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Proceedings of the Measurement Science for Sustainable Construction and Manufacturing Workshop Volume II. Presentations

Bilal M. Ayyub
Gerald E. Galloway
Richard N. Wright
University of Maryland

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National Institute of Standards and Technology
U.S. Department of Commerce

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Proceedings of the Measurement Science for Sustainable Construction and Manufacturing Workshop Volume II. Presentations

Prepared for
U.S. Department of Commerce
Engineering Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899-8600

By
Bilal M. Ayyub
Gerald E. Galloway
Richard N. Wright
University of Maryland

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Penny Pritzker, Secretary

National Institute of Standards and Technology
Willie May, Acting Under Secretary of Commerce for Standards and Technology and Director

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Recommended Citations

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Ayyub, B. M., Galloway, G. E., and Wright, R. N. (editors), 2014, Measurement Science for Sustainable Construction and Manufacturing, Volume II. Presentations, University of Maryland Report to the National Institute of Standards and Technology, Office of Applied Economics, NIST Grant/Contractor Report 00-XXXX, Gaithersburg, MD.

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Ayyub, Bilal M., Galloway, Gerald E., and Wright, Richard N., University of Maryland

About the Workshop on Measurement Science for Sustainable Construction and Manufacturing

1. Background

Achieving long-term suitability poses a linked-systems challenge for policy makers to assess the consequences, trade-offs and synergies in economic, environmental and social domains. A sustainable society can be defined as the one that can thrive over generations; one that is far-seeing enough, flexible enough, and wise enough not to undermine its economic, environmental and social systems of support. A major need for achieving sustainable construction and manufacturing is to establish meaningful measurements for the complex attributes of sustainability suitable for lifecycle considerations. What one can measure, one can manage. NIST, ASCE, ASME and the University of Maryland are hold this workshop to address this challenge.

2. Objectives

The objective of the workshop was to examine the measurement science needed to guide decisions for sustainability throughout the life cycle of design, construction/manufacturing, operations, and maintenance of facilities and systems of the built environment and manufactured products, and to guide NIST and other key stakeholders in developing a portfolio of related programs. The workshop engaged key international and domestic thought leaders and experts from stake-holding disciplines including construction, manufacturing, codes and standards development, economics, government, industry, and academia, and addressed trends and needs relating to sustainable construction and manufacturing. The results from this effort are documented herein in coordination with NIST, ASCE and ASME.

3. Discussion Topics

Discussion topics included:

- Measurement science (definition, standards, metrics, indicators and ratings)
- Systems (aggregation, linkages, system of systems, sustainability-resilience synergy and interdependencies)
- Planning, design and supply chain (lifecycle analyses and treatments, and material and energy efficiency), or
- Economic, environmental and social aspects (valuation, impacts and behavior).

4. Participants

The workshop was attended by about 77 people. A complete list is provided in Appendix A.

5. Agenda

Day 1: June 12, 2014

Time	Topic	Duration	Room	Speakers
8:00-8:30	Breakfast			
8:30-9:00	Welcome and Introduction	30	ASCE	**Darryll Pines**, Dean, School of Engineering, Un. Maryland (UMD)
	Opening remarks			**Howard Harary**, Acting Director, Engineering Laboratory, NIST
	Symposium program			**Bilal Ayyub**, Director, Center for Technology & Systems Management, CEE Professor, UMD
	Perspectives on sustainability for the Nation			**Nabil Nasr**, Associate Provost for Academic Affairs & Director of Golisano Institute for Sustainability, Rochester Institute of Tech., NY
9:00-9:25	Sustainable manufacturing	20+5	ASCE	**William Flanagan**, Director, Ecoassessment Center of Excellence, GE Global Research, General Electric Company
9:25-9:50	Sustainable construction	20+5	ASCE	**Nancy Kralik**, Fluor and Construction Industry Institute
9:50-10:00	Break	10		
10:00-10:20	Sustainability metrics-measurement science	17+3	ASCE	**Subhas Sikdar**, Associate Director for Science, National Risk Management Research Lab, EPA, and AIChE
10:20-10:40	System sustainability: aggregation & linkages	17+3	ASCE	**Joseph Fiksel**, Director, Center for Resilience at The Ohio State Un.
10:40-11:00	Planning, design and supply chain	17+3	ASCE	**Gül Kremer**, Professor, Industrial & Manufacturing Eng., Penn State
11:00-11:20	Economic, environmental and social aspects	17+3	ASCE	**Cliff Davidson**, Director, Center for Sustainable Engineering, Thomas and Colleen Wilmot CEE Professor, Syracuse University
11:20-12:40	Quantified Urban Community at Hudson Yards	17+3	ASCE	**Constantine E. Kontokosta**, NYU Polytechnic School of Engineering
11:40-12:00	Population and Carrying Capacity: Metrics for Sustainability	17+3	ASCE	**Eugenia Kalnay**, NAE, Distinguished University of Maryland Professor of Atmospheric and Oceanic Science
12:00-1:00	Hosted Lunch (sandwiches)	60		
1:00-2:48	Perspectives on sustainable construction and manufacturing	108	ASCE	**Gerald Galloway** (Moderator), NAE, Glenn L. Martin Institute Professor of Engineering, UMD
	Implementation and challenges for metrics	15+3	ASCE	**David Dise**, Director of General Services, MD Montgomery County
	A Case study on the role of metrics	15+3	ASCE	**Fulya Kocak**, Clark Construction Group, Bethesda, MD
	Perspectives of a federal agency on metrics	15+3	ASCE	**Joe Cresko**, Lead internal analysis and strategic planning, Advanced Manufacturing Office, DOE
	Metrics for sustainable products and process	15+3	ASCE	**I. S. Jawahir**, Director, Institute for Sustainable Manufacturing James F. Hardymon Chair, University of Kentucky
	Perspectives of owner and builder on metrics	15+3	ASCE	**James Dalton**, Chief, Engineering and Construction, Directorate of Civil Works, USACE
	International perspectives on metrics	15+3	ASCE	**Bohumil Kasal**, Director of Fraunhofer Institute at Braunsweig, Germany and Professor at the Technical University of Braunschweig
2:48-3:00	Break	12		
3:00-4:00	Panel 1 - Perspectives from users	60	ASCE	**Richard Wright** (Moderator, Research Professor, UMD), **Michele Russo** (McGraw Hill/ENR), **Chris Pyke** (US Green Building Council), **William Bertera** (Instit. for Sustain. Infrastructure), **William Flanagan** (General Electric Company)
4:00-5:00	Panel 2 - Perspectives from researchers	60	ASCE	**Jelena Srebric** (Moderator, Professor, UMD), **Nabil Nasr** (Rochester Institute of Tech), **Damon Fordham** (TRB), **Andrew Persily** (NIST), **Subhas Sikdar** (AIChE/ EPA)
5:00-5:15	Second day breakout sessions	10	ASCE	**Richard Wright**, NAE, Research Professor, UMD (NIST retired)
6:00-8:30	Hosted Dinner (participants seated per breakouts)	150	Ballroom A	**Joannie Chin,** Acting Deputy Director, Engineering Laboratory, NIST

Day 2: June 13, 2014

Time	Topic	Duration	Room	Speakers
8:00-8:30	Breakfast			
8:30-8:45	Getting oriented and allocated to breakout sessions	15	ASCE	**Gerald Galloway**, UMD
8:45-9:45	Breakout 1: Measurement science	60	CH2M Hill	Co-moderators: **I. S. Jawahir** and **Subhas Sikdar**
8:45-9:45	Breakout 2: Systems	60	Harris	Co-moderators: **Joseph Fiksel** & **John Carberry** (affiliation, invited)
8:45-9:45	Breakout 3: Planning, design and supply chain	60	President	Co-moderators: **Nabil Nasr** (Rochester Instit. of Tech) and **Fazleena Badurdeen** (U. Kentucky)
8:45-9:45	Breakout 4: Economic, environmental and social aspects	60	ASCE	Co-moderators: **Cliff Davidson** and **William Flanagan**
9:45-10:00	Break	15		
10:00-11:00	Breakout 1: Measurement science	60	CH2M Hill	Co-moderators: **I. S. Jawahir** and **Subhas Sikdar**
10:00-11:00	Breakout 2: Systems	60	Harris	Co-moderators: **Joseph Fiksel** & **John Carberry** (affiliation, invited)
10:00-11:00	Breakout 3: Planning, design and supply chain	60	President	Co-moderators: **Nabil Nasr** (Rochester Instit. of Tech) and **Fazleena Badurdeen** (U. Kentucky)
10:00-11:00	Breakout 4: Economic, environmental and social aspects	60	ASCE	Co-moderators: **Cliff Davidson** and **William Flanagan**
11:00-11:15	Break to regroup	15		
11:15-12:15	Summaries of breakouts 1, 2, 3 and 4	60	ASCE	By Co-moderators, report requirements (facilitor **Richard Wright**, UMD)
12:15-12:30	Expected products and adjournment	15	ASCE	**Bilal Ayyub,** UMD

Disclaimer and Limitations

This report was prepared for the National Institute of Standards and Technology (hereafter referred to as NIST) as the primary sponsor, and the American Society of Civil Engineers (hereafter referred to as ASCE), the American Society of Mechanical Engineers (hereafter referred to as ASME), the American Institute of Chemical Engineers (hereafter referred to as AIChE) and the American Society of Heating, Refrigerating and Air Conditioning Engineers (hereafter referred to as ASHRAE) by the Center for Technology and Systems Management of the University of Maryland and its associates and subcontractors (hereafter referred to as the UMD). Although this product was prepared using the best available resources, NIST, ASCE, ASME, AIChE and UMD do not make any warranty, expressed or implied, or assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represent that its uses would not infringe on privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by NIST, ASCE, ASME, AIChE, ASHRAE and UMD. Opinions expressed in this report are personal opinions of the participants and do not reflect the opinions of the respective employers of the participants.

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  Fulya Kocak

Technology Analysis: Efficiency, Manufacturing, Processes & Materials
  Joe Cresko

Metrics for Sustainable Products and Processes
  I. S. Jawahir

Perspectives of an Owner & Builder on Metrics
  James Dalton

Perspectives of an Owner & Builder on Metrics
  Bohumil Kasal

High Performance Green Buildings
  Chris Pyke

Introduction to Breakout Sessions
  Richard Wright

Charge to the Breakout Groups
  Joannie Chin

Concluding Remarks and Adjournment
  Bilal M. Ayyub

Measurement Science for Sustainable Construction and Manufacturing

June 12 and 13, 2014

Workshop on Measurement Science for Sustainable Construction and Manufacturing

8:30-9:00 am

Welcome and Introduction	**Bilal Ayyub**, CEE Professor, UMD* **Darryll Pines**, Engineering Dean, UMD
Opening remarks	**Howard Harary**, Acting Director, Engineering Laboratory, NIST
Symposium program	**Bilal Ayyub**, CEE Professor, UMD
Perspectives on sustainability for the Nation	**Nabil Nasr**, Associate Provost for Academic Affairs & Director of Golisano Institute for Sustainability, Rochester Institute of Tech., NY

* CEE Chair Professor Charles Schwartz, and ME Chair Professor Balakumar Balachandran

Symposium Objectives

- Examine measurement science for sustainability throughout the lifecycle of the built environment and manufactured products
- Guide NIST and other key stakeholders in developing a portfolio of related research and development programs
- Engage key international and domestic thought leaders and experts from stake-holding disciplines
- Document in coordination with NIST, ASCE and ASME

Discussion Topics

- **Measurement science** (definition, standards, metrics, indicators and ratings)
- **Systems** (aggregation, linkages, system of systems, sustainability-resilience synergy and interdependencies)
- **Planning, design and supply chain** (lifecycle analyses and treatments, and material and energy efficiency)
- **Economic, environmental and social aspects** (valuation, impacts and behavior)

Workshop on Measurement Science for Sustainable Construction and Manufacturing

Program – June 12, 2014

Opening	Welcome, introduction & national needs
Keynotes	Two on manufacturing & construction
Breakout presentations	Four sessions
Case studies	Two cases
Lunch	Cutoff time for breakout assignments
Six Ted-like lectures	Perspectives on manufacturing & construction
Discussion panels	Two from users and researchers
Orientation for day 2	Presentation & banquet

Workshop on Measurement Science for Sustainable Construction and Manufacturing

Program – June 13, 2014

Orientation	**All participants**
Four concurrent sessions	Problem lists Problem descriptions
Summary	**All participants** by the co-moderators
Expected products and adjournment	Proceedings Recommendations

Workshop on Measurement Science for Sustainable Construction and Manufacturing

A. JAMES CLARK SCHOOL OF ENGINEERING

NIST

9:00-10:00 am

Sustainable manufacturing	**William Flanagan**, Director, Ecoassessment Center of Excellence, GE Global Research, General Electric Company
Sustainable construction	**Nancy Kralik**, Fluor and the Construction Industry Institute
Break	

ASCE AMERICAN SOCIETY OF CIVIL ENGINEERS · ASME SETTING THE STANDARD · AIChE American Institute of Chemical Engineers · ASHRAE

Workshop on Measurement Science for Sustainable Construction and Manufacturing

A. JAMES CLARK SCHOOL OF ENGINEERING

NIST

10:00-11:20 am

Sustainability metrics-measurement science	**Subhas Sikdar**, Associate Director for Science, National Risk Management Research Lab, EPA, and AIChE
System sustainability: aggregation & linkages	**Joseph Fiksel**, Director, Center for Resilience at The Ohio State University
Planning, design and supply chain	**Gül Kremer**, Professor, Industrial & Manufacturing Eng., Penn State
Economic, environmental and social aspects	**Cliff Davidson**, Director, Center for Sustainable Engineering, Thomas and Colleen Wilmot CEE Professor, Syracuse University

ASCE AMERICAN SOCIETY OF CIVIL ENGINEERS · ASME SETTING THE STANDARD · AIChE American Institute of Chemical Engineers · ASHRAE

Workshop on Measurement Science for Sustainable Construction and Manufacturing

11:20-12:00 am

A. JAMES CLARK SCHOOL OF ENGINEERING

NIST

Quantified Urban Community at Hudson Yards	**Constantine E. Kontokosta**, NYU Polytechnic School of Engineering
Population and Carrying Capacity: Metrics for Sustainability	**Eugenia Kalnay**, NAE, Distinguished University of Maryland Professor of Atmospheric and Oceanic Science, and **Sofa Motesharrei**, Systems Scientist at SESYNC, PhD candidate in Econophysics at UMD
Hosted Lunch (sandwiches)	

ASCE AMERICAN SOCIETY OF CIVIL ENGINEERS ASME SETTING THE STANDARD AIChE American Institute of Chemical Engineers ASHRAE

Workshop on Measurement Science for Sustainable Construction and Manufacturing

1:00-2:48 pm

A. JAMES CLARK SCHOOL OF ENGINEERING

NIST

Perspectives on sustainable construction and manufacturing	**Gerald Galloway** (Moderator), NAE, Glenn L. Martin Institute Professor of Engineering, UMD
Implementation and challenges for metrics	**David Dise**, Director of General Services, MD Montgomery County
A Case study on the role of metrics	**Fulya Kocak**, Clark Construction Group, Bethesda, MD
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ASCE AMERICAN SOCIETY OF CIVIL ENGINEERS ASME SETTING THE STANDARD AIChE American Institute of Chemical Engineers ASHRAE

Workshop on Measurement Science for Sustainable Construction and Manufacturing

3:00-5:15 pm

Panel 1 - Perspectives from users	**Richard Wright** (Moderator, Research Professor, UMD), **Michele Russo** (McGraw Hill/ENR), **Chris Pyke** (US Green Building Council), **William Bertera** (Instit. for Sustain. Infrastructure), **William Flanagan** (General Electric Company)
Panel 2 - Perspectives from researchers	**Jelena Srebric** (Moderator, Professor, UMD), **Nabil Nasr** (Rochester Institute of Tech), **Damon Fordham** (TRB), Andrew Persily (NIST), **Subhas Sikdar** (AIChE/ EPA)
Second day breakout sessions	**Richard Wright**, NAE, Research Professor, UMD (NIST retired)
Hosted Dinner (participants seated per breakouts)	**Joannie Chin**, Acting Deputy Director, Engineering Laboratory, NIST

engineering laboratory

Measurement Science for Sustainable Construction and Manufacturing

Dr. Howard Harary
Acting Director
Engineering Laboratory
National Institute of Standards and Technology
U.S. Department of Commerce

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

Workshop on Measurement Science for Sustainable Construction and Manufacturing

By: Prof. Nabil Nasr
Associate Provost for Academic Affairs &
Director, Golisano Institute for Sustainability
Rochester Institute of Technology

June 12, 2014

Sustainability Science[1]

- Defined by *problems* it addresses rather than by disciplines it employs
- Seeks understanding of fundamental *interactions* between nature and society[2]
- Has a goal of creating and applying knowledge in support of decision making for sustainable development
- Energy systems, ecosystem resilience, **industrial ecology**, earth system complexity

[1]Term established by National Research Council, 1999, *Our Common Journey.*
[2]Kates *et al.* 2004. *Science* 292:641-642; [3]Clark & Dickson, 2003. *PNAS* 100:8059-8062.

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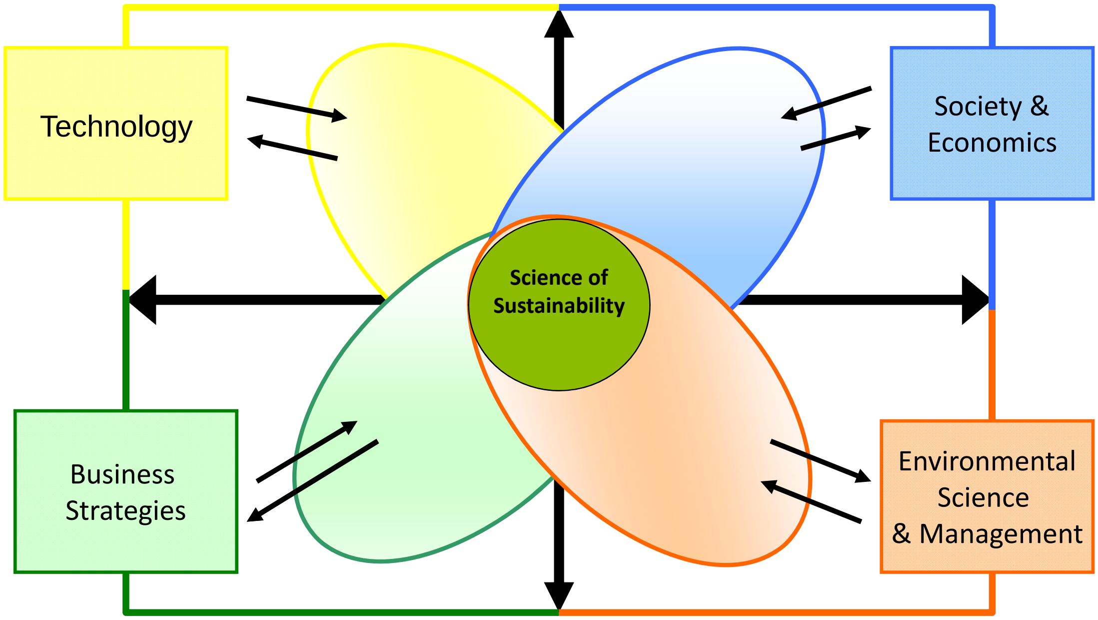
Sustainability Science



The Japanese Model – Inverse Manufacturing

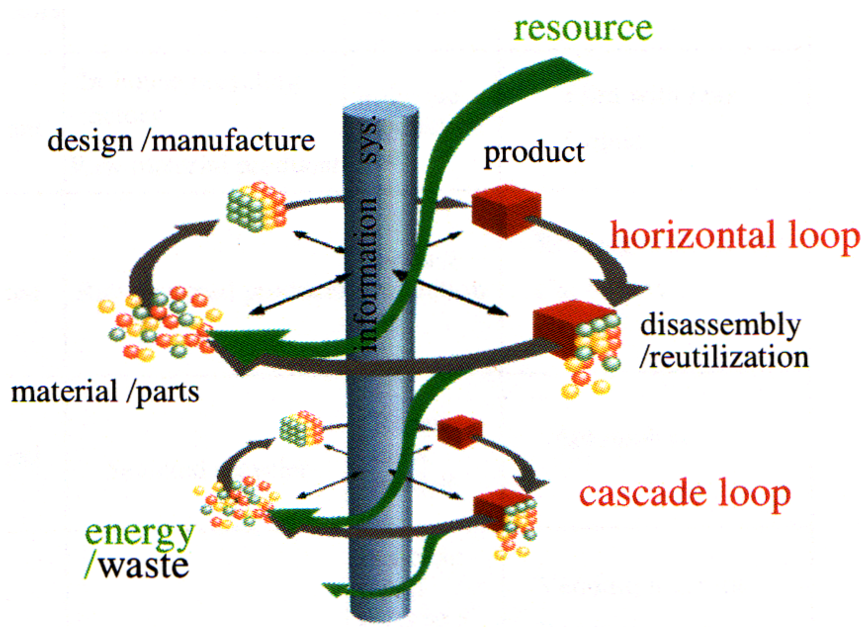
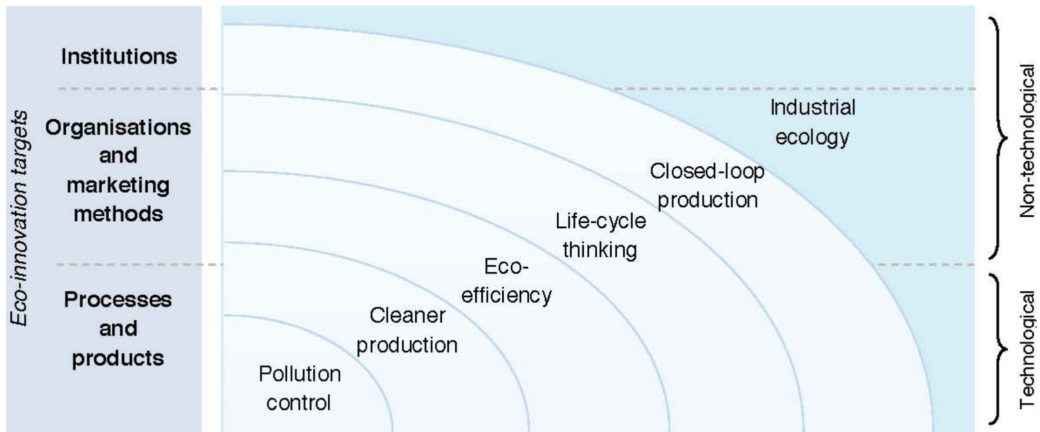


Fig.1 The concept of Inverse Manufacturing

Conceptual Relationship between Sustainable Manufacturing and Eco-Innovation



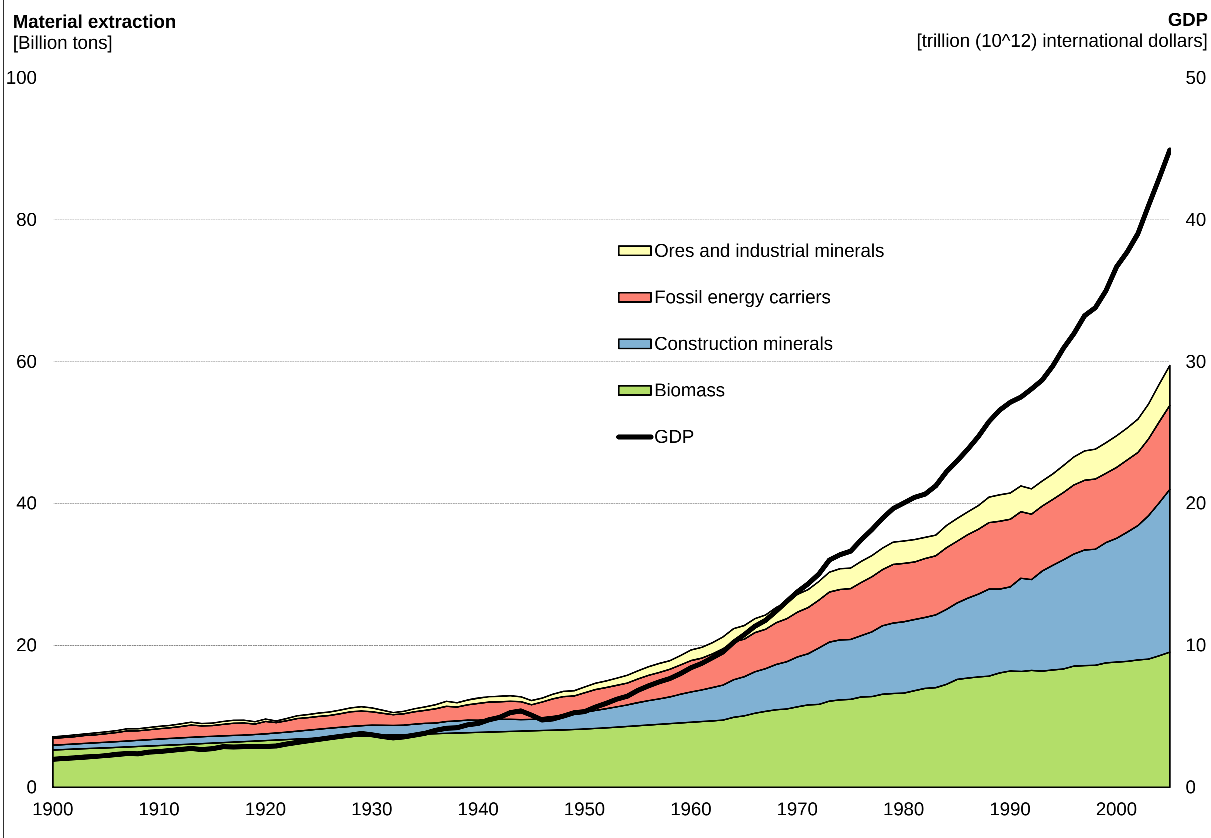
Sustainable Manufacturing and Eco-Innovation, OECD, 2010

EU Initiatives

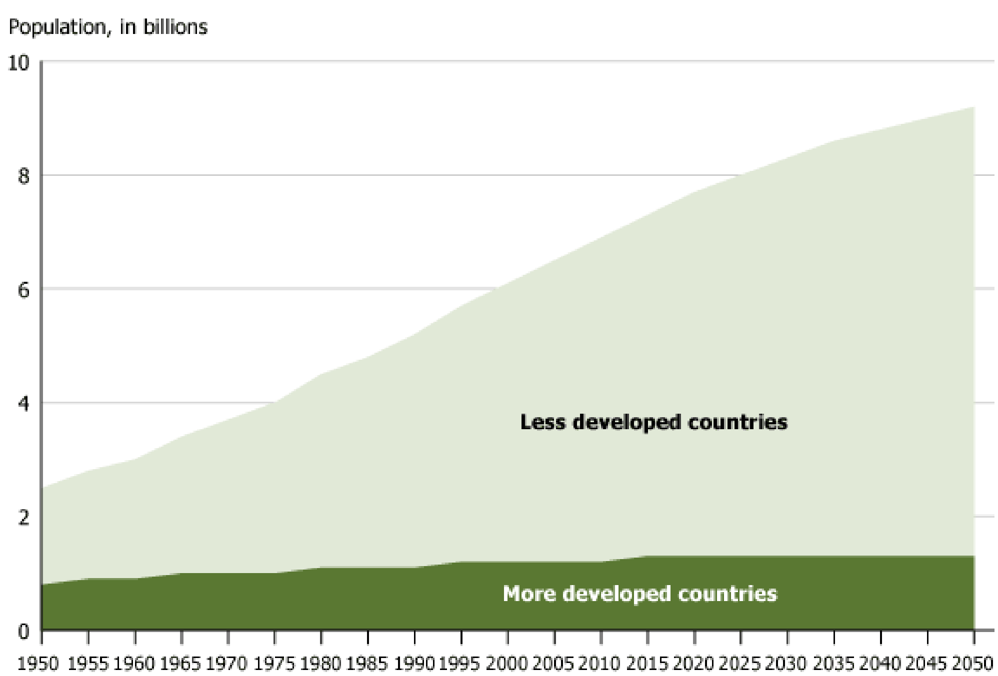
"In a world with growing pressures on resources and the environment, the EU has no choice but to go for the transition to a resource-efficient and ultimately regenerative circular economy"
Manifesto for a Resource Efficient Europe, December 2012

Transforming waste into high value resources is a high priority in today's global economy. ResCoM is an European Commission co-funded project working on the development of closed-loop product systems. The project will focus on some of the key ways to do this including remanufacturing, reuse and multiple lifecycles.

