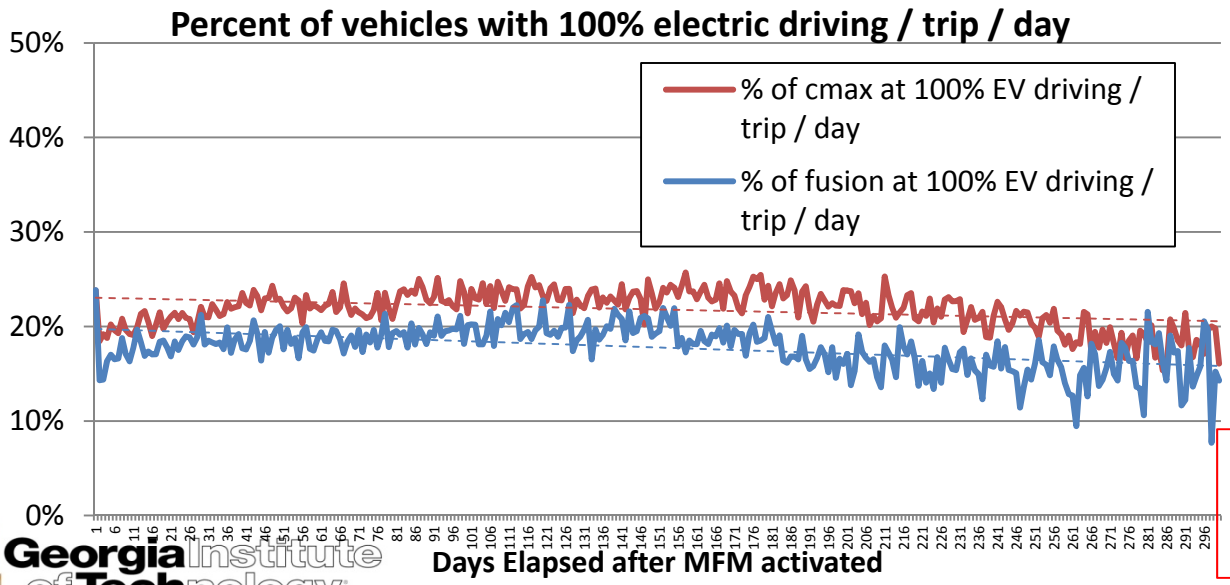
User Behavior Analytics







- Data from 7000+ Cmax and Fusion Energi PHEVs over time
- TCU sends data for every “key-off” event

IT + Energy + Automotive systems

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EV on Renewables:
Ford C-Max Solar Energi Concept

Can you recharge an electric vehicle with renewables without plugging it in?

Ford C-MAX Solar Energi Plug-in Hybrid Electric Vehicle (PHEV) at 2014 CES

http://www.cnn.com/interactive/2014/02/tech/cnn10-future-of-driving/?hpt=hp_c3

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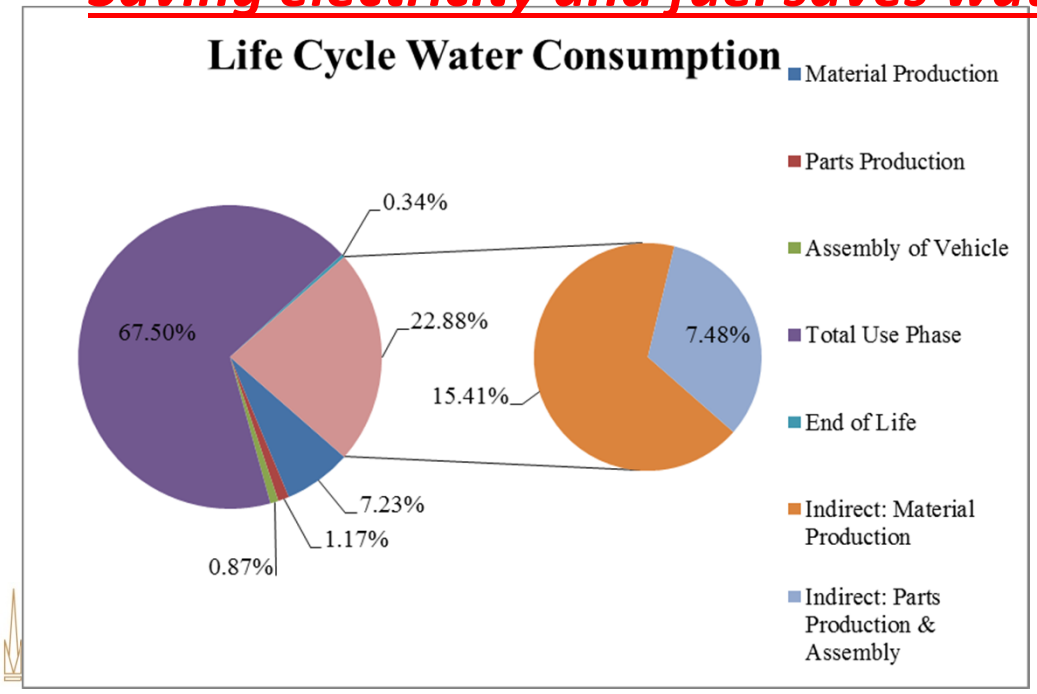
More Synergistic System Improvements: Water Consumption in Automotive Manufacturing