Global Material Extraction & GDP



Population Growth (1950-2050)



Source: United Nations Population Division, World Population Prospects, The 2008 Revision.

OECD ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

OECD Project on Sustainable Manufacturing & Eco-Innovation

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Process overview

- Formed an Advisory Expert Group (AEG)
- 50 members from 17 countries + EC
- Web-forum for ongoing discussions
- Supported questionnaire surveys & focus group meetings
- Review of report drafts prepared by the Secretariat … DSTI/IND(2009)5/PART1-5

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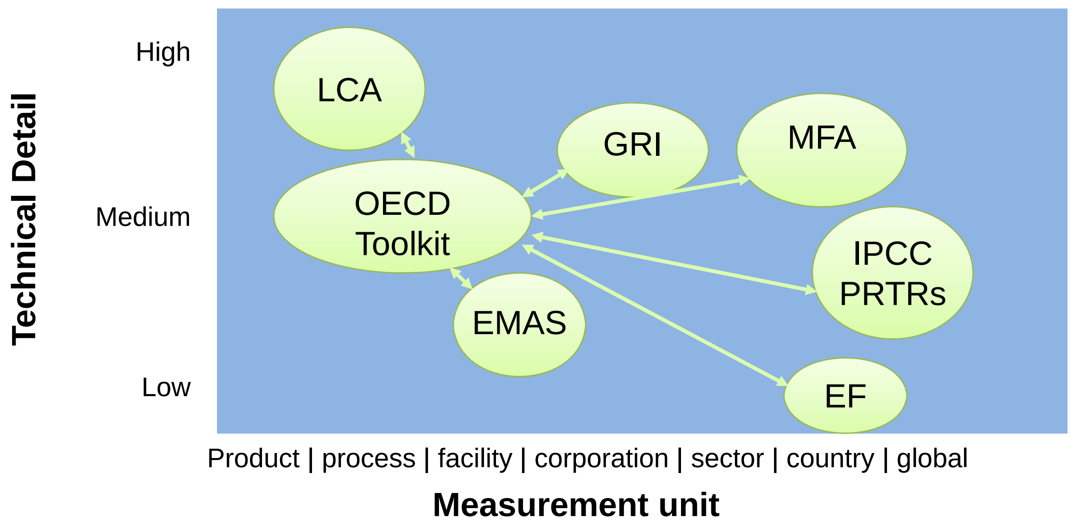
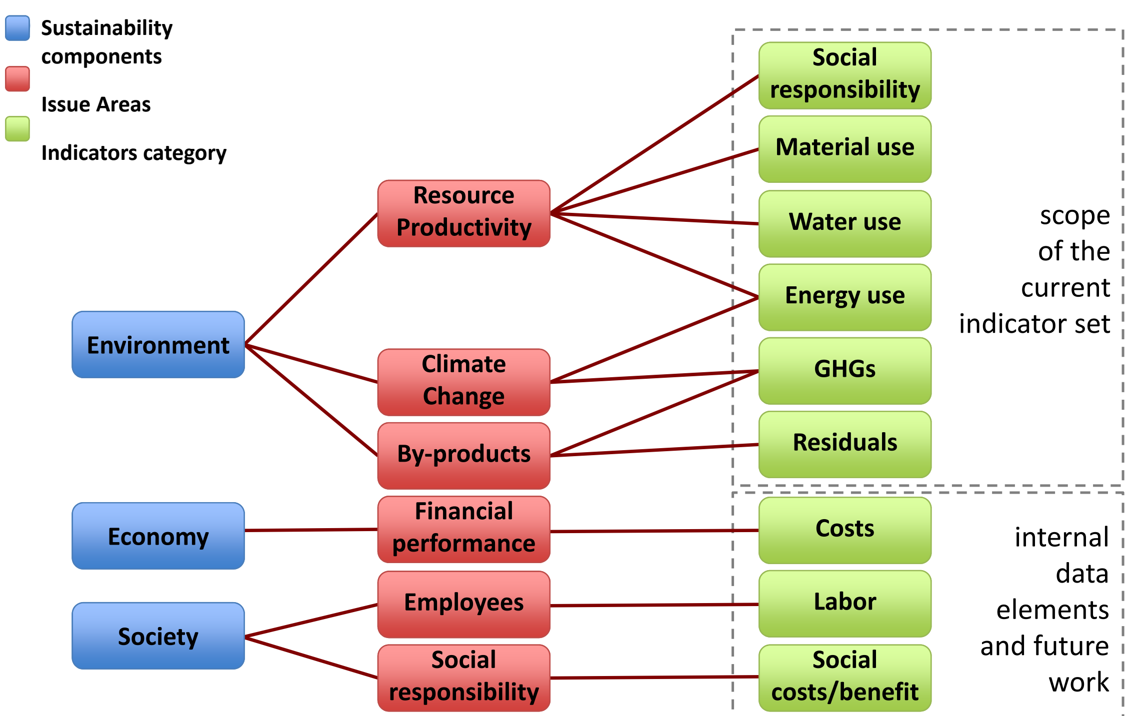
Existing Metrics Approaches



Indicator Categories



- Recycling rates of metals
  - According to the United Nations, recycling rates of metals are often far lower than their potential for reuse. Less than one-third of some 60 metals studied have an end-of-life recycling rate above 50% and 34 elements are below 1% recycling, yet many are crucial to promising clean technologies ranging from hybrid car batteries to the high-efficiency magnets in wind turbines.
- Decoupling natural resource use and environmental impacts from economic growth
  - By 2050, humanity could devour 140 billion tons of minerals, ores, fossil fuels and biomass per year – 3X its current appetite – unless the economic growth rate is "decoupled" from the rate of natural resource consumption. We need to rethink the links between resource use and economic prosperity and invest in technological, financial and social innovation to at least freeze per capita consumption in wealthy countries and help developing nations follow a more sustainable path.

R·I·T Golisano Institute for Sustainability
ROCHESTER INSTITUTE OF TECHNOLOGY

Prof. Nabil Nasr
Caterpillar Professor
Associate Provost for Academic Affairs
& Director, Golisano Institute for Sustainability (GIS)

Rochester Institute of Technology
Rochester, NY USA

Email: nasr@rit.edu
Phone: +1 585-475-5106

http://www.sustainability.rit.edu/

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Sustainable Manufacturing from a Life Cycle Perspective

William P. Flanagan, PhD
Director, Ecoassessment Center of Excellence
General Electric Company
GE Global Research
Niskayuna, NY

Measurement Science for Sustainable Construction & Manufacturing
NIST – ASCE – ASME – University of Maryland
ASCE Bechtel Center, Reston, VA

June 12-13, 2014

ecoassessment center of excellence

GE today

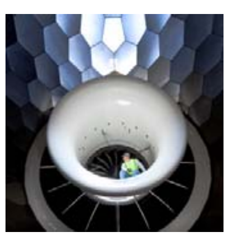
Power & Water

Energy Management

Oil & Gas

GE Capital

Healthcare



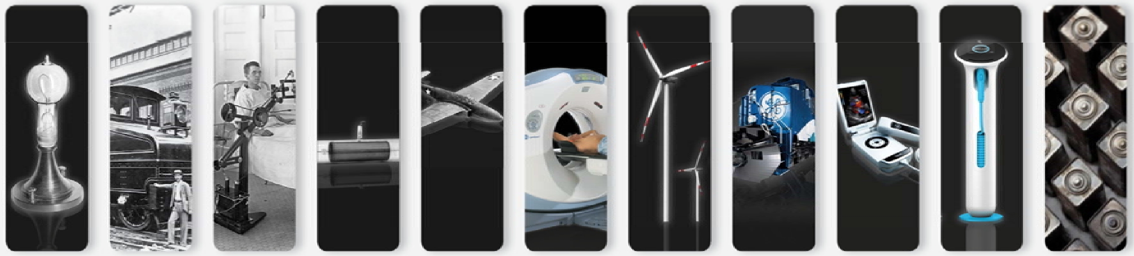
Aviation

Transportation

Home & Business Solutions

Aligned for growth

GE … A heritage of innovation



1879	1895	1920	1921	1941	1998	2002	2003	2009	2010	2012
Carbon Filament Incandescent Lamp	World's Largest Electric Locomotive	Portable X-Ray Machine	The Magnetron	Entering the Jet Age	Lightspeed™ CT Scanner	Wind Power	Evolution® Locomotive	Vscan™	WattStation™	Durathon™ Battery

The Hush Hush Boys

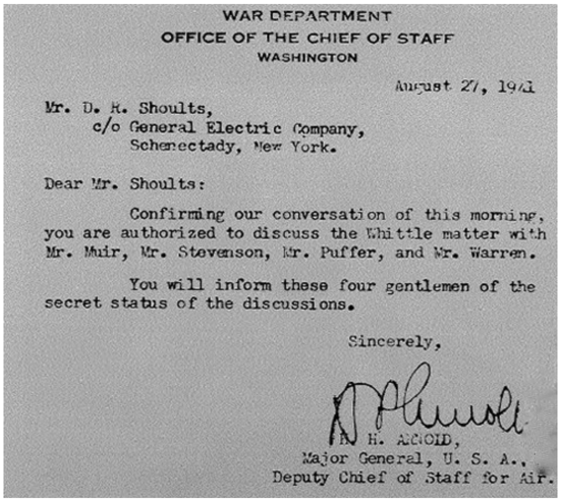
In 1941, a group of GE engineers called the Hush Hush Boys (pictured left) worked in secret on a jet engine design developed by Britain's Sir Frank Whittle (pictured right) and built America's first jet engine.

GE's Hush Hush Boys

Sir Frank Whittle

http://www.gereports.com/post/77296347909/the-hush-hush-boys-ge-engineer-speaks-about-a-top
http://www.gereports.com/post/86230911910/the-most-important-10-pages-in-the-history-of-aviation

WWII


WAR DEPARTMENT
OFFICE OF THE CHIEF OF STAFF
WASHINGTON

August 27, 1941

Mr. D. R. Shoults,
c/o General Electric Company,
Schenectady, New York.

Dear Mr. Shoults:

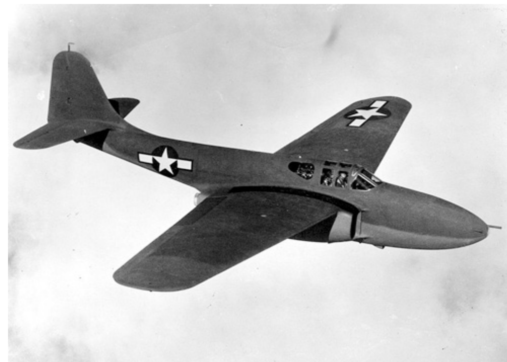
Confirming our conversation of this morning, you are authorized to discuss the Whittle matter with Mr. Muir, Mr. Stevenson, Mr. Puffer, and Mr. Warren.

You will inform these four gentlemen of the secret status of the discussions.

Sincerely,

H. ARNOLD,
Major General, U. S. A.,
Deputy Chief of Staff for Air.

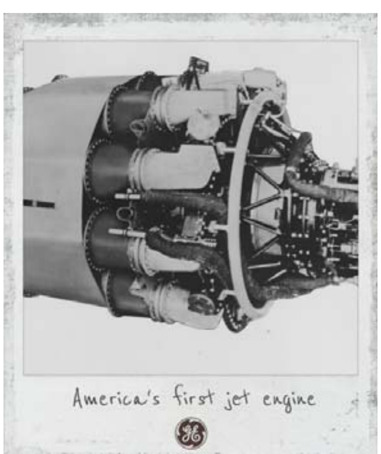
The U.S. War Department picked GE to build the country's first jet engine because of its research and innovation in turbine technology.



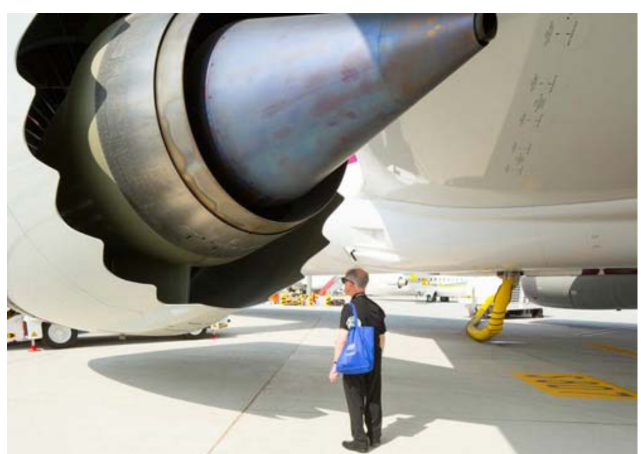
The first GE jet engine powered Bell's experimental XP-59 aircraft.

GE Aviation

That engine, called I-A (pictured on left), launched GE's aviation business and started an engine dynasty culminating today in the largest and most powerful jet engines ever built: the GE90, GE9X, and GEnx (pictured on right).



I-A



GEnx

Star Wars Episode VII

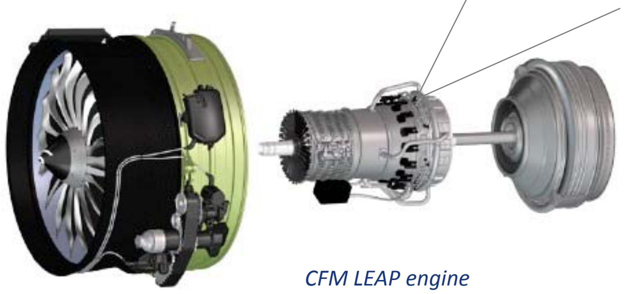
Coming May 2015

CFM LEAP Engine

Coming 2016

- CFM International is a 50/50 joint venture between GE and France's Snecma
- The LEAP engine is CFM's next-generation high-bypass turbofan jet engine
- 3D-printed fuel nozzles offer:
  - >20% weight reduction
  - 5x longer part life

3D-printed fuel nozzle



CFM LEAP engine

http://www.industrial-lasers.com/articles/2012/07/cfm-ge-making-jet-engine-parts-using-additive-manufacturing.html

LCA and systems level thinking

GE Ecoassessment

Center of Excellence

Technical credibility & product support

- Product LCA + LCM toolkits
- Strategic & selective application

Drive eco further into product development

- Customize to business context
- Identify opportunities for real improvement

Deliver customer value

- Strategic engagement
- Environmental and operational savings

Thought leadership

- Drive business perspective on sustainability
- Create & maintain momentum toward real change

Ron Wroczynski, Bill Flanagan, Angela Fisher (with GE CTO Mark Little)

Key Roles:

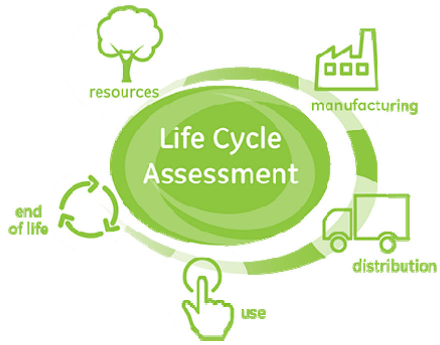
- Expertise and guidance
  - ✓ Life cycle assessment (LCA)
  - ✓ Life cycle management (LCM)
  - ✓ Carbon, energy, water footprint
  - ✓ ecoDesign / Design for Environment
- Tools and resources
- Education and awareness
- External networks

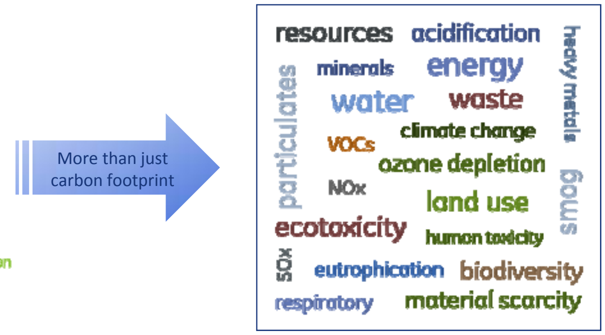
Support:

- Policy and advocacy
- Business strategies / integration
- Stakeholder engagement

Life Cycle Assessment (LCA)

Assess overall environmental impact throughout a product or service's life cycle





Understanding the net environmental impact of a product/service across its value chain, how and where to make improvements

- Differentiate products
- Evaluate alternatives
- Prioritize opportunities for improvement
- Mitigate environmental issues

Ecosystem quality | Natural resources | Human health

Areas of Protection (damage categories)

LCA is not a panacea

Holistic, but not comprehensive

- In practice, limited to existing impact categories and characterization factors
- Difficult to address specific effects and emerging issues (e.g., endocrine disruptors, nano materials)

Global vs. local perspective

- Difficult to address region-specific or application-specific impacts (e.g., regional species impacts, actual vs. potential exposures, other localized issues)

Water impacts under-represented

Social / economic / behavioral aspects often missing

Difficult to apply to emerging technologies (R&D)

LCA is an excellent tool, but is not comprehensive

A tiered life cycle management strategy

1 Environmental Product LCM Tool (qualitative)

Apply level 1 tool early in product development across broad product portfolio

Tool rapidly identifies follow-up needs

Address identified issues
- Substances of concern
- Material scarcity
- Toxicology assessments
- Environmental risk assessment
- Nanomaterial EH&S
- Product regulatory compliance
- Etc.

2 Screening LCA

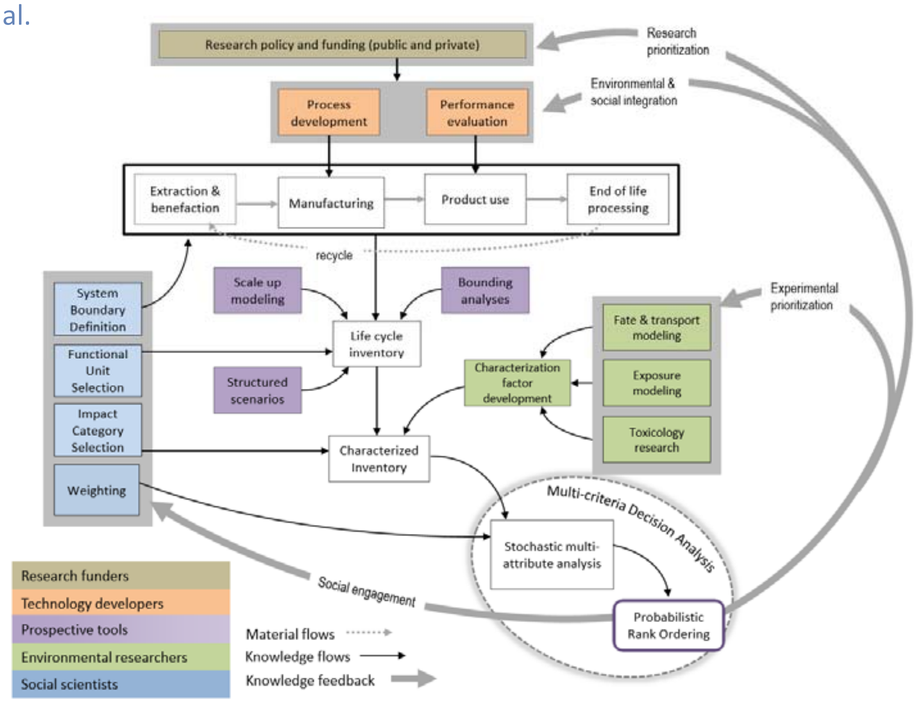
3 Streamlined LCA

4 Detailed LCA per ISO 14044

Strategic | Comprehensive | Efficient | Effective

Anticipatory LCA

Wender et al.



Wender et al., SNO 2013, Santa Barbara, CA:
http://www.susnano.org/images/sessions2013/2B_1wender%20SNO%202013.pdf

Additive manufacturing

Billet vs. additive manufacturing

Conventional

Start with a pre-formed billet, which gets formed and machined

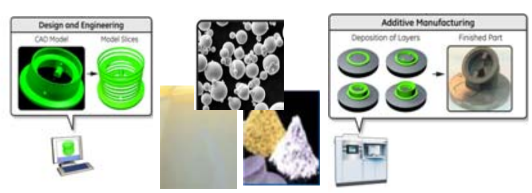
Material properties unchanged and cannot be location specific

Limited to known set of geometries

Design constrained by manufacturing

Requires extensive tooling

Additive



Starts with a powder or wire and produces part layer upon layer upon layer

Build material properties as you build the part … location specific

More complex geometries possible

Allows for faster iterations between design, materials and manufacturing

Minimal tooling required

Ability to design new materials & implement them
during the manufacturing process will create paradigm change

EADS Additive Case Study

Hinge Redesign

Uses less raw material: optimised design, net shaping, DMLS and not casting, titanium and not steel

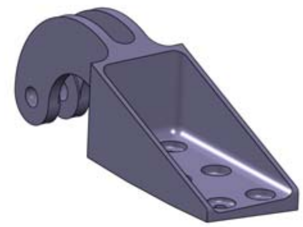
Leads **to important energy consumption/CO_2 emissions reduction** during the **transport phase** (a hundred times better): less material to be transported, based on a European supply chain

Energy consumption is higher compared to Steel Casting, but **less waste produced**.

Allows **10 kg weight reduction per a/c**, **equivalent to €35K savings in fuel consumption and carbon tax**

No significant differences.

Conventional Steel Design

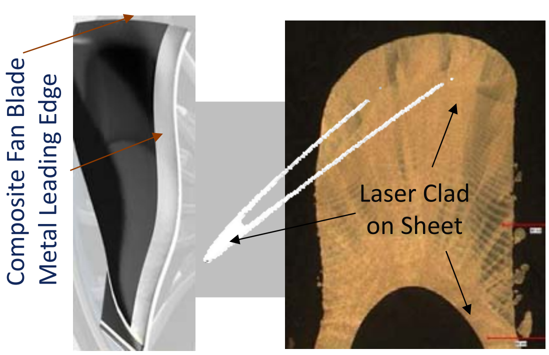


Ti ALM Optimized Design

In this case, additive manufacturing has higher energy consumption during manufacturing, but lower overall life cycle impact

GE Aviation Additive Case Study

Fan Blade Metal Leading Edge (MLE)



- Cost reduction over extensive machining cycles of near net shape forging
- Laser cladding, cold spray, wire technologies and hybrids (e.g., forging/additive) emerging
- Establish new Supply Chain and footprint

PROBLEM

- Composite fan blades enable significant engine performance vs. titanium forged blades
- Composites require metal leading edge for erosion protection
- Cost of machining Ti and other superalloys

OBJECTIVE OR SOLUTION

- Form inner face of MLE from sheet stock and laser clad (or other additive) bulk material

APPROACH

- Establish bulk and hybrid laser clad material properties
- Perform static impact testing of scaled hybrid
- Perform rotational impact on FAA cert program engines

US Department of Defense

- Defense industry consortium: Mission Ready Sustainability Initiative
  - o GE Aviation, Lockheed Martin, BASF, 3M, General Dynamics, others
- Aimed at DoD sustainability initiatives:
  - o DoD Strategic Sustainability Performance Plan, Air Force Energy Plan, Presidential Executive Orders 13514 / 13423
  - o Sustainability tools and metrics may be imposed on DoD acquisitions
- Strong, active engagement from DoD:
  - o Office of Secretary of Defense, Deputy Director of Chemical & Material Risk Management
- **DoD Streamlined LCA / LCC methodology developed for use in defense acquisitions**
  - o Pilots underway: GE, 3M, BASF, Lockheed Martin
  - o Method integrates environmental and cost aspects
  - o Total Cost of Ownership

http://www.denix.osd.mil/esohacq/

GE Aviation LOCKHEED MARTIN BASF The Chemical Company 3M GENERAL DYNAMICS

Understand and build capability for emerging acquisition criteria

Additive Manufacturing of Fuel Nozzles

Pilot of US DoD streamlined LCA/LCC methodology

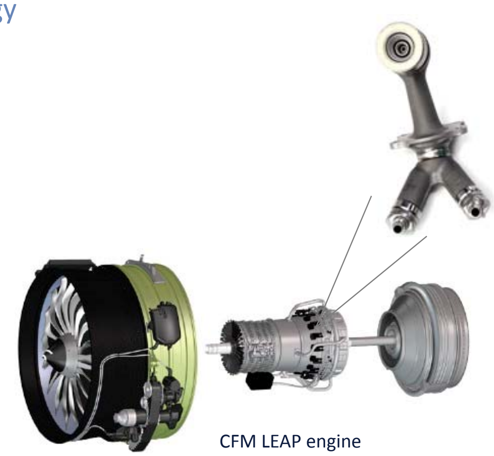
Traditional fuel nozzles are manufactured via forging and machining processes

Fuel nozzles manufactured by additive manufacturing processes offer:

- >20% weight reduction
- 5x longer part life

Potential for significantly reduced life cycle environmental impact and total cost of ownership due to:

- Reduced part weight:
  - o Reduced fuel consumption over the life of the aircraft system
  - o Increased mission capability (load capacity)
- Net lower raw material consumption
- Enhanced performance



CFM LEAP engine

Direct metal laser sintering
Courtesy EADS Innovation Works

Pilot project benefits

Clear need for trade-off assessment

- Environmental impact
- Total cost of ownership
- Trade-offs relevant to supplier: design, supply chain, manufacturing, performance
- Trade-offs relevant to US DoD: total cost, mission, sustainment & operations

Opportunity to pilot methodology early in product development

- Ability to leverage insights gained

Focus on additive manufacturing

- Understand trade-offs before paradigm shift

LCA XIV, San Francisco, Oct 6-8, 2014
Special session: "Streamlined LCA/LCC in Defense Acquisitions"

Understand net benefit and trade-offs associated with paradigm shift to advanced manufacturing processes

Sustainable manufacturing

Sustainable manufacturing should consider all life cycle stages

Different manufacturing processes may:

- ✓ enable novel material choices
- ✓ have different material and energy efficiencies
- ✓ enable unique part geometries or other features affecting performance
- ✓ offer enhanced repair-ability, re-usability, recyclability at end of life

Different materials may have different:

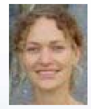
- ✓ supply chain impacts
- ✓ manufacturability
- ✓ performance properties (e.g., thermal, mechanical)
- ✓ end of life options (e.g., recyclability, re-usability)

Additive manufacturing offers the potential for unique part geometries or performance that can yield environmental benefit across the full life cycle

Thanks!

Bill Flanagan
flanagan@ge.com

Acknowledgements



Angela Fisher
GE Ecoassessment

Ron Wroczynski
GE Ecoassessment

Todd Rockstroh
GE Aviation

Sustainable Construction: An EPC Perspective

Nancy Kralik

Senior Director, Health, Safety, Environment & Sustainability

Fluor Corporation

June 12, 2014

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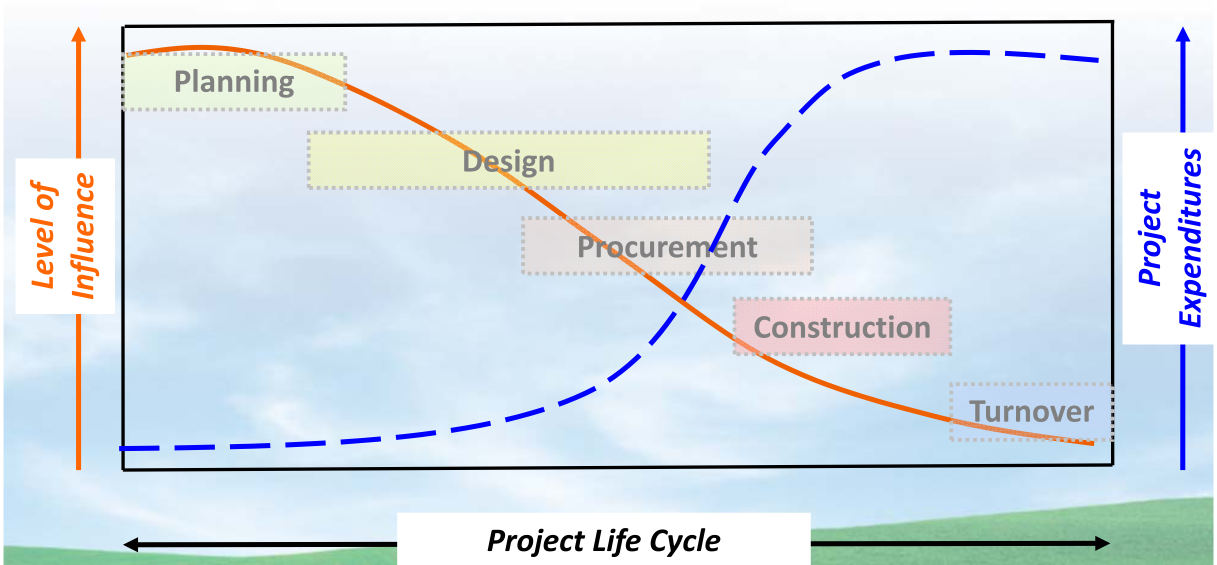
Influence Curve



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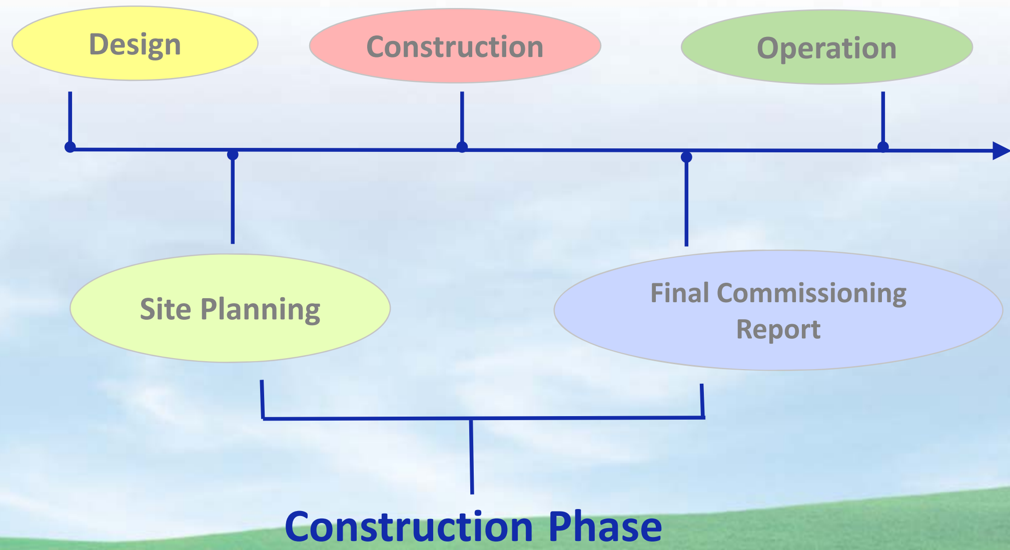
Adapted from CII Constructability Primer

Construction Phase



Safety Metrics (Social)

- **Lagging**
  - Lost time incidence rate
  - Recordable incident rate
  - Etc.
- **Leading**
  - Audits
  - Inspections
  - Training
  - Etc.

Economic Metrics

- Budget
- Schedule
- Cost of energy
- Cost of raw materials
- Water consumed

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Environmental Metrics

- Brownfield
- Greenfield

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Social Metrics

- Human Rights
- Labor Practices
- Community Impact and Involvement
- Worker Safety

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Construction Industry Institute

- Guidance on sustainability during construction
  - RT304
- Compendium of sustainability practices
  - RT250

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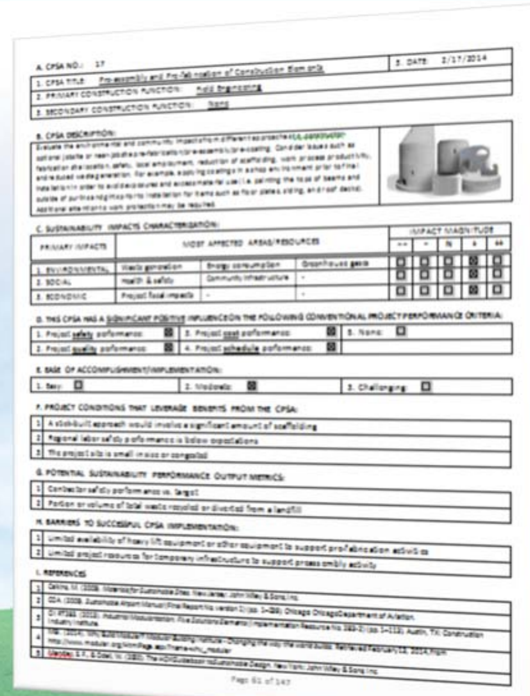
Sustainability Action Catalog

– Sustainability Impacts
– Project Conditions
– Output Metrics



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Sustainability Action Screening Tool

- **2 types of Input:**
  – Relative priorities/weightings of desired Sustainability impacts
  – Applicability of project conditions

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Screening Tool Output

- **Also available for Tablet or Smart Phone**

Implementation Resource 304-3: The CPSA Screening Tool

CII The Knowledge Leader for Project Success — Owners • Contractors • Academics

OUTPUT - CPSA SCREENING RESULTS

Instructions: Below are the CPSA screening results ranked and ordered by RI score. Refer to IR304-2 for guidance on CPSA implementation.

Back: Project Conditions

Rank	CPSA #	CPSA Title and Description	Leveraging Project Conditions	RI	Catalog Link
1	4	Sustainability Provisions in Construction Execution Plans: Incorporate sustainability provisions and solutions in the construction execution plans similar to provisions for safety, quality, cost, schedule, and resource management, among others. Include a discussion on sustainability requirements and opportunities as part of the preconstruction/kick-off meeting agenda to align the project team on sustainability objectives and expectations. Confirm that the team understands any sustainability specifications and assigns responsibilities and commitments for documentation.	a) Project management has taken a lead role in endorsing sustainable solutions b) The project is large and complex c) The project team has experience incorporating sustainability provisions	0.06	CPSA #4
2	5	Sustainability Risk Management: Ensure that sustainability risks are incorporated into the project risk management process by addressing environmental, social, and economic threats and opportunities. Perform a sustainability risk assessment to identify sources and root causes of accidents, releases or spills of hazardous material (i.e. exposure to the worker, community, and environment), and cultural clashes, among other events. Record such events in a Risk Register. Mitigation measures should be developed and employed to minimize negative sustainability impacts.	a) The project is large and complex b) The project is located in an environmentally/socially-sensitive area c) The project owner, stakeholders, and/or local community have diverse interests relative to sustainability	0.06	CPSA #5
3	9	Paperless Communication and Construction Documentation: Replace hardcopy-based communications with electronic/digital forms wherever possible. Consider developing and implementing digital data collection systems and real-time field reporting technologies to electronically streamline traditional paper-based processes and further reduce the reliance on paper files, drawings, and other documents during construction. Adopting green meeting practices can further reduce negative sustainability impacts. Examples of eco-friendly meeting practices include distributing meeting materials electronically, arranging meetings via telephone or Internet to reduce travel, and encouraging carpools or public transportation when travel cannot be avoided. If printing is required, modify the default setting of the printer to print double-sided and encourage recycling of all documents.	a) All parties are willing to use electronic communications and align on same electronic systems b) Electronic programs / forms are available and individuals with expertise are available to run them c) Projects where all parties have computers or tablets and knowledge of electronic systems	0.06	CPSA #9
4	13	Contractor Prequalification based on Safety and Sustainability Performance: Consider employing contractors and sub-contractors with sustainability experience and knowledge (e.g. LEED-accredited or Envision-certified staff). Routinely include safety performance in the prequalification of contractors, sub-contractors, and suppliers. Enhanced safety performance can have a major impact on the local	a) Sufficient number of contractors are available b) The project is large and complex c) The project owner, stakeholders, and/or local community have diverse interests relative to sustainability	0.06	CPSA #13

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Implementation Index

IR 304-4: CPSA Implementation Index Calculator

CII The Knowledge Leader for Project Success — Owners • Contractors • Academics

INPUT - CPSA IMPLEMENTATION EFFORT CHECKLIST

Instructions: Please read the descriptions for the following 54 CPSAs and select/check the degree to which the CPSAs were implemented on your project.

Back: Project Information | CLEAR ALL CHECKBOXES | Next: Implementation Index

CPSA Title and Description	Extent of CPSA Implementation					Comments:
	None or almost none	Minimal	Substantial	Full or almost full	Not Applicable	
CPSA #1. Leadership Team Staffing for Sustainable Projects: Seek to establish a "hearts and minds" sustainability-oriented culture much like organizations pursue a safety or quality culture. Employ administrative staff that possess skills and experience in the management of sustainable projects. Identify voids in knowledge and be prepared to offer supplemental training on project environmental and community impacts, worker safety cultures, effective project communication, etc.	○	○	○	○	○	
CPSA #2. Community Social Responsibility Program: Consider establishing a formal community social responsibility program as a way to respond to stakeholder needs. Formal community signoffs on individual initiatives can be very beneficial. Related volunteer-based programs can have a significant impact as well. This responsibility program should include the development and maintenance of a project website for the local community and holding community forums to discuss project issues, such as traffic impacts and upcoming construction work.	○	○	○	○	○	

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Predominant Output Metrics

- Percent of projects with Sustainability Performance section in project reports;
- Cost savings;
- Portion or volume of total waste recycled or diverted from a landfill;
- Street value of recycled material;
- Equipment environmental performance;
- Size of carbon footprint from project; and
- Number of complaints from community, agency, or camp residents.

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7-Step Implementation Process

1. Establish Objectives
2. Rank Top Actions
3. Select Actions
4. Plan Action Implementation
5. Implement Actions
6. Measure Outcomes
7. Improve Process

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Gaps & Research Needs

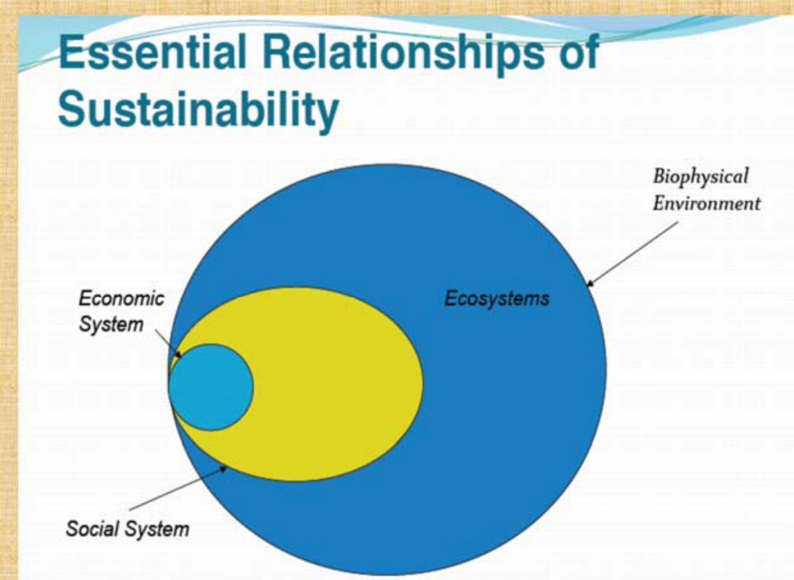
- **Quantitative social metrics**
- **Easy-to-generate life-cycle assessments**
- **Industrial Sustainability Index Metrics**
- **Case studies for identified sustainability actions**
  - New metrics?
  - Benchmarking
- **Field use**

Questions and Comments Welcome

How to Quantify Sustainability in Construction and Manufacturing, and the Need for Standards

Subhas Sikdar, US EPA, and
Humberto S. Brandi, INMETRO, Brazil

NIST-ASCE-ASME Sustainability Workshop, Rockville, MD, June 12-13, 2014



Sustainability is like the proverbial elephant. We, much like blind people, describe it in terms that depend on our field of expertise. Thus - - - -

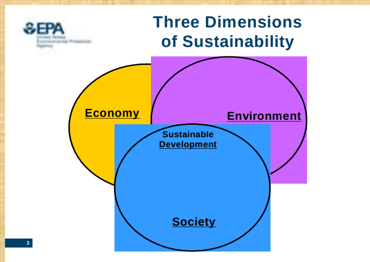
Many Men, Many Minds
Sustainability through disciplinary lenses

- **For an economist, sustainability is at first related to new economic models of growth and regulation, taking into account not only the traditional quantifiable components of welfare, but also a lot of environmental "externalities" and qualitative assets.**
- **For an ecologist, sustainability means the use of natural resources to the extent that the carrying and regenerative capacities of the ecosystems are not jeopardized.**
- **For a physicist, sustainability means the ability of biological systems to fight against degradation of energy and resources (entropy) by creating new forms of order (negentropy) using the various inputs of solar energy.**
- **For a chemist or an engineer, the challenge of sustainability is to complete material and energy life cycles created by human activities, through new techniques for material design, re-use, recycling and waste management.**
- **For a social scientist, sustainability implies the social and cultural compatibility of human intervention in the environment with its images constructed by different groups within society.**

J. Pop-Jordanov, in Technological Choices for Sustainability, Ed. Sikdar, Glavic and Jain, Springer 2004, p. 305

Bruntlund Sustainability

Economic development (i.e. by technology application) with decreasing environmental impact and improving societal benefit



An Engineering Definition:

For a man-made system, sustainable development is continual improvement in one or more of the three domains of sustainability, i.e., economic, environmental, and societal without causing degradation in any of the rest, either now or in the future, when compared with quantifiable metrics, to a similar system it is intended to replace.

Scale and Nesting of Sustainable Systems

Five levels of scales for sustainable systems:

Level I: Global Systems (e.g. global CO2 budgeting)

Level II: National Systems (energy system, material flow)

Level III: Regional Systems (e.g. watersheds, Brownfields)

Level IV: Business Systems (e.g. business networks, waste exchange networks)

Type V: Sustainable technologies (e.g. green materials, sustainable products)

System-Surrounding Paradigm

Sustainability analysis is essentially an accounting of what impacts (environmental, economic, and societal) the system is causing to itself and to the surrounding, and how these impacts can be minimized.

I: Global Scale (e.g. global CO2 budgeting)

II. National Scale (e.g. energy)

III: Regional Scale (e.g. watersheds)

IV: Business or Institutional Scale (e.g. eco-industrial park)

V: Sustainable Technologies Scale (e.g. sustainable products)

Measurement and Standards

Quality, Uniformity, Confidence: Three Pillars of Sustainable Development

Clear understanding of what is wanted:
Standardization – Documentary standards

Proceeding to implement " what is wanted":
Conformity Assessment - Certication, labelling, supliers declaration, auditing. Accreditation

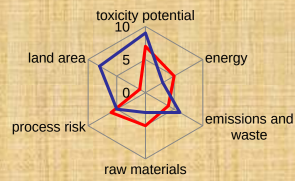
Guaranty that "what one has is what is wanted":
Trust in measurements:
Metrology – Measurement standards

Example: GHG emision standards require:

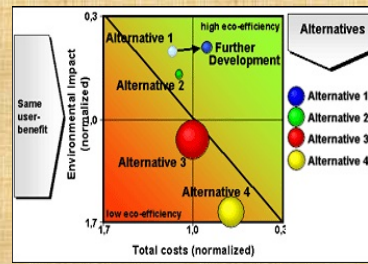
Harmonize knowledge
Harmonize measurements
Harmonize methodologies
Harmonize inventories

Metrics and Indicators

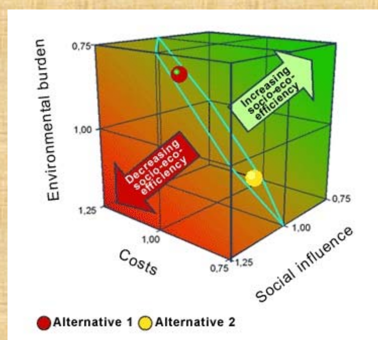
Methods of Sustainability Analysis:



BASF Eco-efficiency Analysis

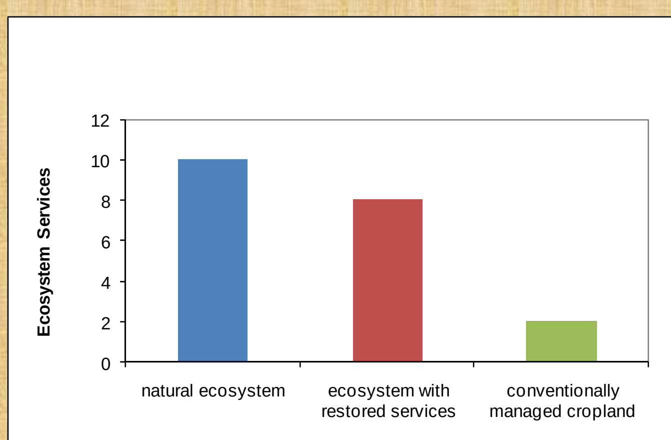


BASF Eco-efficiency analysis: combines Environmental and Economic Dimensions Of Sustainability



BASF Sustainability Analysis: combines All three dimensions of sustainability (called socio-eco-efficiency)

Metrics Aggregation for a Sustainability View



Eco services indicator is a qualitative composite of 8 indicators: **crop production, forest production, preserving habitats and biodiversity, water flow regulation, water quality regulation, carbon sequestration, regional climate and air quality regulation, infectious disease mediation.**

Construction of aggregate index:

hypothesis: sustainability footprint D_e or $D = f(x_i$, i=1 to n), represents the overall state of the system as revealed by the set of chosen indicators

Sustainability footprint

$$D_e = \sqrt{\sum_j^n \left[c_j \frac{(y_j - x_{j0})}{(y_j - x_{j0})_{\max}} \right]^2}$$

- **Euclidean Distance Method**
- **Canberra Index Method**
- **Others**

$$D = \left(\prod_i^n \left[c_i \left(y_i' / x_i' \right) \right] \right)^{1/n}$$

$$y_i' = y_i - \left(x_{i0} - C_{offset} \right)$$

$$x_i' = x_i - \left(x_{i0} - C_{offset} \right)$$

or perfect sustainability, the value of Sustainability Footprint is zero

Indicators, X_i

Process options	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9
Option 1	$X_{1,1}$	$X_{1,2}$							$X_{1,9}$
Option 2	$X_{2,1}$	$X_{2,2}$							$X_{2,9}$
Option 3	$X_{3,1}$	$X_{3,2}$							$X_{3,9}$
Option 4	$X_{4,1}$	$X_{4,2}$							$X_{4,9}$
Option 5	$X_{5,1}$	$X_{5,2}$							$X_{5,9}$
Option 6	$X_{6,1}$	$X_{6,2}$							$X_{6,9}$
Option 7	$X_{7,1}$	$X_{7,2}$							$X_{7,9}$

Typical Data Matrix for m options and n indicators

PCA-PLS-VIP (Finding Redundant Indicators, and Rank Order)

Starting point: mxn data matrix *X*, m options, n indicators

PCA designs n-dimensional unit vectors (q's) and a correlation matrix *R* (nxn), such that the following eigen value Problem represents the data set.

$$RQ = \Delta Q$$

Mapping √λ onto *Q*, we get the loading matrix *L*. The product of *L* and *X* is called score matrix *T* (*XL = T*)

PCA-PLS-VIP, contd.