- **Use phase water consumption dominates**
- **Indirect water consumption is high**
  - Use phase excluded
  - Material production dominates
  - Magnitude benchmark
    - Variability in operations
    - Dependent on local energy inputs
- ***Saving electricity and fuel saves water!***



Stage	Water Consumption (Liters)
Direct Material Production	5,569
Direct Parts Production	902
Direct Vehicle Assembly	670
Total Use Phase	**51,965**
Direct End of Life	259
Indirect: Material Production	***11,859***
Indirect: Parts & Assembly	***5,757***
Total	76,981

Tejada, F., Bras, B., and T. Guldberg (2012). Direct and Indirect Water Consumption in Vehicle Manufacturing. Paper DETC2012-71307, Proceedings of the ASME 2012 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference, Chicago, IL, Aug 12-15.

A Biological Approach to Sustainable Manufacturing

- 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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CBET-0967536

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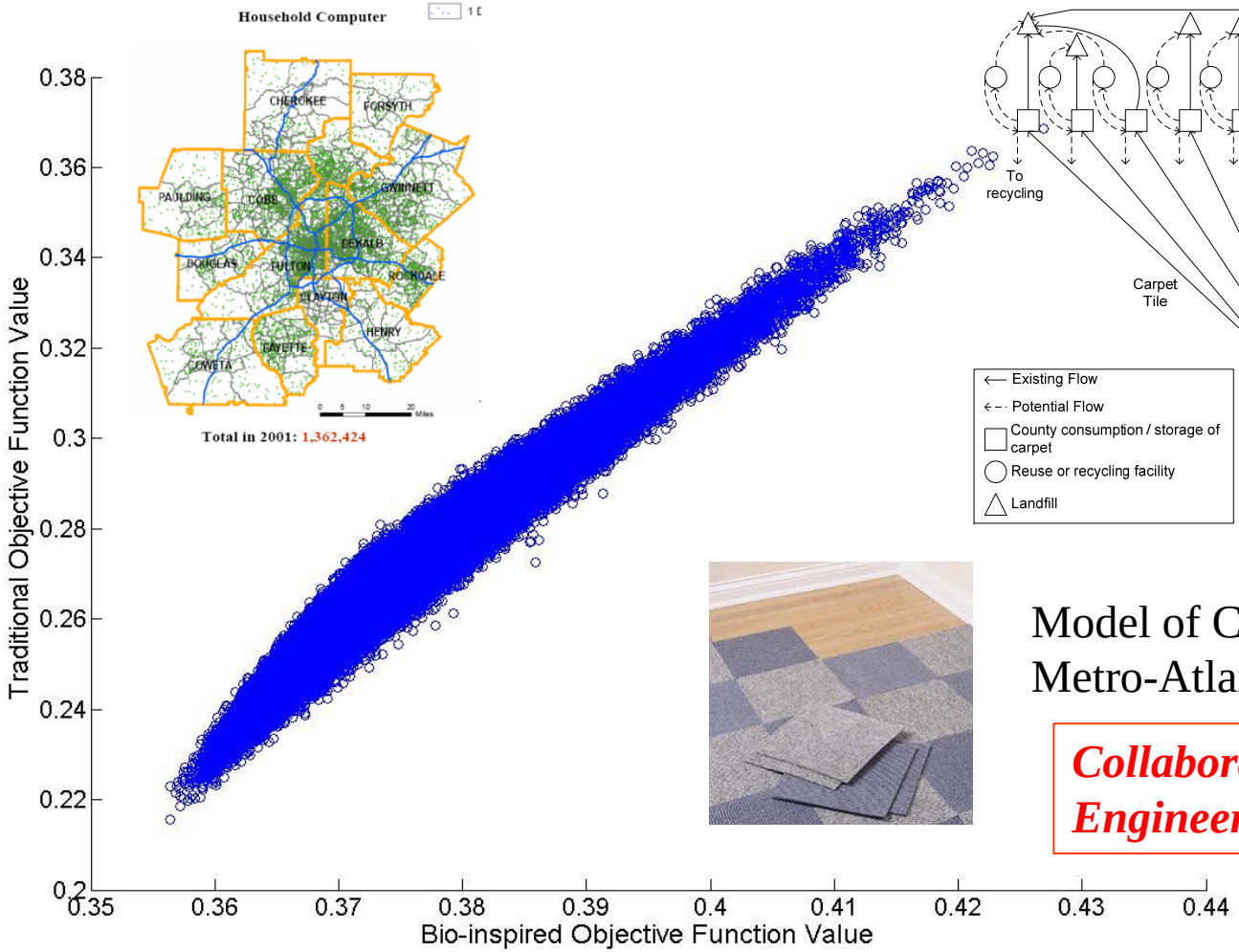
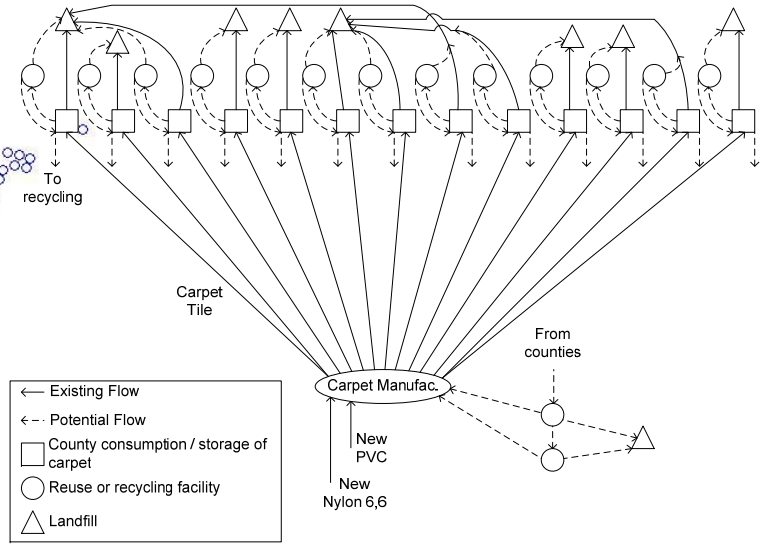
Using Ecology Metrics for Carpet Recycling Network Design





Model of Carpet Tile Flow in Metro-Atlanta Region

Collaborative project between Engineering and Biology

High correlation between traditional cost-based and bio-inspired ecological community metrics-based objective function values for 100,000 randomly generated designs