PLS-VIP is based on projecting the information from data with more variables to that with fewer.

Using the score of *X*, PLS develops a regression model between *X and* D_e . In a reduced subspace of dimension a (a ≤ n)

$$X = TL^T + E = \sum_{j=1}^{a} t_j l_j^T + E$$

T is score matrix, L is load matrix, E, the residual. Score matrix T can be related to response vector D_e through a regression matrix *B*.

Each option vector x from *X* can be related to the score vector t_j Through weight vectors w_j as $t_j = w_j^T x_i$

VIP for k is

$$VIP_K = \sqrt{n \frac{\sum_{j=1}^{a} b_j^2 t_j^T t_j \left(\frac{w_{kj}}{\|w_j\|} \right)^2}{\sum_{j=1}^{a} b_j^2 t_j^T t_j}}$$

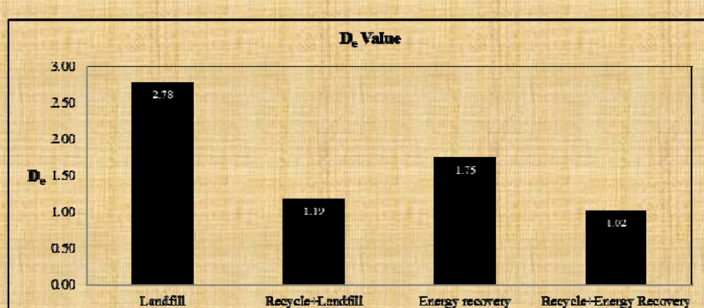
Case: Automotive Shredder Residue Treatment (Catholique U, Leuven)

(where improvement is described as negative)

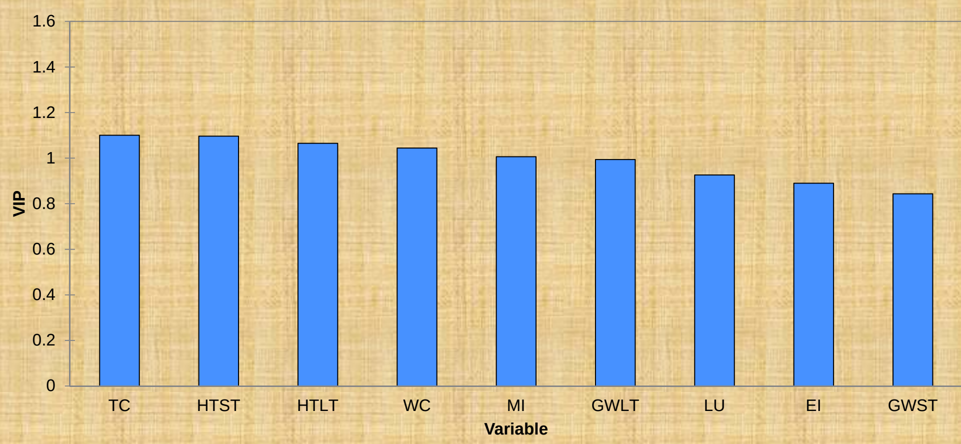
Treatment strategy	EI	MI	WC	LU	GW		HT		TC
y					ST	LT	ST	LT	
Landfill	1.8	3.6	1.7	8.7	637	3844	472	533	106
Recycle+Landfill	-13.1	-408	-4.3	-3.6	-641	1614	-675	-2617	161
Energy recovery	-24.6	-48.2	-5.2	-11.5	841	841	12	-383	133
recycle+Energy Recovery	-26	-438	-7.8	-14.6	-325	-325	-812	-3000	177
Minimum	-26	-438	-7.8	-14.6	-641	-325	-812	-3000	106
y'									
Landfill-Minimum	27.8	441.6	9.5	23.3	1278	4169	1284	3533	0
Recycle+Landfill-Minimum	12.9	30	3.5	11	0	1939	137	383	55
Energy recovery-Minimum	1.4	389.8	2.6	3.1	1482	1166	824	2617	27
recycle+Energy Recovery-Minimum	0	0	0	0	316	0	0	0	71
Maximum	27.8	441.6	9.5	23.3	1482	4169	1284	3533	71

Normalized										Root Square D'
Landfill	1	1	1	1	0.86235	1	1	1	0	2.78
Recycle+Landfill	0.464029	0.067935	0.36842	0.472103	0	0.4651	0.1067	0.108406	0.774648	1.19
Energy recovery	0.05036	0.882699	0.27368	0.133047	1	0.279683	0.64174	0.74073	0.380282	1.75
recycle+Energy Recovery	0	0	0	0	0.21323	0	0	0	1	1.02

Best-->Worst D,B,C,A

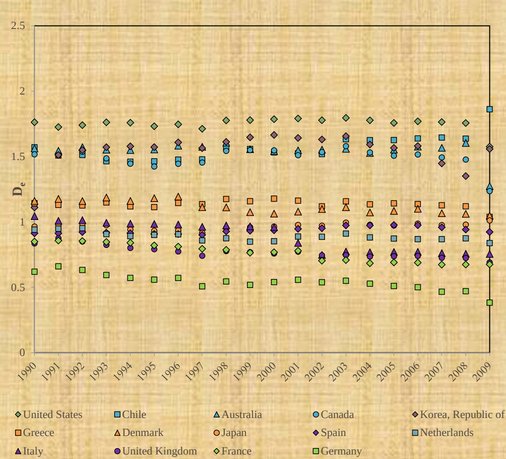


PLS-VIP



The PLS-VIP score shows that Total Cost (TC) has the maximum contribution to overall sustainability.

Case: Comparison of Sustainability Footprint (D_e) for OECD Countries over 20 Years

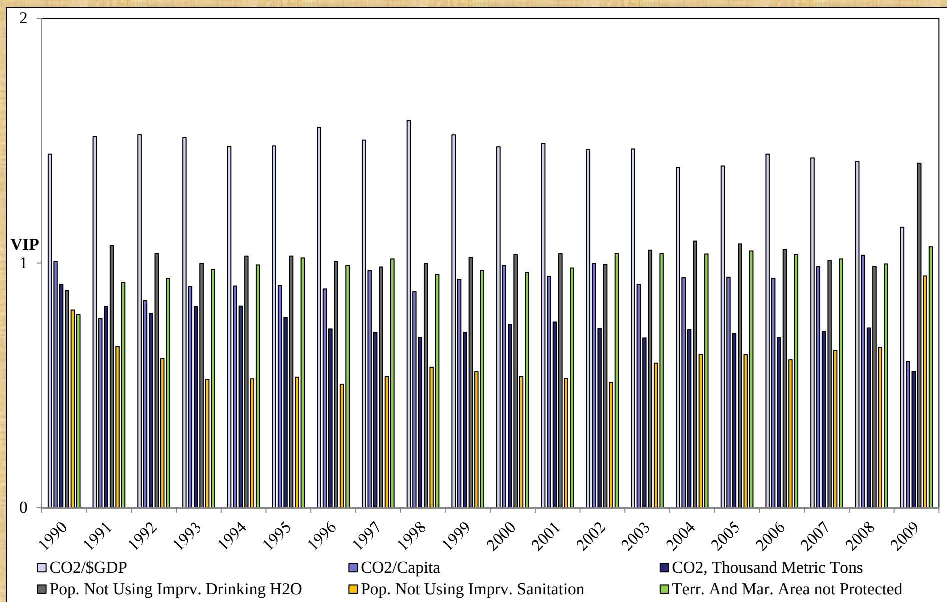


Environmental sustainability of OECD countries using UN MDG data and indicators

Only 6 Indicators could be used because of data availability:

CO_2/\$GDP, CO_2/capita, CO_2 giga tons, ODP Metric tons, Population NOT using safe drinking water, and wetlands protection

Comparison of VIP Scores for OECD Indicators for 20 Years



Future Research Needs

- Needed a Methodology to confirm if all necessary indicators have been chosen for analysis (e.g., cost frequently not included as an indicator but should be)
- A method to determine the sensitivity of Sustainability Footprints (D_e *or D)* to individual indicators
- Method for identifying which indicators and their underlying variables can be manipulated to make further sustainability advances of systems
- System optimization of Sustainability Footprint with respect to the indicators by process integration techniques

How to Quantify Sustainability in Construction and Manufacturing, and the Need for Standards

Subhas Sikdar, US EPA, and
Humberto S. Brandi, INMETRO, Brazil

NIST-ASCE-ASME Sustainability Workshop, Rockville, MD, June 12-13, 2014

Measurement Science for Sustainable Construction & Manufacturing
June 12-13, Reston Virginia

A Systems Approach to Sustainability and Resilience

Joseph Fiksel

Executive Director, Center for Resilience
The Ohio State University

Special Assistant for Sustainability
Office of Research & Development
U.S. Environmental Protection Agency

System Resilience

Resilience is the capacity for complex, adaptive systems (e.g., cities, business enterprises) to survive, adapt, and flourish in the face of turbulent change… much like living systems

Operational resilience – coping with the risk of disruptions that threaten continuity and well being

↔

Strategic resilience – sensing and responding to external pressures and opportunities

Indicators of System Resilience

Indicators	Urban community	Enterprise supply chain
Diversity	Economic sectors, resource channels, workforce skills	Markets, suppliers, facilities, and employee capabilities
Cohesion	Community identity, social networks, local coordination	Corporate identity, stakeholder relations, collaboration
Adaptive capacity	Ability to rapidly modify urban services, management practices	Ability to modify products, technologies, or processes
Resource productivity	Quality of life (security, peace) relative to ecological footprint	Shareholder value (profits, assets) vs. ecological footprint
Vulnerability to Change	Disruptive forces that threaten safety and well being	Disruptive forces that threaten business continuity
Stability	Ability to continue normal activities if disruptions occur	Ability to continue normal activities if disruptions occur
Recoverability	Ability to overcome disruptions, restore critical public services	Ability to overcome disruptions, restore key business operations

Source: J. Fiksel, I. Goodman, A. Hecht, "Navigating Toward a Sustainable Future," *Solutions*, Oct. 2014

Sustainability is the capacity for:

- human health and well being
- economic vitality and prosperity
- environmental resource abundance

continuity

fitness

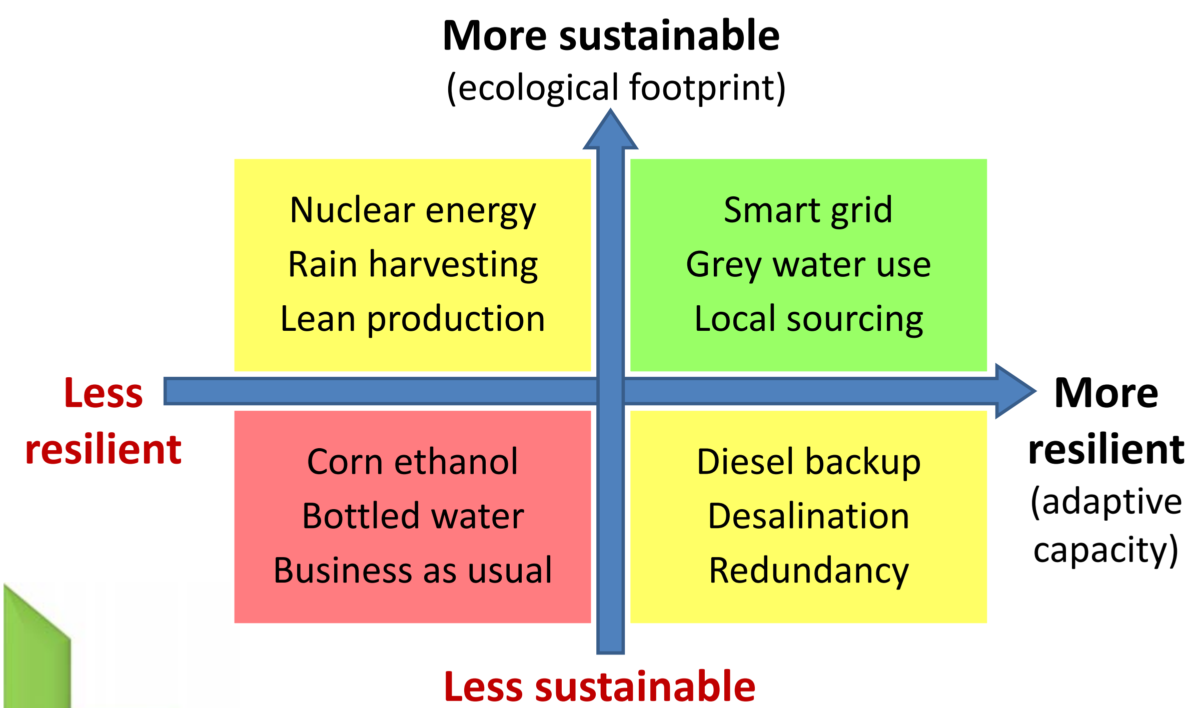
Resilience is the capacity to:

- overcome unexpected problems
- adapt to change (e.g., sea level rise)
- prepare for and survive catastrophes

Examples of initiatives aimed at resilience and sustainability

- **Energy systems**—smart grid, distributed, renewable, PHEV
- **Eco-efficiency**—green buildings, local sourcing, waste reuse
- **Water systems**—rainwater harvesting, green infrastructure
- **Mobility**—alternative transport, vehicle sharing
- **Urban renewal**—brownfields, affordable housing
- **Smart growth**—land use, resource stewardship
- **Education**—STEM careers, workforce retraining
- **Economic development**—incubators, business clusters
- **Emergency preparedness**—early detection, evacuation plans

Examples of Synergies and Trade-offs



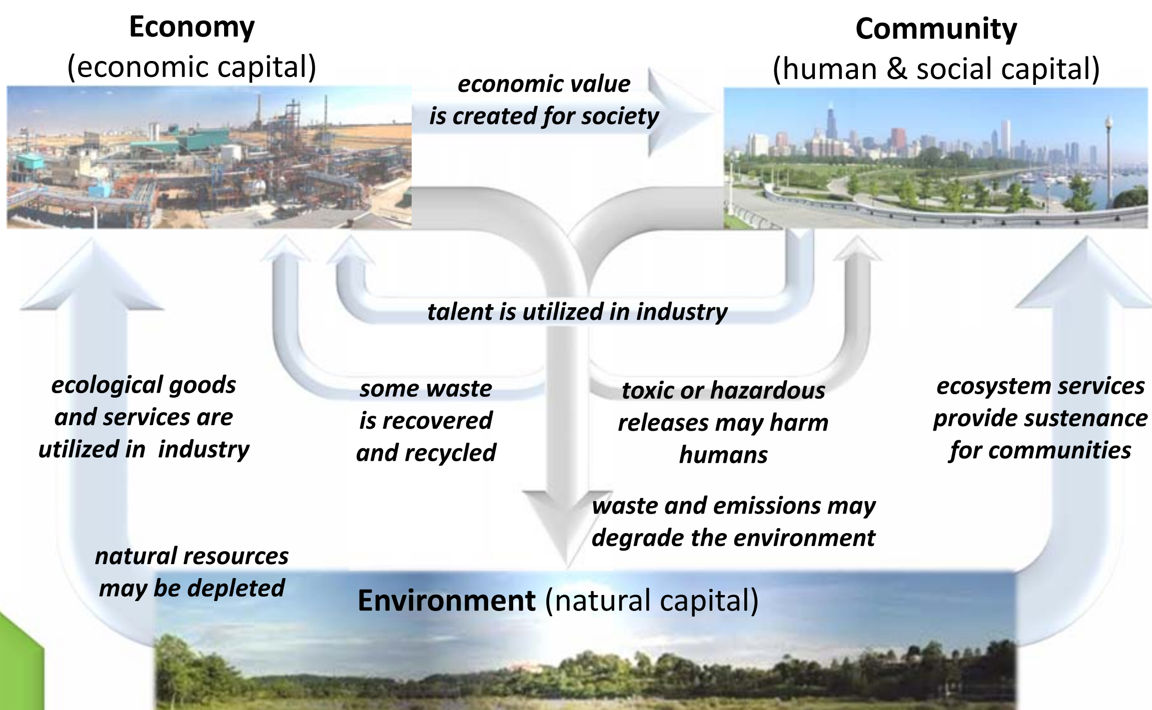
Source: J. Fiksel, I. Goodman, A. Hecht, "Navigating Toward a Sustainable Future," *Solutions*, Oct. 2014

What is a Systems Approach?

- A comprehensive methodology for understanding the interactions and feedback loops among
  - Economic systems—companies, supply chains….
  - Ecological systems—forests, watersheds….
  - Societal systems—cities, networks….
- Reveals consequences (sometimes unintended) of human interventions, such as new policies, technologies, and business practices
- **Case in point**: Degraded ecosystems threaten the sustainability and resilience of human communities

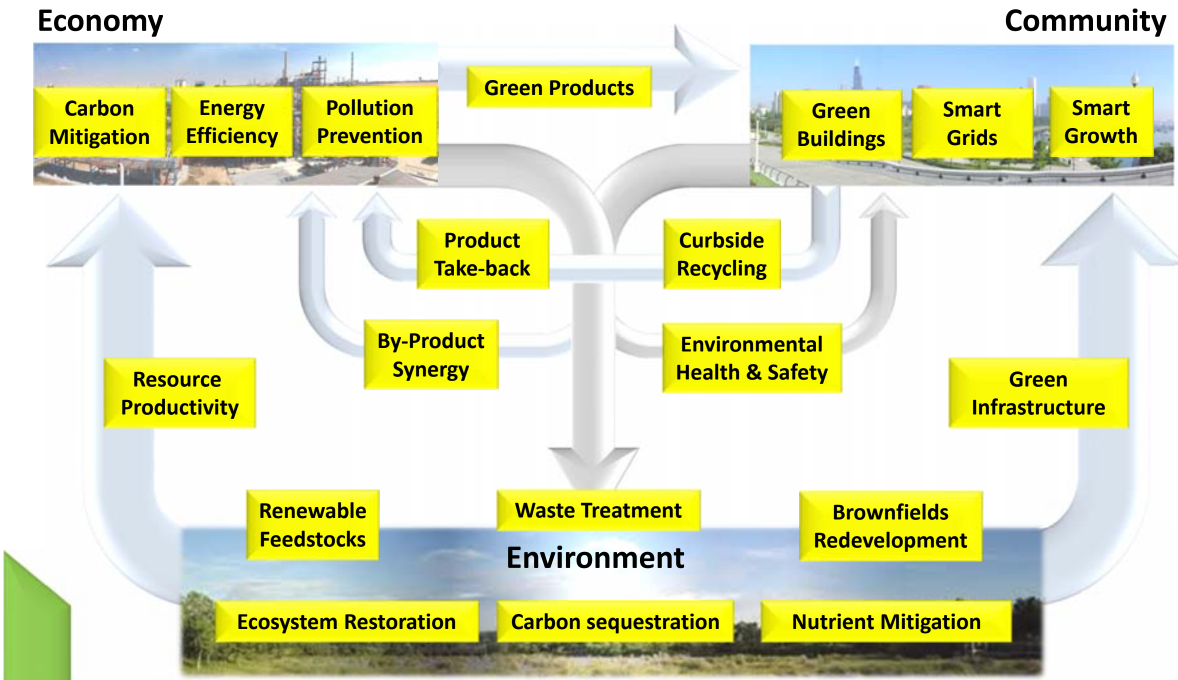
(Millennium Ecosystem Assessment, 2005)

Triple Value (3V) Framework



J. Fiksel, "A Systems View of Sustainability: The Triple Value Model," *Environmental Development*, June 2012.

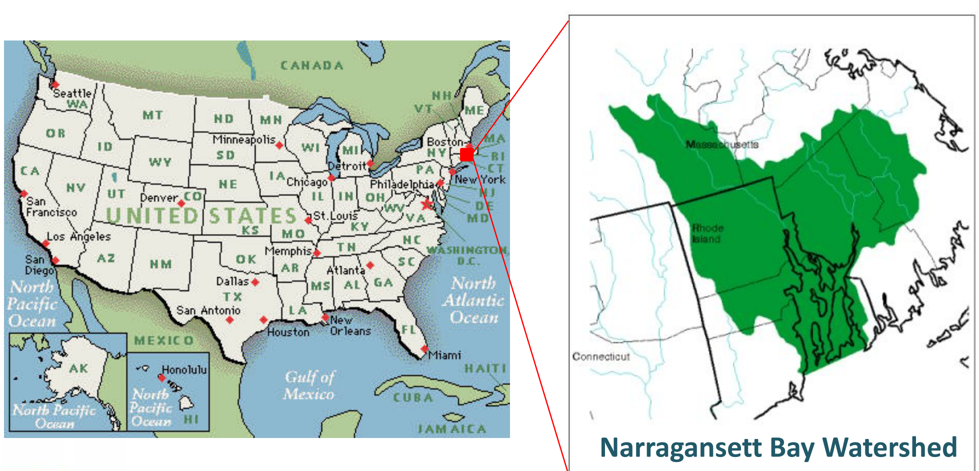
Triple Value (3V) Framework



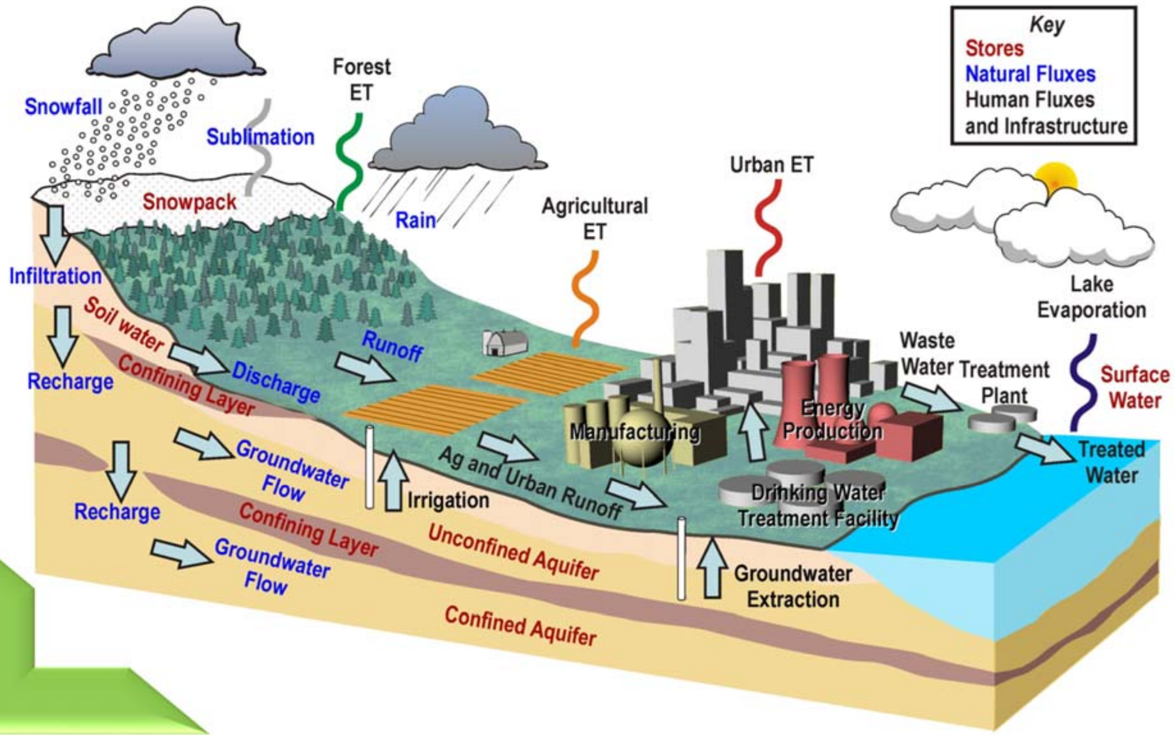
J. Fiksel, "A Systems View of Sustainability: The Triple Value Model," *Environmental Development*, June 2012.

Example from U.S. EPA Narragansett Bay 3VS Project

Apply "systems thinking" to the problems of nutrient pollution and coastal resilience in New England, working closely with Region 1 stakeholders



Modeling Coupled Human-Natural Systems at a Watershed Scale Requires Aggregation



Modeling the Nutrient Cycle

products & services

Economic Activities
- Agriculture
- Commercial Fisheries
- Energy & Transportation
- Land Development
- Recreation & Tourism
- Water Treatment

water supply

Community Stakeholders
- Consumers & residents
- State & local agencies
- Water & energy utilities
- Regional businesses
- Septic tank users
- Private well users

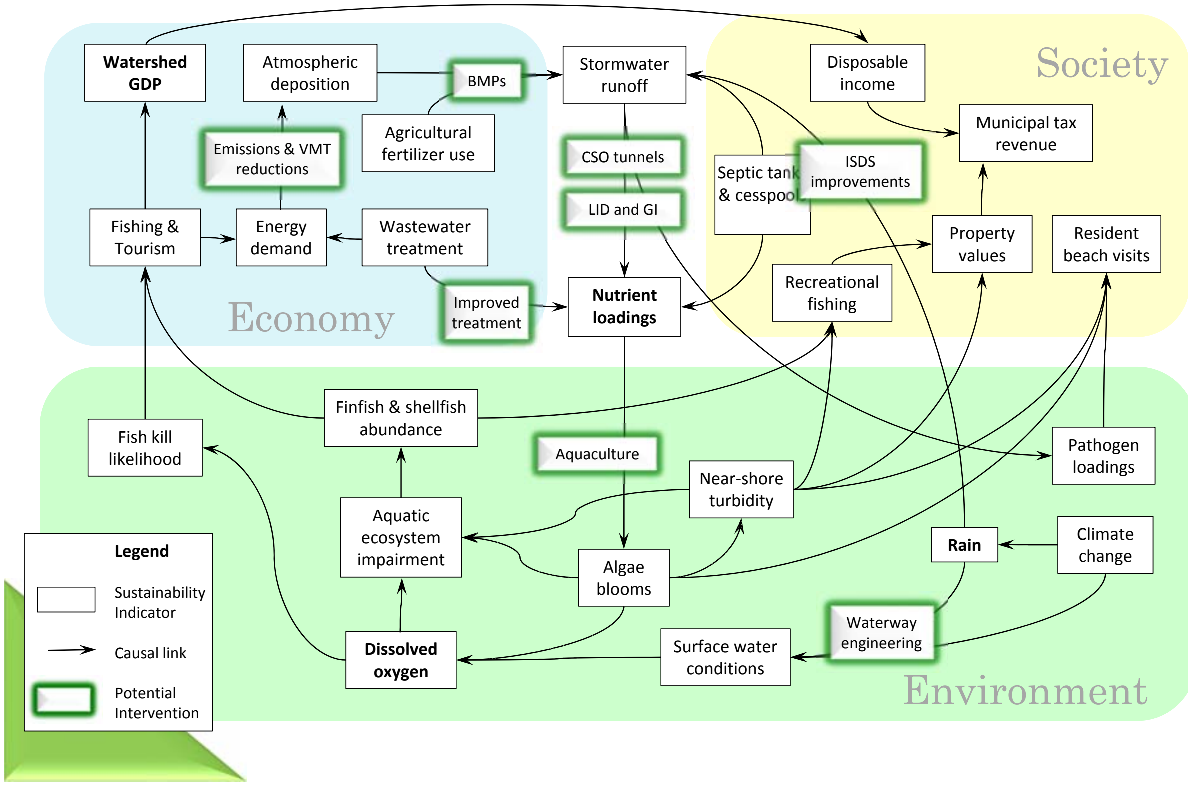
runoff and wastewater

industrial & commercial uses

Environmental Resources
- Surface water
- Ground water
- Coastal areas
- Fish & shellfish
- Regional ecosystems
- Atmosphere & climate

recreational and cultural uses

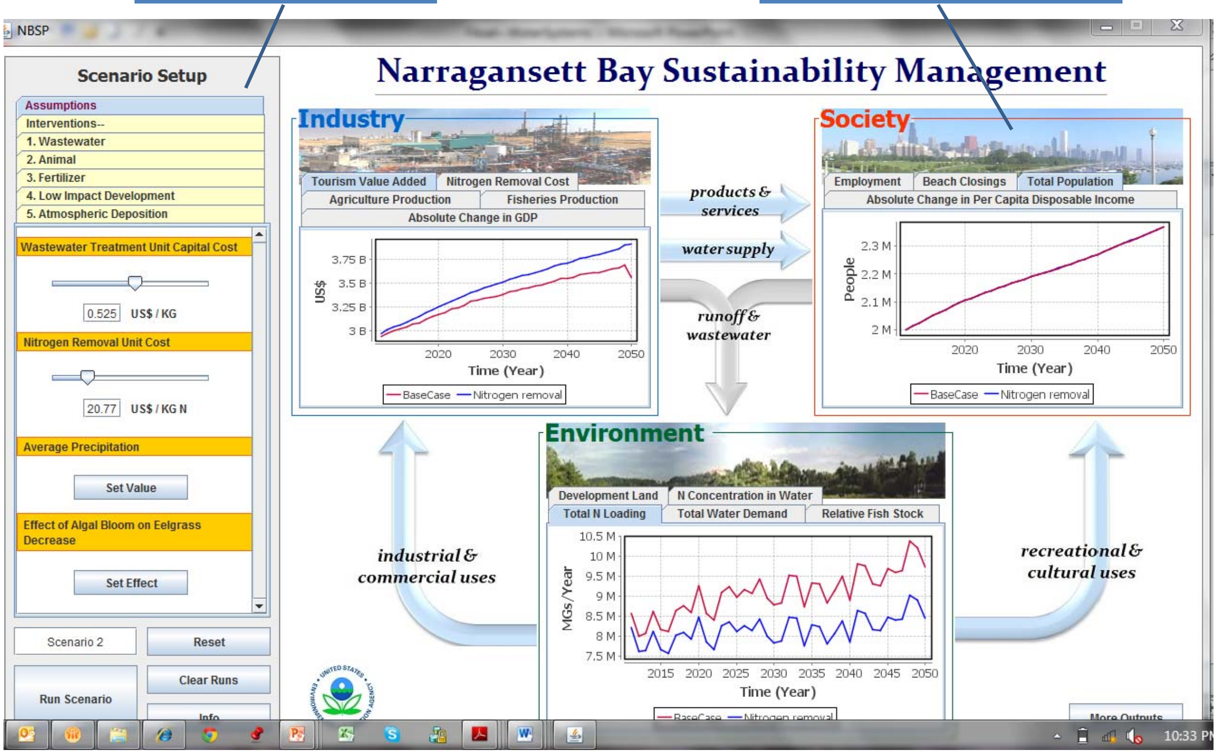
Causal Relationships in 3VS Model



Graphical User Interface

Define interventions

Foresee consequences



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Alan Hecht, Ramona Trovato, Marilyn ten Brink, Nick Ashbolt

Model implementation team:
Eric Ruder and Nadav Tanners, Industrial Economics, Inc.
Andrea Bassi, Millennium Institute
Chien-Chen Huang, The Ohio State University

Sustainability Improvement at the Supply Chain Level Through Product Architecture Optimization

Gül E. Okudan Kremer
Professor of Industrial Engineering & Engineering Design

Summaries of collaborative work with Profs. Karl Haapala, Kyoung-yun Kim, Ratna Chinnam, Leslie Monplaisir, Alper Murat and current and former ADAPS Group Members: Saraj Gupta, Ming-Chuan Chiu, Wu Hsun Chung, Nirup Philip, Ting Lei and Junfeng Ma

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Outline

- ADAPS Group
- Sustainable Product Collaboratory Project
- Lessons Learned
- Research Directions

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Applied Decision Analysis for Improved Products & Systems Group (ADAPS Group)

http://www.personal.psu.edu/gek3

Sustainable Product Development
DfX

Supply chain integration
Design for Assembly & Remanufacturing

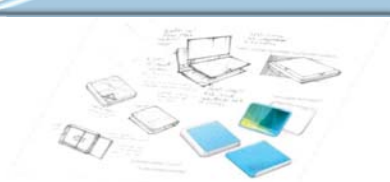
Product Family Design & Optimization

Design Complexity
Systematic Design Ideation (TRIZ, SmartPens)

Smart Health (Triage improvement through MAUT, GT)

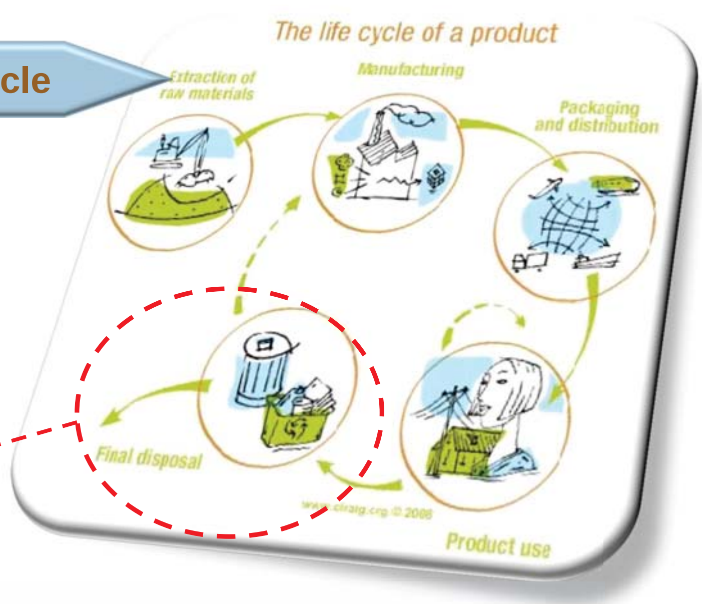
Sustainable Product Collaboratory

Design for Life Cycle



- Low life cycle cost
- Low life cycle environmental impact

Retirement Stage



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What is Sustainability?

For the business enterprise, sustainable development means adopting business strategies and activities that meet the needs of the enterprise and its stakeholders today, while protecting, sustaining and enhancing the human and natural resources that will be needed in the future

International Institute for Sustainable Development (2011)

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IISD, 2011, "Business Strategies for Sustainable Development," International Institute for Sustainable Development, Winnipeg, Manitoba, CA, www.iisd.org/business/pdf/business_strategy.pdf

Sustainability in the Design Stage

The design stage determines 70% of life cycle costs.

It is important that design concurrently considers manufacturing of the product and its supply chain so that a company may gain:

- The ability to reduce waste or increase recyclability of materials
- Supplier selection insight
- Integrated modularity options
- End of life product recovery plans
- Flexibility
- Reduced costs
- Sustainability for profitability

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Sustainable Supply Chain Management

The strategic, transparent integration and achievement of an organization's social, environmental, and economic goals in the systemic coordination of key inter-organizational business processes for improving the long-term economic performance of the individual company and its supply chains.

Carter and Rogers (2008)

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C.R. Carter and D.S. Rogers (2008). "A framework of sustainable supply chain management: moving toward new theory," International J. of Physical Distribution & Logistics Management, 38(5) 360 – 387.

Broader Methods for Sustainable Design

- General goals for sustainability are to eliminate waste, improve energy efficiency, **design products for reuse or recycling,** conserve natural habitats and move toward zero consumption of non-renewable resources.
- Stakeholders should be considered including the **customers, energy and material suppliers**, community, waste contractors, trade associations, environmental agency, professional institutions, employers, local council, **manufacturers**, and end users.

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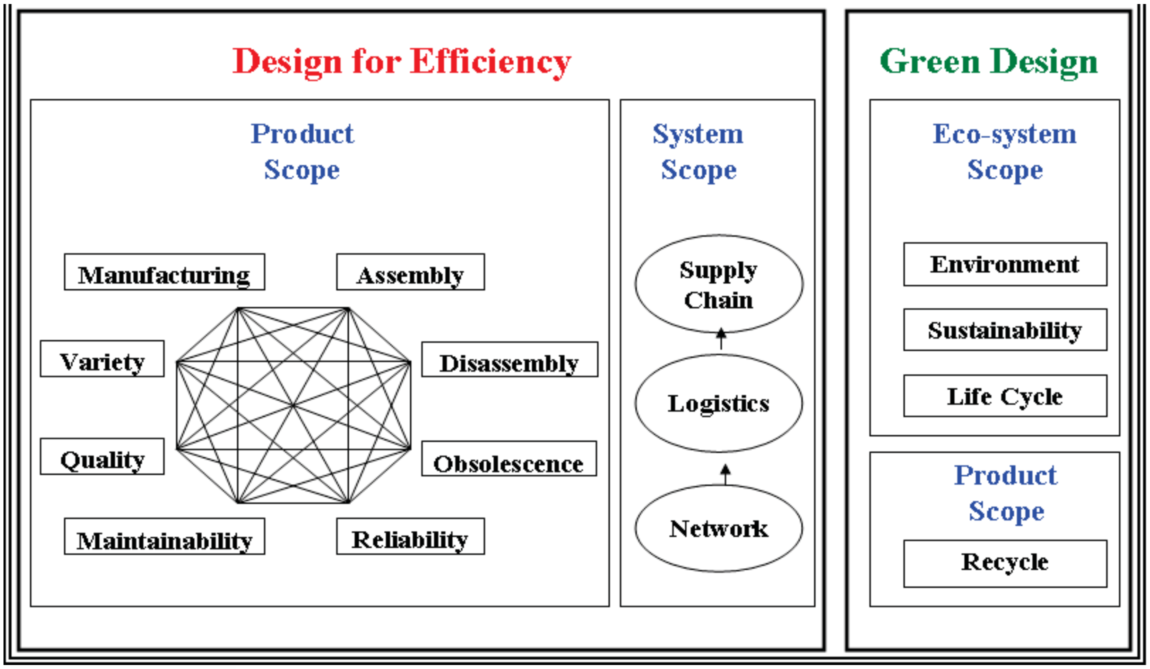
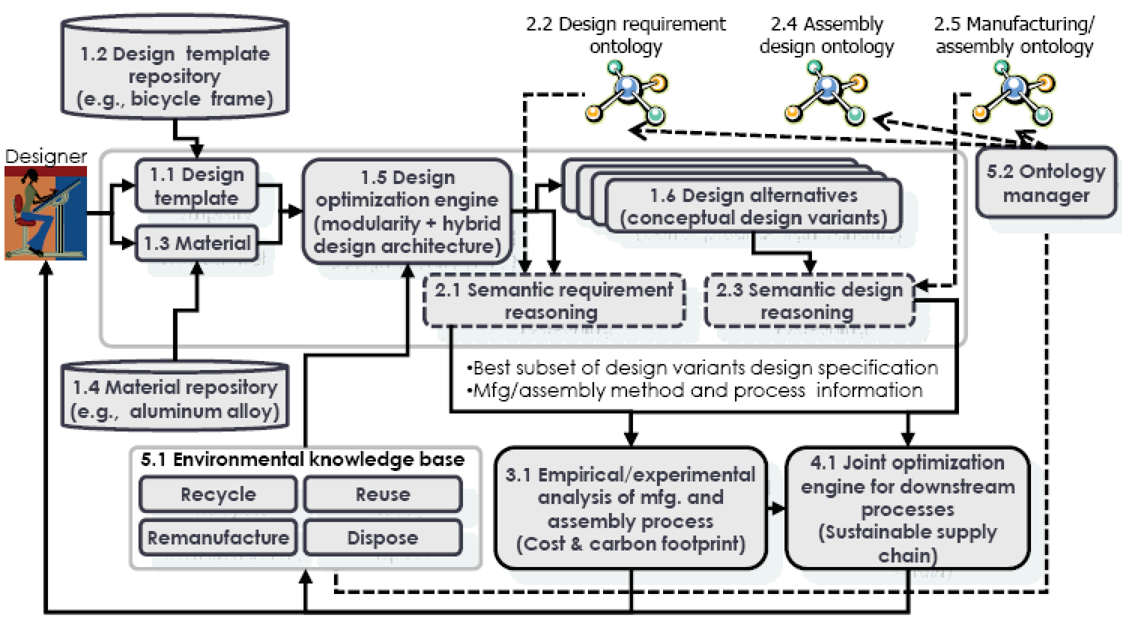
Optimization Challenge

Chiu, M-C. and Okudan, G.E. (2011). "Investigation of the Applicability of Design for X Tools during Design Concept Evolution: A Literature Review", **International Journal of Product Development**, Vol. 13, No. 2, pp.132-167.



Collaborative R&D Framework



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Jointly developed R&D Framework for Sustainable Product Collaboratory with colleagues from Wayne State & Oregon State

Tasks

1. Exploitation of existing and evolving design repositories (including component specifications, interaction matrices) to **automatically generate conceptual design variants**.

   The research extends functional decomposition-based concept generation to integrate modularity and hybrid design architectures, which enables customization (at the architecture level) to better serve life cycle concerns.

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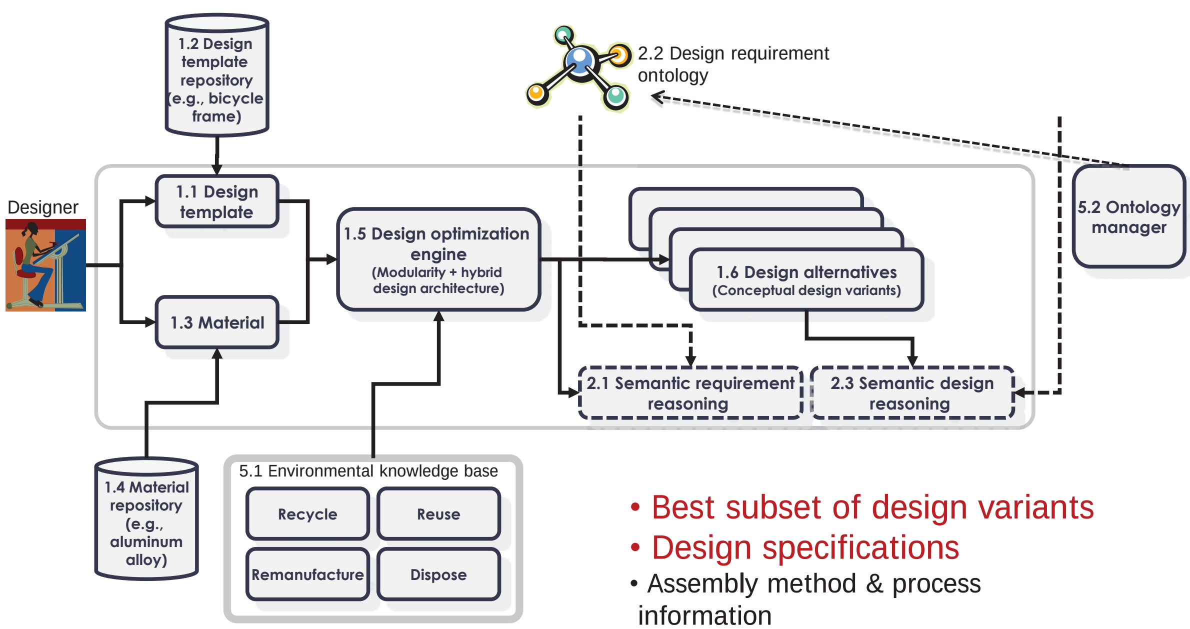

- Best subset of design variants
- Design specifications
- Assembly method & process information

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Tasks

2. Evaluating customer needs and design specifications (design requirements) using semantic design and interaction requirements reasoning with ontologies. This ontology-based semantic reasoning approach can facilitate **efficient selection of the best subset of design variants** for their impact on procurement, manufacturing, assembly, distribution, sustainment, collection, and disposal.

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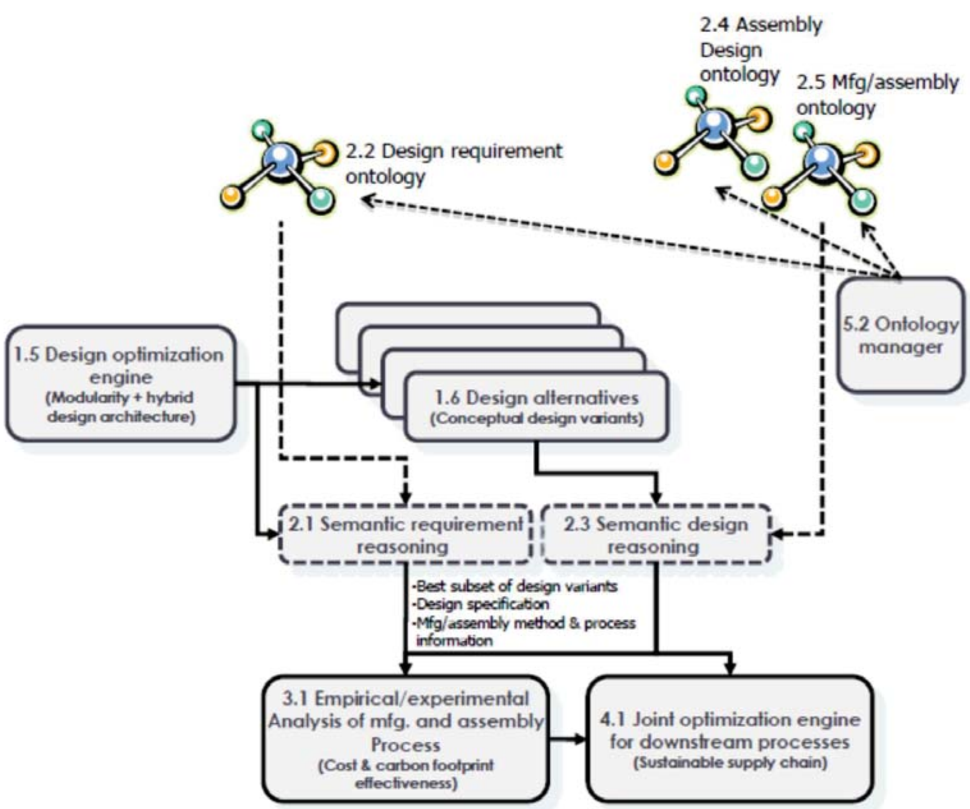
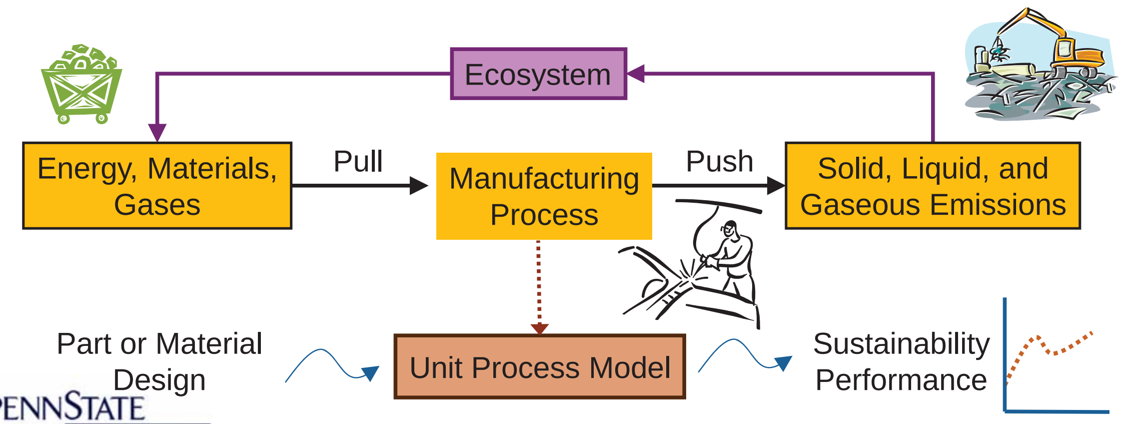


Tasks

3. Modeling of supply chain processes through empirical/experimental investigations. This will **allow prediction of cost and carbon footprint of life cycle processes** (e.g, manufacturing, assembly, and transportation) to evaluate different product architectures.