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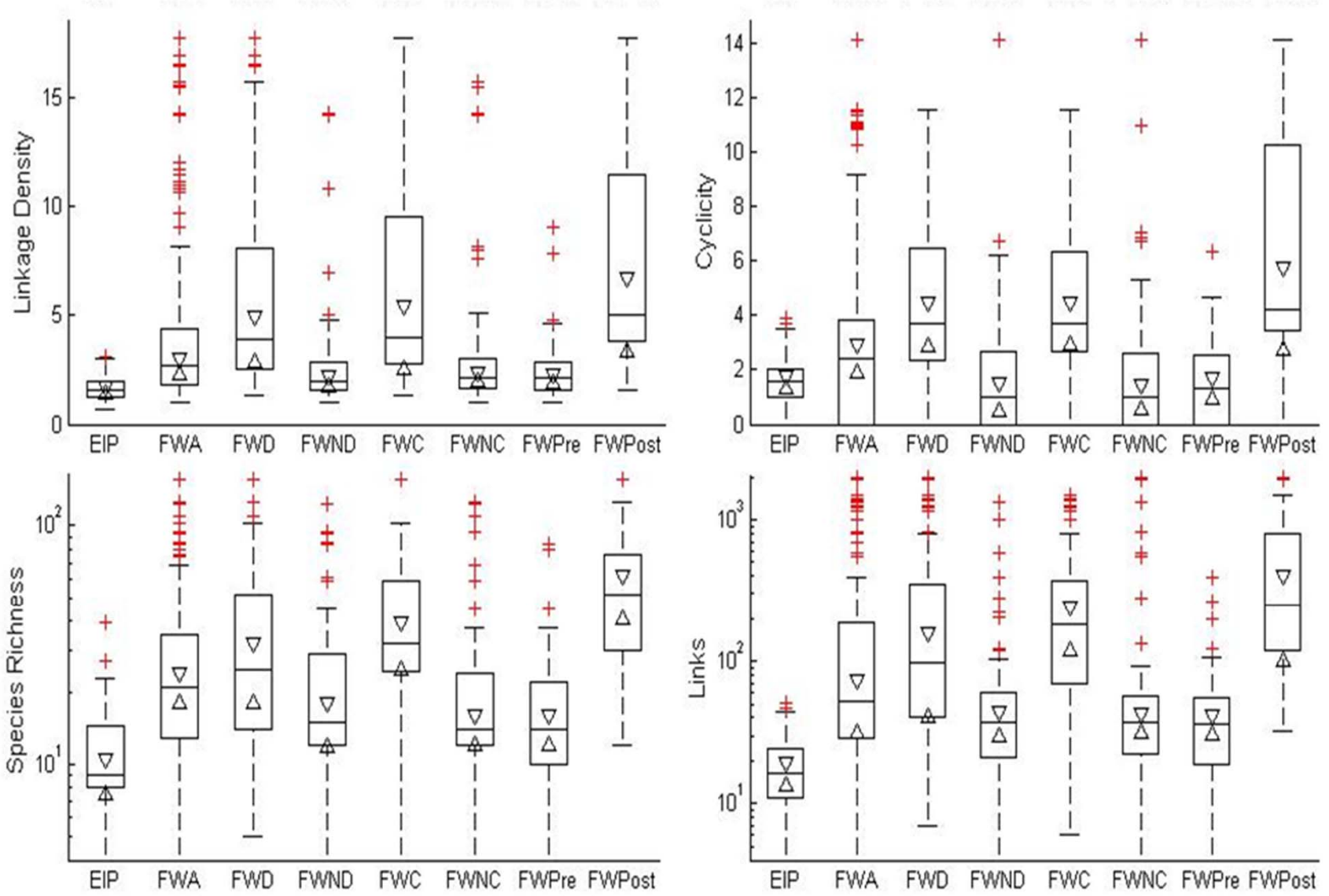
48 Eco-Industrial Parks vs 144 Natural Eco-Systems – Comparison using Ecological Performance Metrics