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Tasks

4. Optimization of the product architecture variants while balancing the impact on procurement, manufacturing, distribution, sales/demand, sustainment, collection, and disposal. The algorithms will facilitate **joint optimization of the best subset of design variants and configurations with mathematical models of life cycle processes**. The research will develop hierarchical optimization models to jointly address the life cycle processes and product architecture

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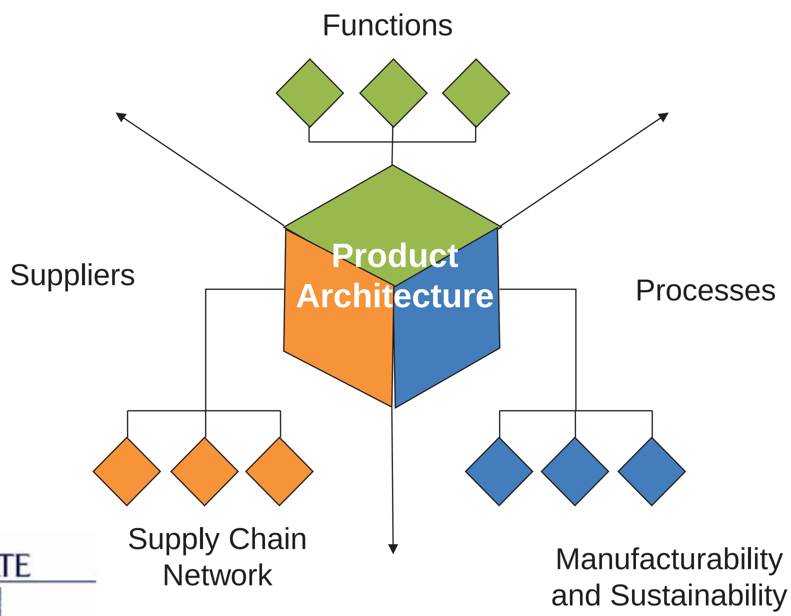
Integrated View

Product architecture should be decided for its broader implications on product functions, its manufacturing and supply chain



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Lessons Learned

1. Product architecture & supply chain should be optimized simultaneously
2. Realistic case studies show that cost, lead time and carbon footprint minimization goals favor different type of product architectures
3. Existing modularity methods favor different performance measures
4. Robust modularity methods need to be developed to optimize life cycle costs & a proposed approach

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Lesson 1. Product architecture & supply chain should be optimized simultaneously

Bicycle case study developed in collaboration with input/data from industry

- Content expertise pertaining to the components & assembly relations
- Supplier data and locations
- Part data (material, dimensions, cost, etc.)

Software architecture used to minimize bias in generating conceptual designs

- Uses functional decomposition of a product to build the product from bottom-up
- Energy-Material-Signal Diagram defines flows
- Generated designs are modularized based on Decomposition Approach, Design for Assembly filtering is used.

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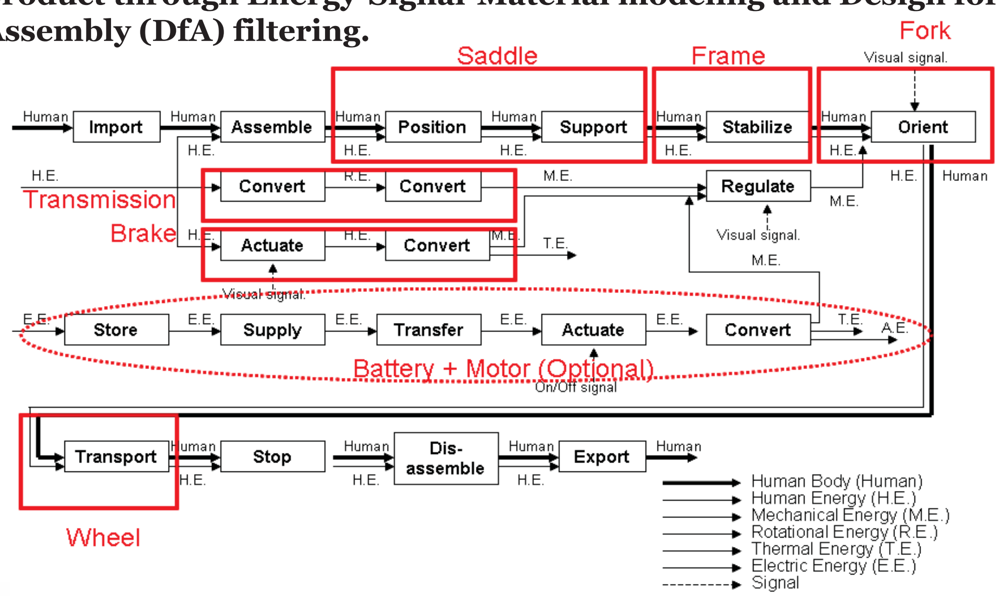
Unbiased experimentation requires automated generation of all design variants. This is accomplished through conceptualizing the product through Energy-Signal-Material modeling and Design for Assembly (DfA) filtering.



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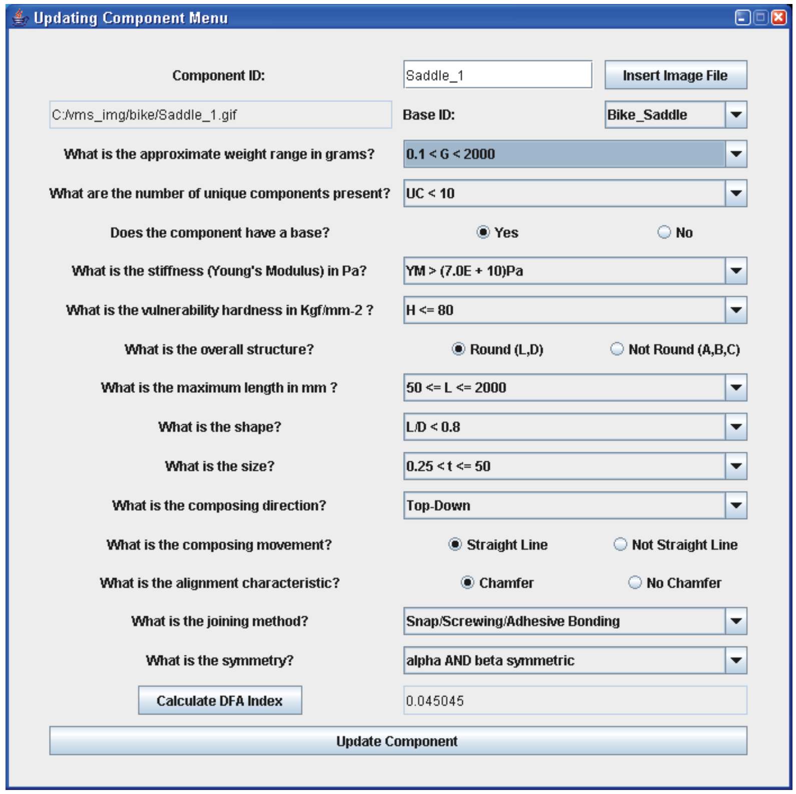
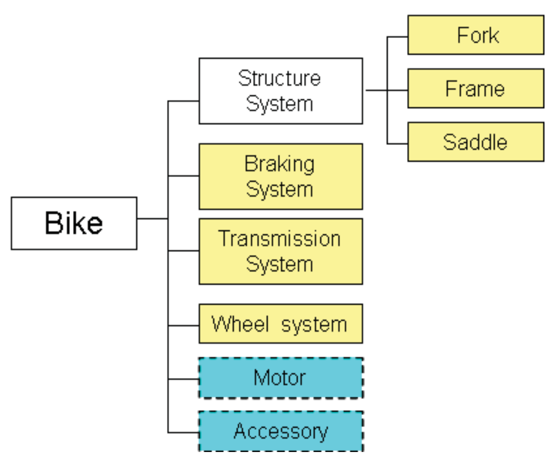
DfA filtering involves the following criteria:

1)weight, 2) number of unique component, 3) stiffness, 4) length, 5) presence of the base component, 6) vulnerability hardness, 7) shape, 8) size, 9) composing movement, 10) composition direction, 11) symmetry, 12) alignment, and 13) joining method.

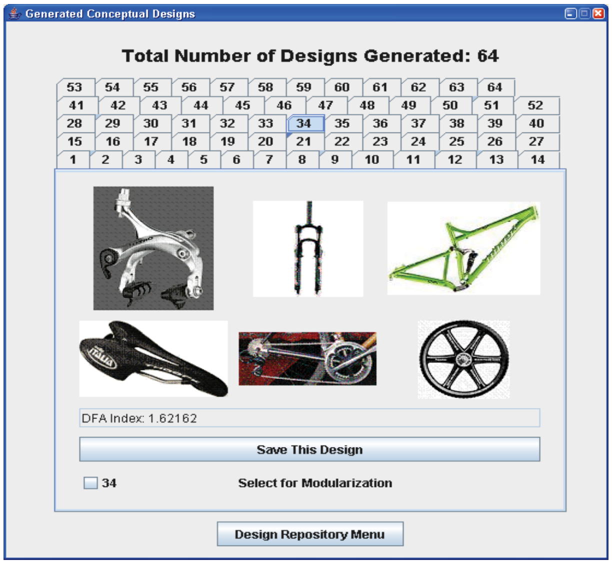


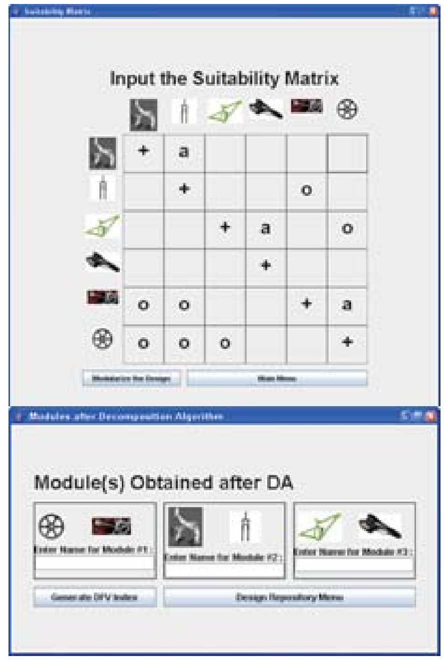
Road Bicycle Design

- Sample case, medium complexity
- 6 components with two alternatives
- Yields 64 design combinations with various DfA scores



Concept generation & Modularization Completed in a Dedicated Software Environment





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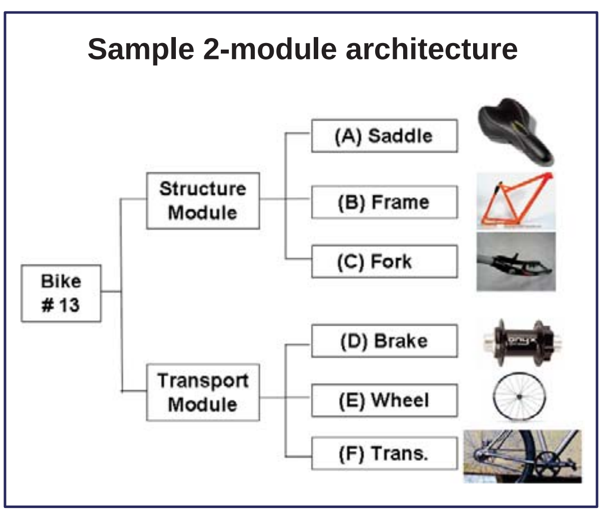
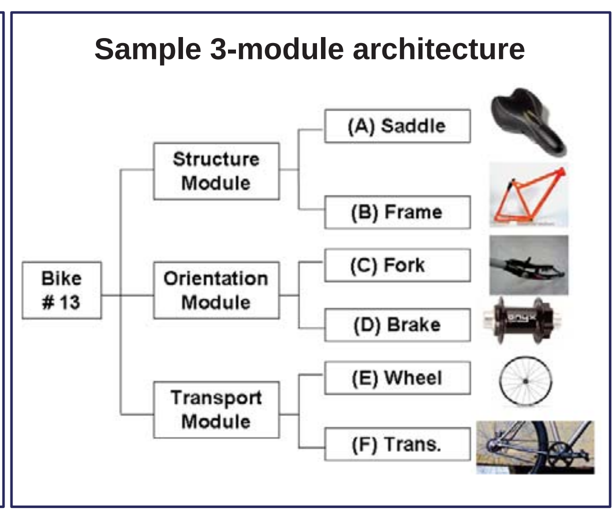
Gupta, S. and Okudan, G. (2008). “Computational Modularized Conceptual Designs with Assembly and Variety Considerations”, **Journal of Engineering Design**, Vol. 19, No. 6, December, pp. 533 - 551.

Sample Design Combinations





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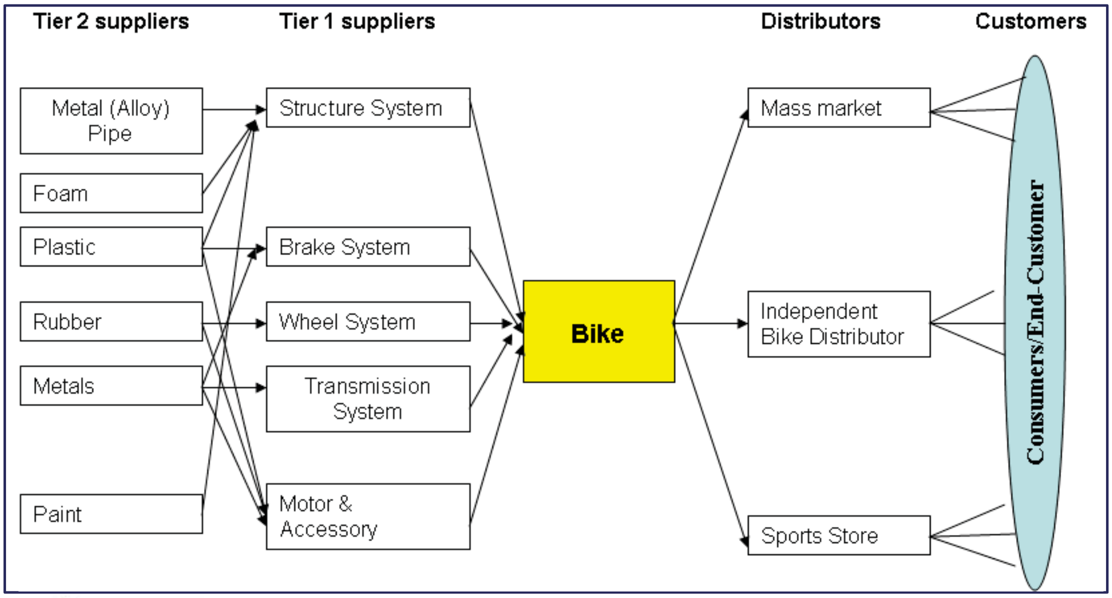
Supply Chain Structure



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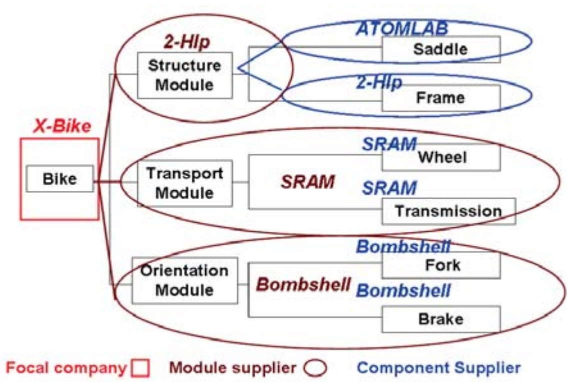
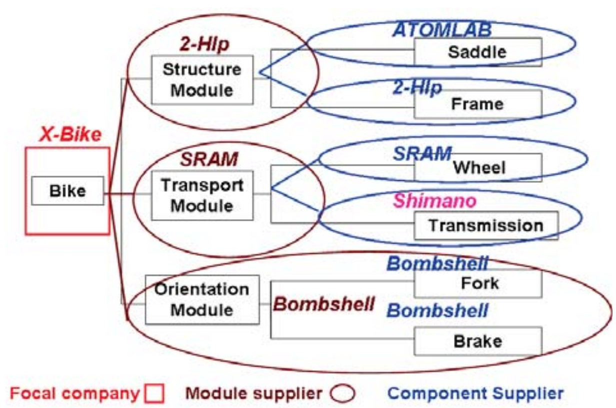
Supplier Optimization for Specific Designs



B13



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Mixed Integer Programming for Centralized Supply Chain Optimization

Objective Function

Min [Process costs (*C1*) + Transportation cost(*C2*) + Inventory cost(*C3*)]

Subject to

1) Upstream and downstream loading balance
2) Product architecture module
3) For each component, select one component supplier
4) For each module, select one module supplier
5) For final product, select one final supplier
6) Time constraint from decision maker
7) Cost constraints from decision maker

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Chiu, M-C. and Okudan, G.E 2011 "An Integrative Methodology for Product and Supply Chain Design Decisions at the Product Design Stage", ASME **Journal of Mechanical Design**, Vol. 133, pp. 0211008-1-15.

Measures	Only Design is Considered	Both Design & Supply Chain are considered
Component Cost ($USD)	500.60	500.60
Assemble Cost ($USD)	39.00	31.00
Transportation Cost ($USD)	53.23	34.13
Inventory Cost ($USD)	15.42	15.19
Total Cost ($USD)	**608.25**	**580.92**
Diff	**4.70%**	
Total Lead Time (days)	159.5	128.2
Diff	**24%**	
Number of suppliers	**9**	**8**

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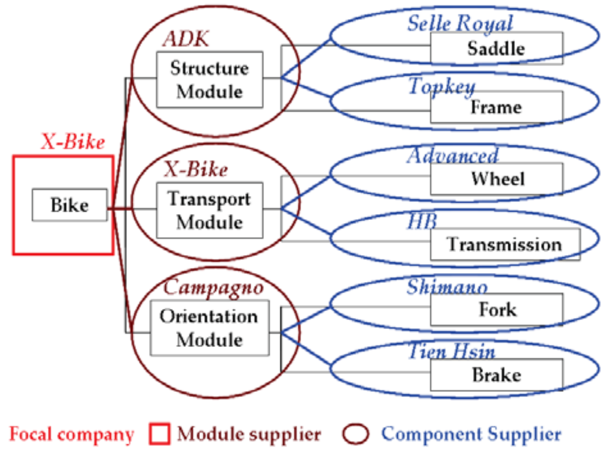
Chiu, M-C. and Okudan, G.E 2011 "An Integrative Methodology for Product and Supply Chain Design Decisions at the Product Design Stage", ASME **Journal of Mechanical Design**, Vol. 133, pp. 0211008-1-15.

Part Type	Supplier (Process #)
ABCDEF	X-bike(2)
ABC	
DEF	
AB	ADK(8)
BC	
CD	X-bike(10)
EF	Campagno(11)
A	Selle Royal(12)
B	Topkey(13)
C	Advanced(14)
D	HB(15)
E	Shimano(16)
F	Tien Hsin(17)



Optimum Solution for the case where only design is considered

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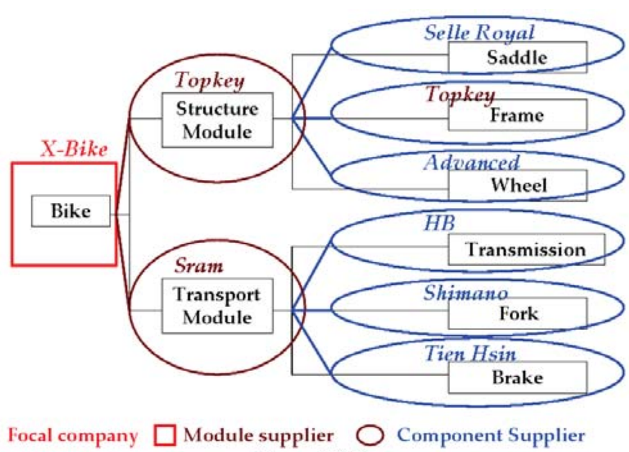
Part Type	Supplier (Process #)
ABCDEF	X-bike(1)
ABC	Topkey(3)
DEF	Sram(4)
AB	
BC	
CD	
EF	
A	Selle Royal(12)
B	Topkey(13)
C	Advanced(14)
D	HB(15)
E	Shimano(16)
F	Tien Hsin(17)



Phase II (b)

Optimum Solution for the case where both design & supply chain are considered

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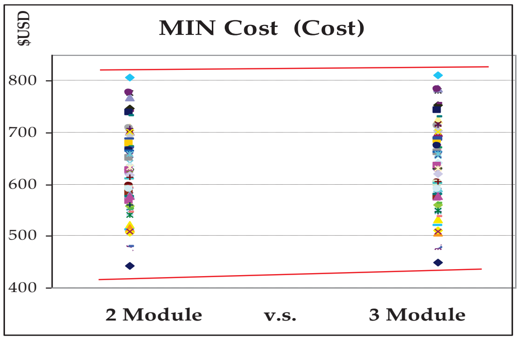
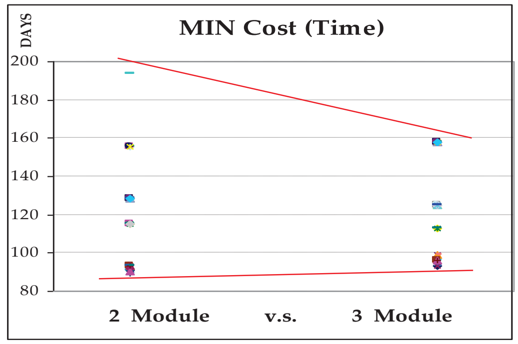
2-Module Versus 3-Module Product Architecture in MIP





	Cost($USD)		Time (Day)	
	2 module_ Cost	3 module_ Cost	2 module_ Time	3 module_ Time
Avg.	627.02	631.55	120.88	135.30
Diff	-	1%	-	12%
STD	84.630	86.351	21.983	24.823

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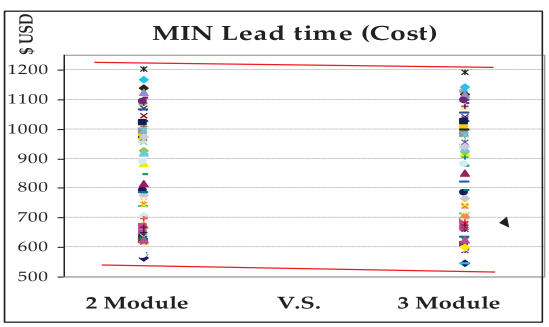
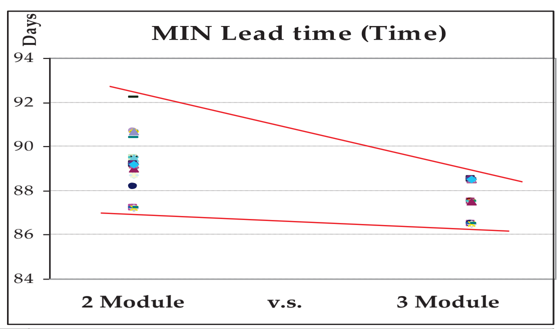
Does modularity level impact the design performance?

2-Module Versus 3-Module Product Architecture in MIP





	Cost($USD)		Time (Day)	
	2 module	3 module	2 module	3 module
Avg.	851.42	852.17	89.14	88.13
Diff	-	0.09%	-	-1.13%
STD	186.859	187.045	0.958	0.701

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Chiu, M-C. and Okudan, G.E. 2014 "An Investigation on the Impact of Product Modularity Level on Supply Chain Performance Metrics: An Industrial Case Study", **Journal of Intelligent Manufacturing**, 25(1), pp. 129-145.

Lesson 1. Product architecture & supply chain should be optimized simultaneously

- The difference of supply chain consideration 5% in cost and 24% in lead time.
- The influence of modularity:
  - 2-module architecture dominates in MIN Cost condition,
  - 3-module is superior in time in MIN Lead time condition.

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Chiu, M-C., and Okudan, G.E. (2013). "An Investigation on Centralized and Decentralized Supply Chain Scenarios at the Product Design Stage to Increase Supply Chain Performance", **IEEE Engineering Management**, in press.

Lesson 2. Cost, lead time and carbon footprint minimization goals favor different type of product architectures

- Previous work
  - Included cost and lead time
  - Design for Assembly (DfA) rankings
  - Product architecture and modularity
- Previous work is expanded to include kg CO_2 equivalent as a sustainability metric accounting for:
  - Material extraction
  - Material processing
  - Transportation

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Components and Supplier Options

Component	Type 1	Type 2
Saddle	Comfortable saddle	Light weight saddle
Frame	Steel frame w/ suspension	Steel frame w/ suspension
Fork	Steel fork w/o suspension	Steel fork w/ suspension
Transmission	Single speed transmission	Transmission w/ six fly wheels
Brake	Reverse brake rotor	Braking system with brake shoes
Wheels	Wheels w/ steel spokes	Wheels w/ plastic spokes

Supplier	Location
2-Hip	CA, USA
BBB	Holland
Bombshell	CA, USA
ATOM LAB	CA, USA
Axxis	CA, USA
SRAM	IL, USA
Velo	Taiwan
Tektro	Taiwan
Shimano	Japan
ALEX	Taiwan
Spinner	Taiwan
Falcon	Taiwan

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Analysis Tools

- **SimaPro LCA software** used to calculate kg CO_2 equiv. for materials, processing, and transportation
  - **Life cycle inventory:** *ecoinvent* database
  - **Impact assessment:** *IPCC 2007 GWP 20a V1.02*
- **LINGO software** used to find the combination of components, suppliers, and product architecture using non-linear programming to optimize:
  - Cost
  - Lead time
  - Sustainability

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Example: Actual Processes to Produce Steel Fork

No.	Process	Description
10	Pipe cutting	Cut the pipes to form the fork blade and steering tube
20	Machining to precise dimension	For the tips which connect fork and wheel
30	Welding	Weld the tubes and tips together
40	Sanding	Polish the surface of fork
50	Heat treatment	Restore metal to its original condition
60	Painting	Create a more finished appearance and protect the fork.

Fork Materials and Processes for Life Cycle Inventory

Part	Material	Weight (Kg)
Fork	Steel, low-alloyed, at plant/RER U	1.105
	Alkyd paint, white, 60% in H2O, at plant/RER U	0.05

Part	SimaPro	Weight (Kg)
Fork	Drawing of pipes, steel/RER U	1.095
	Steel product manufacturing, average metal working/RER U	1.105
	Sheet rolling, steel/RER U	0.01

Sustainability: Material Compositions

Material mass (kg)	B13	B54	SimaPro Process (*ecoinvent* database)
Medium carbon steel components (e.g., frame, fork)	7.5294	5.3464	Steel, low-alloyed, at plant/RER U
Alloy and stainless steel components (e.g., bearings)	2.47	2.784	Steel, electric, chromium steel 18/8, at plant/RER U
Composite nylon wheels		1.88	Nylon 66, glass-filled, at plant/RER U
Rubber components (e.g., tires and brake pads)	1.52	1.554	Synthetic rubber, at plant/RER U
Saddle support structure (shell)	0.41	0.4	Polypropylene, granulate, at plant/RER U
Saddle cover	0.08	0.07	Polyvinylchloride, suspension polymerised, at plant/RER U
Saddle padding	0.033	0.024	Polyurethane, flexible foam, at plant/RER U
Saddle thread	0.006	0.006	Viscose fibres, at plant/GLO U
Paint	0.06		Alkyd paint, white, 60% in H2O, at plant/RER U
Saddle glue	0.02		Acrylic binder, 34% in H2O, at plant/RER U

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Sustainability: Manufacturing Process

Mass (kg) or Length (m) processed	B13	B54	SimaPro Process (*ecoinvent* database)
Steel component manufacturing (e.g., sprocket cutting/assembly)	9.9994	8.238	Steel product manufacturing, average metal working/RER U
Tube drawing (e.g., frame tubes)	4.9114	4.0254	Drawing of pipes, steel/RER U
Injection molding (e.g., saddle shell and tires)	1.93	3.834	Injection moulding/RER U
Wire drawing (e.g., springs and spokes)	0.54	0.775	Wire drawing, steel/RER U
Forming of medium carbon steel flat stock (e.g., for brackets)	1.044	0.546	Sheet rolling, steel/RER U
Forming of alloy/stainless steel flat stock (e.g., for sprockets)	1.38	0.035	Sheet rolling, chromium steel/RER U
Welding of frame (estimated overall weld length)	1 (m)	1 (m)	Welding, gas, steel/RER U

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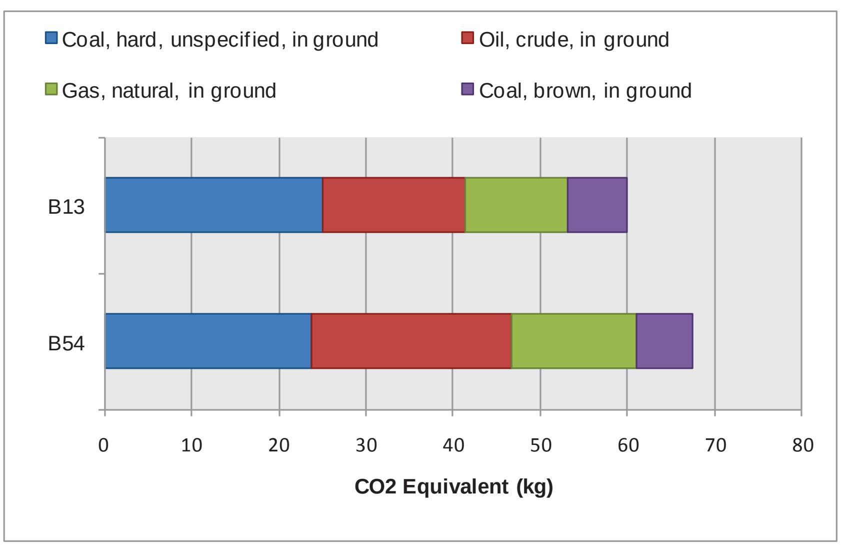
Sustainability - Comparison of carbon footprint



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Graph shows the carbon footprint difference of two design variants

Mathematical Model

Objective Function

Min [Processing (*MPCF*) + Transportation (*TCF*)]

Decision Variables
MPCF – Carbon footprint for manufacturing and processing the chosen components
TCF – The total carbon footprint for transporting the chosen components, modules and assembly

parameters
MPXpi – The carbon footprint value for process p and supplier i
TLDpi – The distance travelled on land for process p and supplier i
TSDpi – The distance travelled by sea for process p and supplier i
TLDI – The carbon footprint per ton-mile travelled on land
TSDI –The carbon footprint per ton-mile travelled by sea
CWpi – The fraction of a ton for each component or module from process p and supplier i

Optimization Results

NUMERICAL RESULTS

Optimizing (Minimizing)	Cost (US Dollars)	Lead Time (Days)	Carbon Footprint (kg CO2 eq.)
Cost	**83.74**	54.20	60.48
Lead Time	109.3	**38.80**	65.85
Carbon Footprint	99.94	172.80	**44.18**

COST: Product Architecture

Part or Module	Supplier	Location
ABCDEF	X-Bike	PA, USA
AB	2 Hip	CA, USA
CD	SRAM	IL, USA
EF	BBB	Holland
(A) Saddle	ATOM LAB	CA, USA
(B) Frame	2 Hip	CA, USA
(C) Fork	X-Bike	PA, USA
(D) Brake	SRAM	IL, USA
(E) Wheel	BBB	Holland
(F) Trans.	BBB	Holland

Optimization Results - 2

LEAD TIME

Part or Module	Supplier	Location
ABCDEF	X-Bike	PA, USA
ABC	X-Bike	PA, USA
DEF	ATOM LAB	CA, USA
EF	Shimano	JAPAN
(A) Saddle	ATOM LAB	CA, USA
(B) Frame	Axxis	CA, USA
(C) Fork	X-Bike	PA, USA
(D) Brake	SRAM	IL, USA
(E) Wheel	Shimano	Japan
(F) Trans.	BBB	Holland

CARBON FOOTPRINT

Part or Module	Supplier	Location
ABCDEF	X-Bike	PA, USA
ABC	X-Bike	PA, USA
DEF	BBB	Holland
(A) Saddle	BBB	Holland
(B) Frame	X-Bike	PA, USA
(C) Fork	SRAM	IL, USA
(D) Brake	BBB	Holland
(E) Wheel	ATOM LAB	CA, USA
(F) Trans.	BBB	Holland

Lesson 2. Cost, lead time and carbon footprint minimization goals favor different type of product architectures

- Optimization results point to different product architectures for cost, lead time and CF
- Development of computational artificial intelligence is needed to:
  - Analyze more complex products
  - Exploit objective tradeoffs
  - Improve customization for products

Olson, E., Okudan, G. E., Chiu, M-C., Haapala, K. R. (2011) “Positioning Product Architecture As the Driver for Carbon Footprint & Efficiency Trade-offs in A Global Supply Chain”, 4th International Conference on Industrial Engineering and Systems Management (IESM 2011), Metz, France.

Olson, E., Haapala, K. and Okudan, G.E. "Integration of Sustainability Issues during Early Design Stages in a Global Supply Chain Context", AAAI Spring Symposium Series, March 21–23, 2011, at Stanford University, Stanford, CA.

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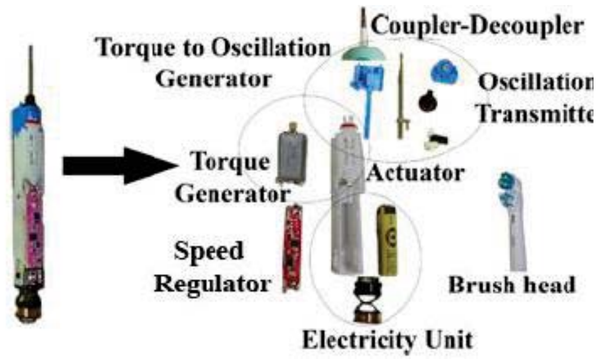
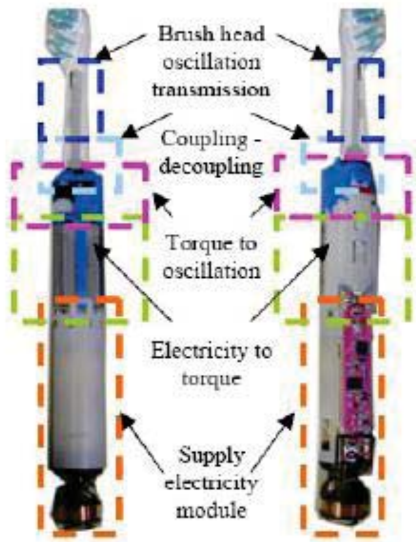
Lesson 3. Existing modularity methods (logic) favor different performance measures





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Modularity has implications on:

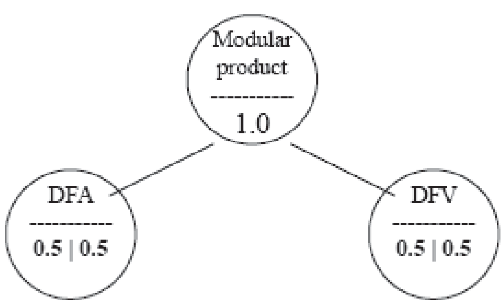
- **Disassembly**
  - Standard time
  - Energy
  - Geometrical constraint
  - Accessibility & Positioning
- **Recycle/reuse/ Disposal**
  - Component classification
  - Life Cycle spanning
  - Recycling methods
  - Material compatibility
  - Special handling
  - Material classification
- **Material selection**
  - Material properties
  - Material compatibility
  - Hazardous material
  - Federal/local regulations
- **Serviceability**
  - Reliability factors
  - Repair factors
  - Human factors
  - Facility factors

We applied Stone et al.'s approach (FHM), Zhang et al.'s approach (B-FES), and Huang and Kusiak's (DA) for modularity on the same product.

Stone et al.'s approach					
Modules	**Supply electricity**	**Electricity to torque**	**Torque to oscillation converter**	**Coupling – decoupling**	**Brush-head Oscillation transmission**
Units	Electricity unit	Torque generator	Oscillation generator	Coupling – decoupling unit	Oscillation transmitter
	Actuator				
	Speed regulator				

Zhang et al.'s approach			
Modules	**Electricity - actuation**	**Electricity to oscillation transmission**	**Brush head coupling**
Units	Electricity unit	Speed regulator	Coupling-decoupling unit
		Electricity to Torque converter	
	Actuator	Torque to Oscillation converter	
		Oscillation transmitter	

Huang and Kusiak's approach		
Modules	**Electricity - Oscillation**	**Brush head oscillation transmission**
Units	Electricity unit	Oscillation generator
	Actuator	
	Speed regulator	Coupler-Decoupler
	Electricity to Torque converter	Oscillation transmitter



	Electricity/ Oscillation	Brush Head / Oscillation transmission
Weight (g)	1	1
Cost (S)	3	3
Battery Life (weeks)	3	
Decibels (dB)	1	1
Compatibility		3

Alternative	DFA Index
FHM	17.82
B-FES	10.8
DA	8.64

The final values for the three concepts are: 12.32 for DA, 14.40 for B-FES, and 23.41 for FHM.

Based on these results, we observe that the DA is better in comparison to B-FES and FHM approaches with regards to DfA and DfV index values.

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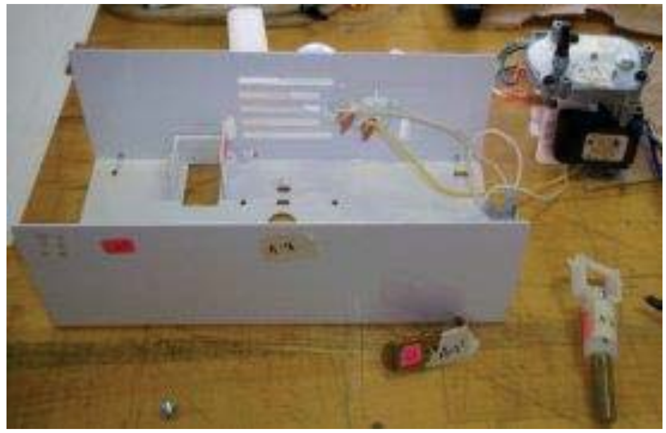
Okudan, G.E. and Gupta, S. (2013). "Analysis of Modularity Implementation Methods from an Assembly and Variety Viewpoint", **International Journal of Advanced Manufacturing Technology**, 6(9), pp. 1959-1976.

	Reuse	Recycle	Disposal
Reuse	Strongly desired	Desired	Strongly undesired
Recycle	Desired	Strongly desired	Undesired
Disposal	Strongly undesired	Undesired	Strongly desired

Can we modularize for sustainability?



Comparison of DA & Multivariate Clustering

Module	**DA** (component numbers within module)	**Carbon Footprint** (**465.66** kg CO2 eq.)	**MC(I)** Interaction weight 0.35; End of life weight 0.65	**Carbon Footprint** (**461.53** kg CO2 eq.)	**MC(II)** Interaction weight 0.65; End of life weight 0.35	**Carbon Footprint** (**466.16** kg CO2 eq.)
1	1, 2, 3, 4, 5, 6	25.2	1, 2, 3, 4, 6	21.2	1, 2, 3, 4, 5, 6	25.2
2	7, 8, 9, 10, 11	30.8	5, 10	0.01	7, 8, 9, 10, 11	30.8
3	12, 13, 26	323	7, 8, 9, 11	30.5	12, 13,	321
4	14	13.6	12, 13, 14, 20, 21, 22, 26	352.6	14, 21, 22	24.3
5	15, 16, 17, 18	40.3	15, 16, 17, 23	40.3	15, 16, 17	37.7
6	20	6.07	18	1.72	18	1.72
7	21, 22	9.03	19, 24, 25	15.2	19, 23, 24, 25	17.7
8	23, 24	3.26			20, 26	7.74
9	19, 25	14.4				

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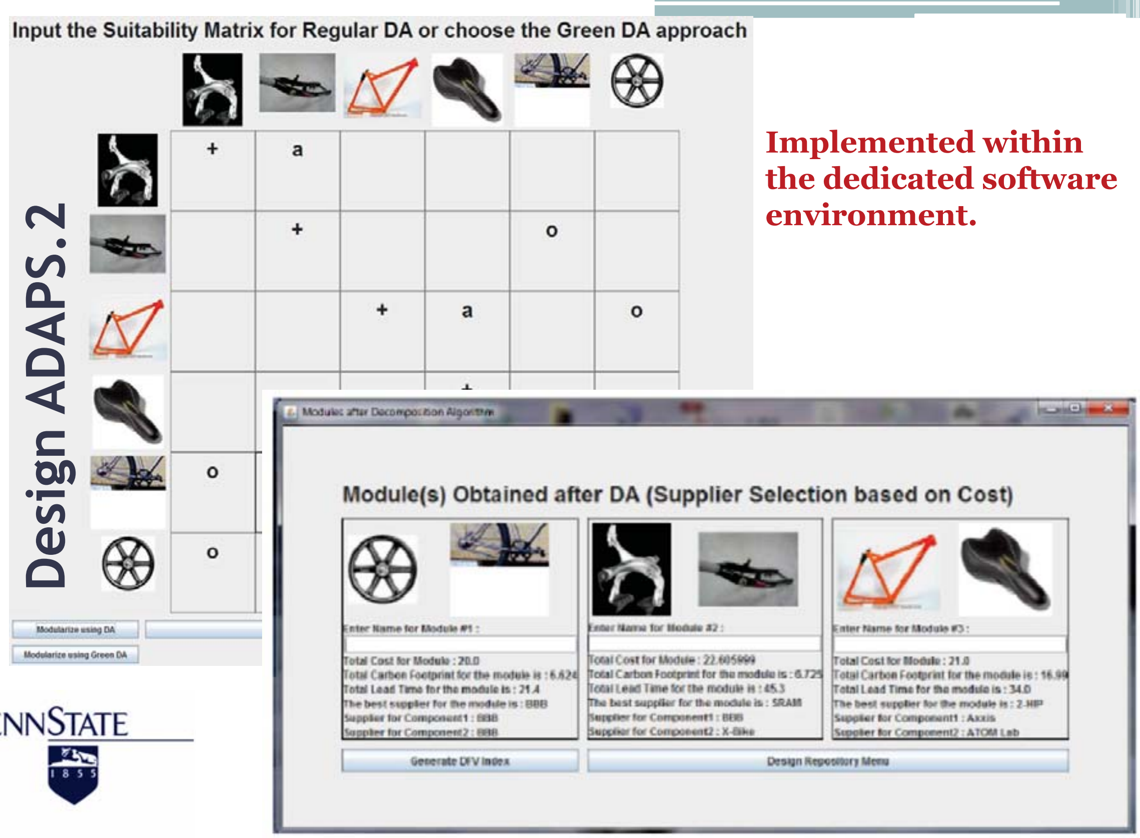
Results show reduction in carbon footprint.

Comparison of DA & Multivariate Clustering

Module	DA	Module End of Life	MC(I)	Module End of Life	MC(II)	Module End of Life
1	1, 2, 3, 4, 5, 6	Recycle/Disposal	1, 2, 3, 4, 6	Recycle	1, 2, 3, 4, 5, 6	Recycle/Disposal
2	7, 8, 9, 10, 11	Recycle/Disposal	5, 10	Disposal	7, 8, 9, 10, 11	Recycle/Disposal
3	12, 13, 26	Recycle	7, 8, 9, 11	Recycle	12, 13,	Recycle
4	14	Recycle	12, 13, 14, 20, 21, 22, 26	Recycle	14, 21, 22	Recycle
5	15, 16, 17, 18	Recycle/Reuse	15, 16, 17, 23	Reuse	15, 16, 17	Reuse
6	20	Recycle	18	Recycle	18	Recycle
7	21, 22	Recycle	19, 24, 25	Recycle	19, 23, 24, 25	Recycle/Reuse
8	23, 24	Recycle/Reuse			20, 26	Recycle
9	19, 25	Recycle				

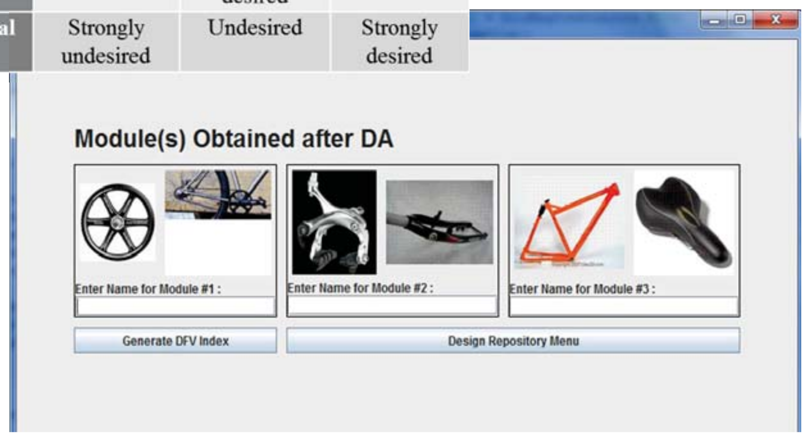
Results show easy to separate subassemblies for disposal and recycle.



Implemented within the dedicated software environment.

Implemented within the dedicated software environment.

	Reuse	Recycle	Disposal
Reuse	Strongly desired	Desired	Strongly undesired
Recycle	Desired	Strongly desired	Undesired
Disposal	Strongly undesired	Undesired	Strongly desired



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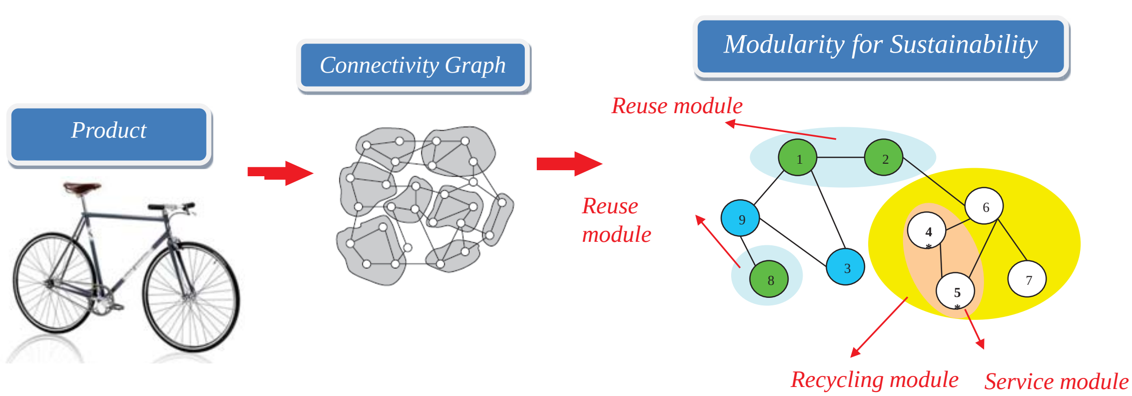
Lesson 4. Robust modularity methods need to be developed to optimize life cycle costs & a proposed approach



Integer Partition	Subset1	Subset2
[19 1]	[2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20]	[1]
[19 1]	[1 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20]	[2]
……	……	……
[19 1]	[1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 20]	[19]
[19 1]	[1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19]	[20]

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Methodology Flow

Chung, W.H., Okudan Kremer, G. and Wysk, R. (2014) Modular Design Approach to Improve Product Life Cycle Performance Based on the Optimization of a Closed-Loop Supply Chain", **ASME Journal of Mechanical Design**

Step1 — Construct a connectivity graph for the product based on component interactions and component attributes

Step2 — Construct a universal supply chain (SC) optimization model for possible modular structures

Step3 — Form an initial modular structure on the connectivity graph

Step4 — Use the SC model to evaluate the initial modular structure

Step5 — Use the heuristic based on the output of SC model to generate promising modular structures for evaluation

Step6 — Use the SC model to evaluate the promising modular structures generated

Can the objective value be improved?