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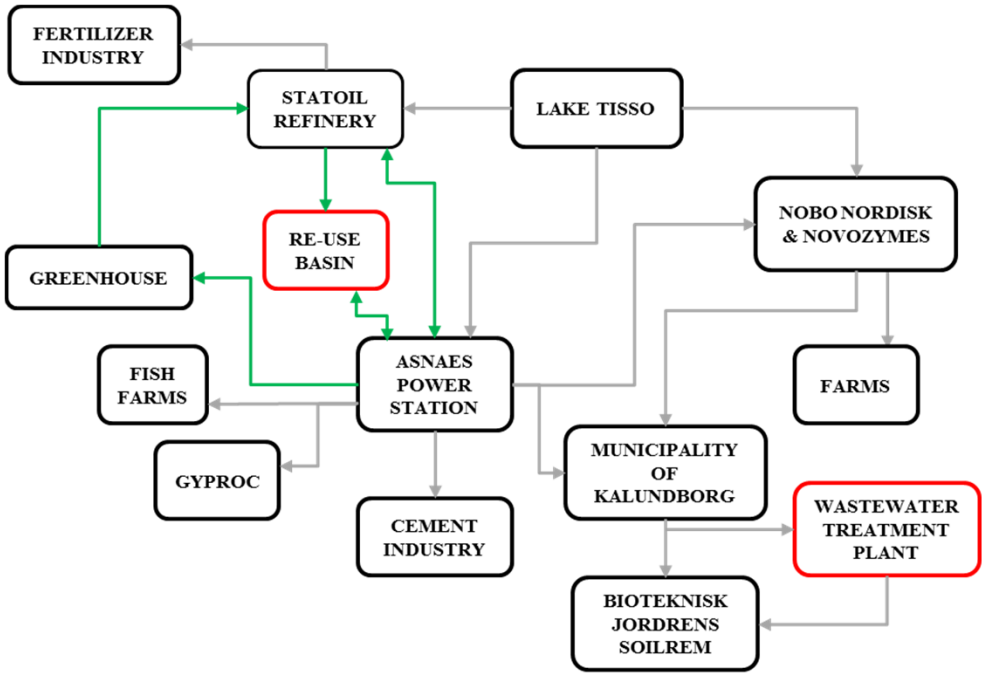
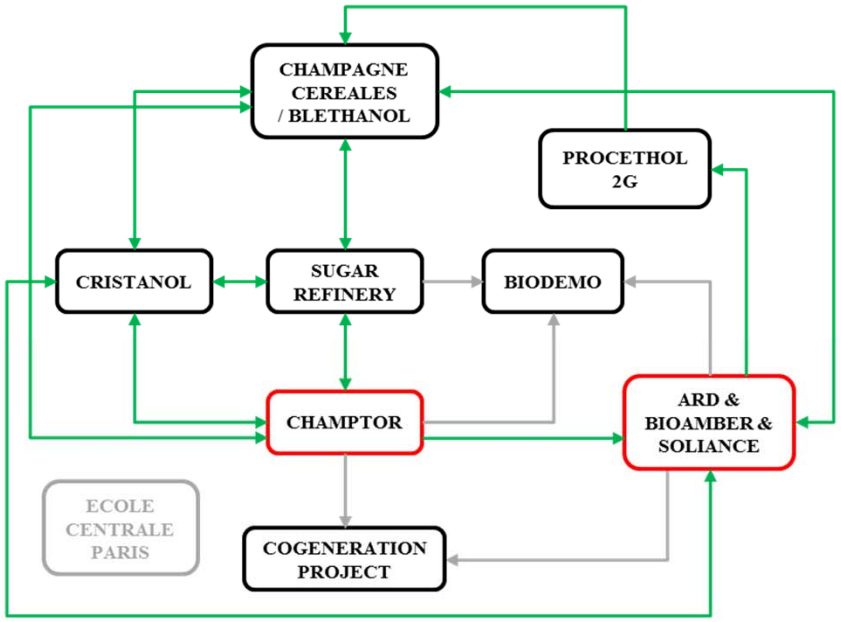
Comparison of Internal Materials and Energy Cycling



Kalundborg EIP

- Pomacle-Bazancourt EIP is best performer among 48 EIPs.
- Kalundborg is mediocre peforming EIP
- **Difference is due to number of internal cycles**



Pomacle – Bazancourt EIP

- **Green arrows represent linkages which participate in a cycle**, greyed out linkages do not.
- **Actors highlighted in red are the acting detritus** of the EIP

Natural ecosystems have more cycling

In Closing

- Carefully consider system boundaries
- Relative improvements are good, but in the end we need (large) absolute improvements to reverse negative trends.
- To have true sustainability impact, design may have to move to designing “systems of systems”
- Multi-disciplinary collaborations are needed

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