Yes → Step7 — Update the modular structure with the one having the min. value

No → A near-optimal modular structure

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Connectivity Graph

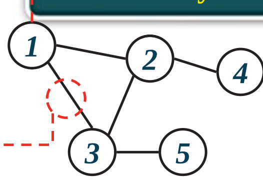
Component Attributes (Vertices)

Vertex/ Component	Mfg. cost ($)	Mfg. energy (kWh)	Weight (g)	MTBF (month)	Reuse value ($)	Recycling value ($)	End-of-life option	Service intent
Component 1	19.10	8.3	2693	336	19.2	0.78	RU/RC/D	Y/N

RU: Reuse
RC: Recycling
D: Disposal

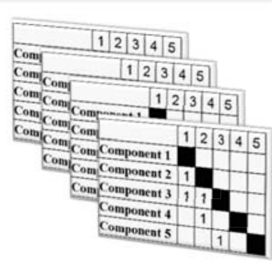
Product

Connectivity Graph



Or

Design Structure Matrix



Component Interactions (Edges)
Function relationship
Joining relationship
Disjoining relationship

Edge /Interaction	Function	Manufacturing		Service				Retirement	
		Assembly time (sec)	Assembly cost ($) /energy (kWh)	Assembly time (sec)	Assembly cost ($) /energy (kWh)	Disassem. time (sec)	Disassem. cost ($) /energy (kWh)	Disassem. time (sec)	Disassem. cost ($) /energy (kWh)
Component 1- Component 3	1	20	0.184 /0.15	20	0.084 /0.07	20	0.084 /0.07	20	0.084 /0.07

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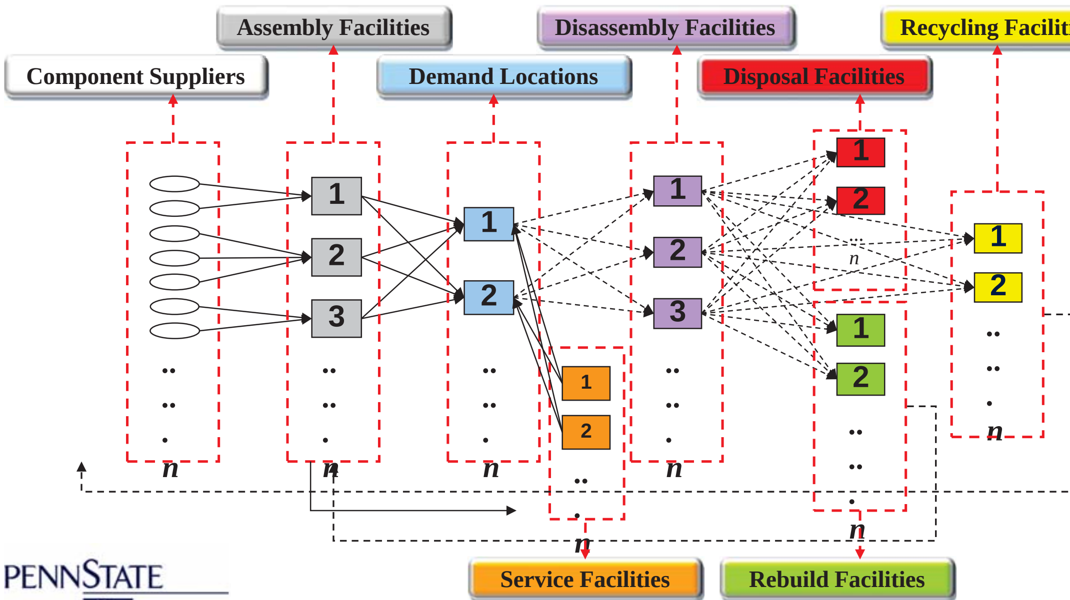
Closed-Looped Supply Chain Network



Formulation of the Supply Chain Optimization Model

Objective

$$Min \quad Z_{LCC}$$

$$Min \quad Z_{LCEC}$$

where

Z_{LCC} *the life cycle cost in the supply chain ($)*

Z_{LCEC} *the life cycle energy consumption in the supply chain (kWh)*

Constraints

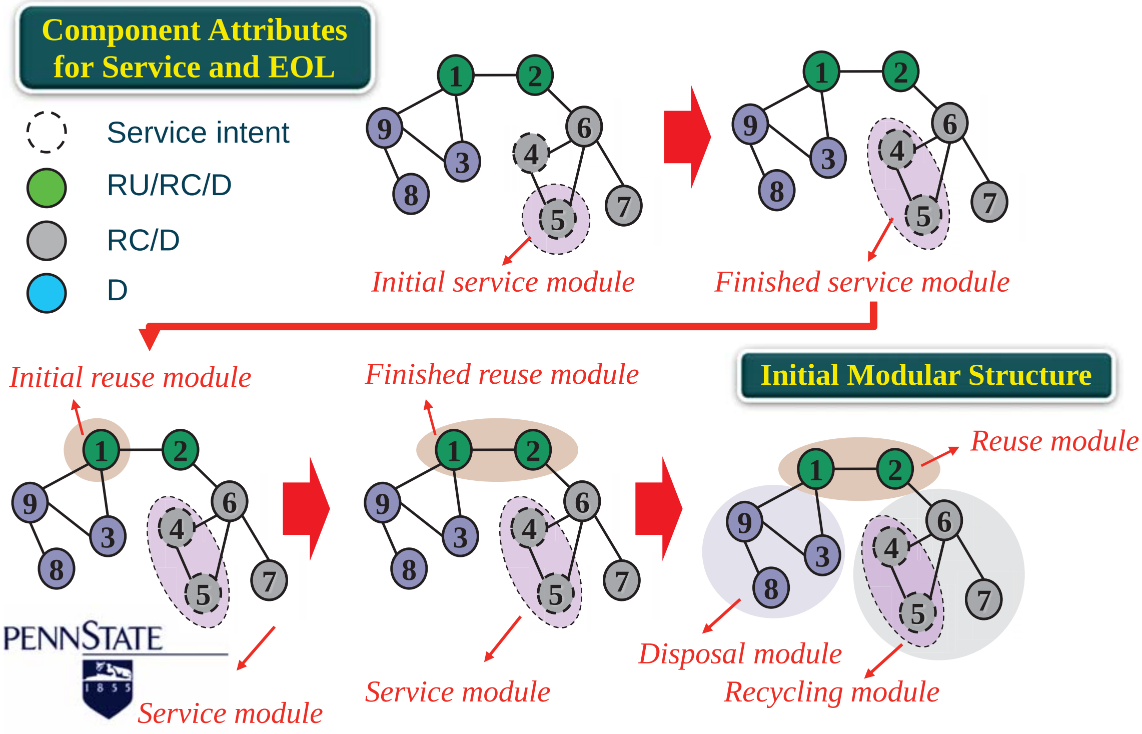
Forward Logistics Balance (Pull)

Σoutbound product/module flow from the facilities in the forward flows= Σinbound component/module/product flow to the facilities in the forward flows

Reverse Logistics Balance (Push)

Σoutbound module flow from the facilities in the reverse flows= Σinbound component/module/product flow to the facilities in the reverse flows

Formation of an Initial Modular Structure



The Criteria for Evaluating Potential Modular Structures in Costs

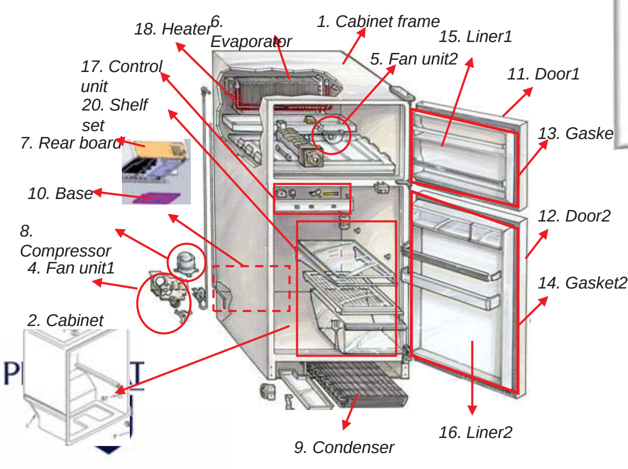
When the capacity is insufficient, the reuse/recycling value is divided by the resource required

SC conditions	Stage1: for reuse modules	Stage1: for recycling modules
SC1	$V_{rem} = \sum_k (r_{rem\,k} - C_{dk})$	$V_{rec} = \sum_k (r_{rec\,k} - C_{dk})$
SC2	$V_{rem} = \sum_k (r_{rem\,k} - C_{dk})$	$\frac{V_{rec}}{resource} = \frac{\sum_k (r_{rec\,k} - C_{dk})}{w_m}$
SC3	$\frac{V_{rem}}{resource} = \frac{\sum_k (r_{rem\,k} - C_{dk})}{t_{reb}}$	$V_{rec} = \sum_k (r_{rec\,k} - C_{dk})$
SC4	$\frac{V_{rem}}{resource} = \frac{\sum_k (r_{rem\,k} - C_{dk})}{t_{reb}}$	$\frac{V_{rec}}{resource} = \frac{\sum_k (r_{rec\,k} - C_{dk})}{w_m}$
SC5	$\frac{V_{rem}}{resource} = \frac{\sum_k (r_{rem\,k} - C_{dk})}{t_d}$	$V_{rec} = \sum_k (r_{rec\,k} - C_{dk})$
SC6	$\frac{V_{rem}}{resource} = \frac{\sum_k (r_{rem\,k} - C_{dk})}{t_d}$	$\frac{V_{rec}}{resource} = \frac{\sum_k (r_{rec\,k} - C_{dk})}{w_m}$
SC7	$\frac{V_{rem}}{resource} = \frac{\sum_k (r_{rem\,k} - C_{dk})}{t_d + t_{reb}}$	$V_{rec} = \sum_k (r_{rec\,k} - C_{dk})$
SC8	$\frac{V_{rem}}{resource} = \frac{\sum_k (r_{rem\,k} - C_{dk})}{t_d + t_{reb}}$	$\frac{V_{rec}}{resource} = \frac{\sum_k (r_{rec\,k} - C_{dk})}{w_m}$

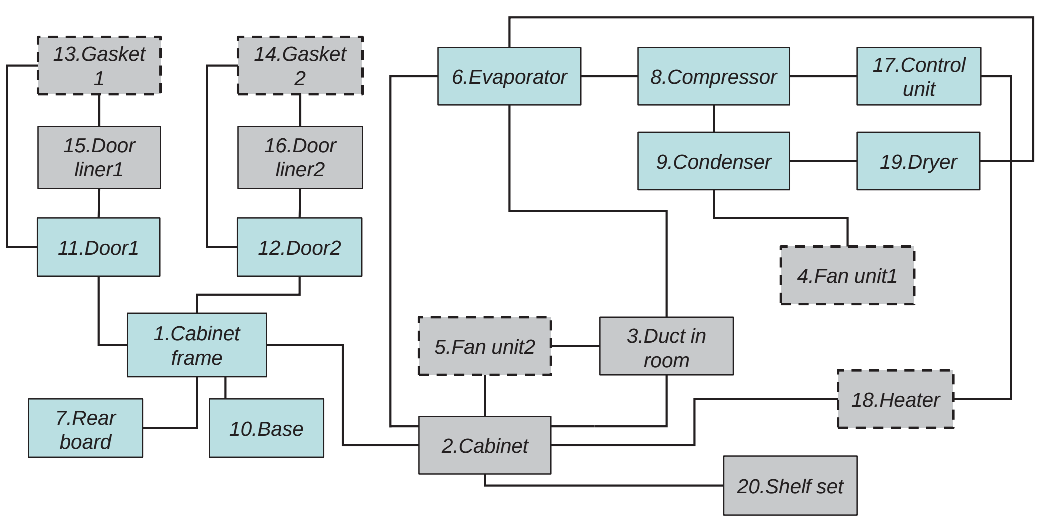
k the index of the module affected by the module assignment
V_{rem} the total value affected by the module assignment of a reuse component
$r_{rem\,k}$ the return of module k affected by the module assignment of a reuse component
C_{dk} the disassembly cost of module k affected by the module assignment
t_{reb} the rebuild time of modules affected by the module assignment of a reuse component
t_{dk} the disassembly time of modules affected by the module assignment of a reuse component
V_{rec} the total value affected by the module assignment of a recycling component
$r_{rec\,k}$ the return of module k affected by the module assignment of a recycling component
w_m the weight of modules affected by the module assignment of a recycling component

Numerical Examples: Refrigerator & Coffee Maker

- The product data set for the refrigerator is based on data from Umeda et al.'s work (2000) and is supplemented by data from websites.
- The data set for the coffee maker (Product Model: Mr. Coffee PR15) is based on product dissection and supplemented by the literature.



Connectivity Graph of the Refrigerator



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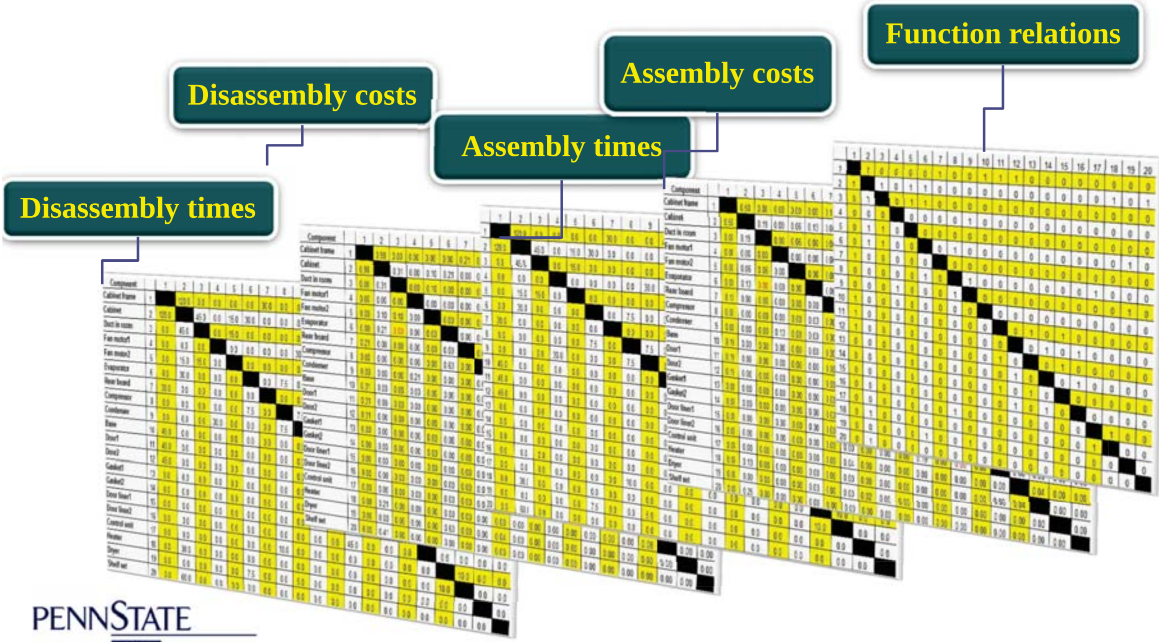
Component Interactions in DSM



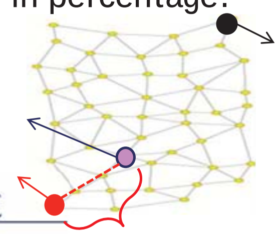
Processing Facilities

Process	Process description	Location
P1	Product and module assembly	F1, F2, F3
P2	Service (maintenance)	F4, F5
P3	Product collection and disassembly	F6, F7
P4	Module inspection and rebuild	F8, F9
P5	Material recycling	F10, F11
P6	Disposal	D1, D2

Criteria for the Performance of SCEM

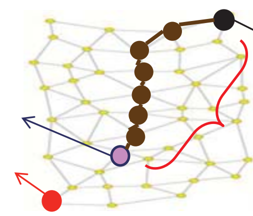
Effectiveness

Effectiveness refers to how good the quality of the modular structure found by ASCEM is. It indicates how far the life cycle performance (LCC or LCEC) of the modular structure is from the true optimal modular structure, and is measured by LCC or LCEC difference in percentage.



Efficiency

Efficiency refers to how quickly a near-optimal modular structure can be found and is measured by the number of iterations taken by the supply chain optimization model to reach the near-optimal modular structure.



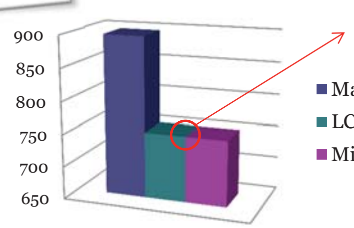
Performance of ASCEM - Refrigerator

Effectiveness

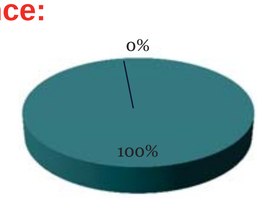
Efficiency

Modular Structures for LCC

LCC Comparison

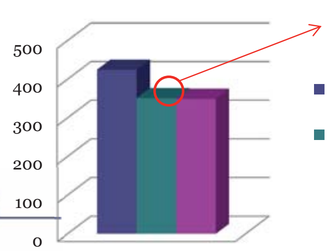


Iteration Comparison

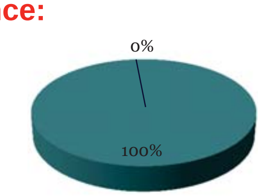


Modular Structures for LCEC

LCEC Comparison



Iteration Comparison

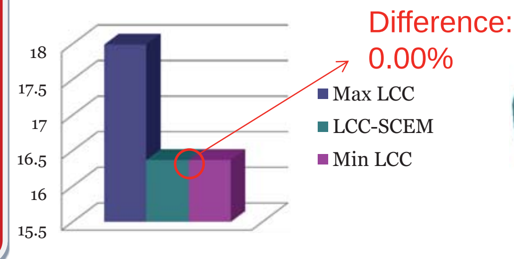


Performance of ASCEM - Coffee Maker

Modular Structures for LCC

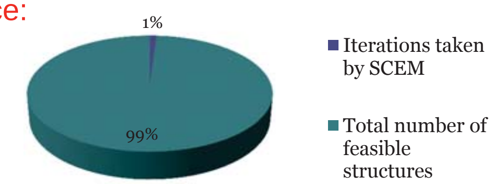
Effectiveness

LCC Comparison



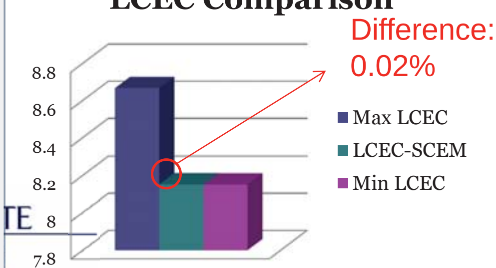
Efficiency

Iteration Comparison

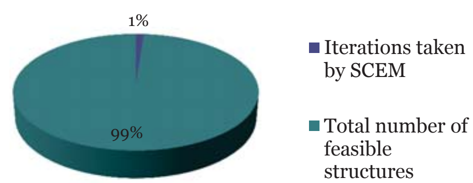


Modular Structures for LCEC

LCEC Comparison



Iteration Comparison

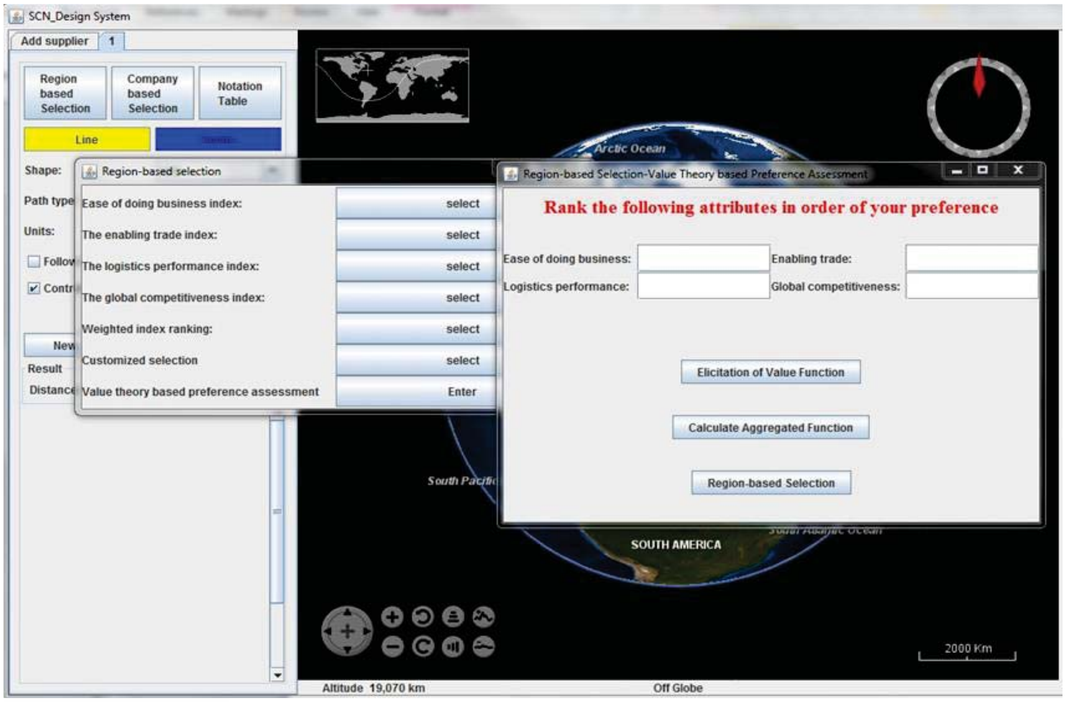


Lesson 4. Robust modularity methods should be developed to optimize life cycle costs

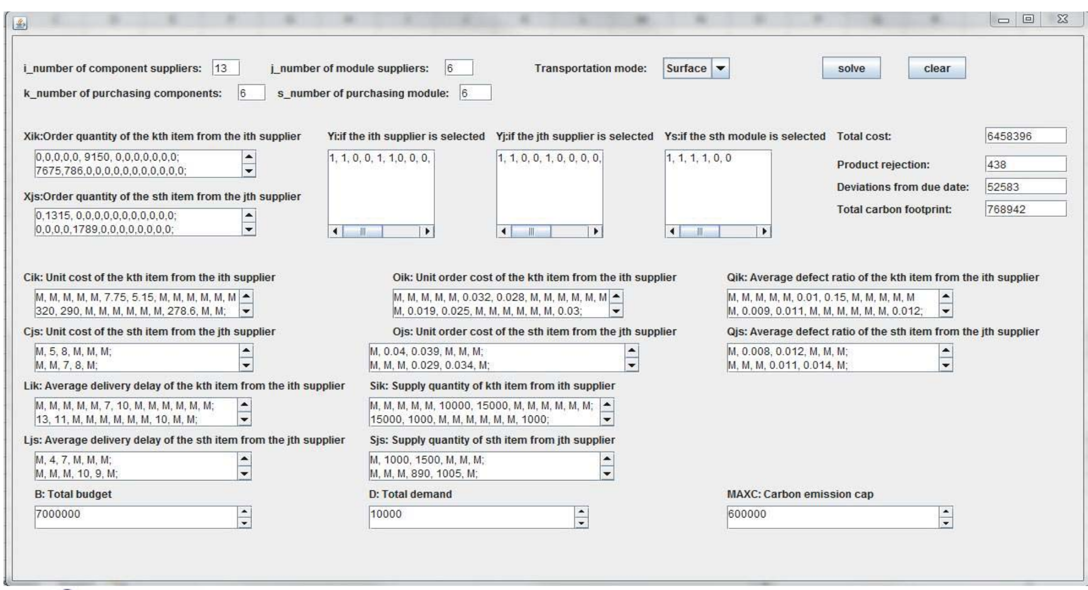
Category	Small products	Large product
Tested product	Coffee maker	Refrigerator
Number of vertices (components)	11	20
Number of edges (interactions)	13	25
LCC-ASCEM	16.37	751.72
Min LCC	16.37	751.48
Effectiveness: Difference%	0%	0.03%
Max LCC	17.99	896.28
Efficiency: Iterations used	26	55
Total number of feasible structures	2,583	4,173,557
LCEC-ASCEM	8.1544	351.66
Min LCEC	8.1533	350.12
Effectiveness: Difference%	0.014%	0.44%
Max LCEC	8.67	425.2
Efficiency: Iterations used	31	86
Total number of feasible structures	2,583	4,173,557

Active Research Directions

GIS Enabled Design Architecture/Supply Chain Optimization Utilizing Open Source GIS tools and Optimization Software



Goal is to seamlessly infuse data sources into decision making (e.g., World Bank data on countries' capabilities in manufacturing, logistics, and business operations.



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Lei, T. and Okudan Kremer, G.E. "GIS-Based Hierarchical Multi-Objective Supply Chain Network Design: A Proposed Tool & Case Study", Industrial and Systems Engineering Conference (ISERC 2013), May 18-22, San Juan, Puerto Rico.

For more information on these works, contact information is provided below.

Gül E. Okudan Kremer
Professor of Engineering Design & Industrial Engineering
Fellow ASME

213T Hammond Building
University Park
The Pennsylvania State University
University Park, PA 16802

Tel: 814 8631530
Email: gkremer@psu.edu

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1855

Measurement Science for Sustainable Construction and Manufacturing

Breakout 4
Economic, Environmental, and Social Aspects

Cliff I. Davidson
Thomas & Colleen Wilmot Professor of Engineering
Director, Center for Sustainable Engineering
Syracuse University

ASCE, Reston, Virginia
June 12, 2014

Outline

Economic, Environmental, and Social Issues summarized from papers by participants of Breakout 4:

- **Individual buildings**

- **Infrastructure projects**

- **Entire urban areas**
- **Overarching issue: Changing Human Behavior**

Individual Buildings

Design → Construction → Operation & Use → Demolition

- **Ability to incorporate sustainability decreases as we move forward**
- **Previously: cost dominated design considerations. New software includes sustainability, but not used much (Athena Sust. Materials Inst.)**
- **Could apply current knowledge of sustainable product manufacturing to buildings (RFID tags to track logistics)**

Individual Buildings

- **Data collection during construction**
  - **-- Energy, materials, water, social issues**
  - **-- Embedded energy and water in materials**
- **Data collection during use phase**
  - **-- Sensors for microclimate, HVAC, lighting, electricity, appliance use, flow of people**
  - **-- Personal monitors – air quality, noise, vibrations**
  - **-- Monitors for interaction with natural environment – wind, temp, humidity, rain runoff, vegetation growth**

Individual Buildings

- Data collection during demolition
  - -- Degradation of building envelope over time
  - -- Differences in degradation for different parts of the building
  - -- Re-use, recycle building components

Infrastructure Projects

Design → Construction → Operation & Use → Demolition

- As with individual buildings, ability to incorporate sustainability decreases as we move forward
- Indicators of safety are well-established – need the equivalent for sustainability
- Need for quantifiable social sustainability metrics

Infrastructure Projects

Design → Construction → Operation & Use → Demolition

- **Need to make infrastructure more resilient**

  -- Performance of infrastructure during disasters such as severe storms, terrorist attacks, evacuation
  -- Avoiding increase in vulnerability due to human development close by – buildings adjacent to a major roadway
  -- Avoiding increase in vulnerability by not accounting for natural processes – beach erosion

Urban areas

- **Establish ability to obtain large data sets for metabolism of a city**

  -- Flows of energy, materials, water, people, information

- **Can we use such data to improve Quality of Life and resilience?**

  -- Energy balance, material balance, water balance
  -- How people are spending their time in cities: Performing services, engaged in recreation, engaged with family, etc.
  -- Health monitoring of people in cities

Urban areas

Reduce social inequity

- **Low income and minority residents in cities are generally under-represented in decision making**

  -- distrust of government
  -- language problems
  -- previously marginalized

- **Necessary for engineers to make special effort to bring these people into discussion**

Changing Human Behavior

Habits are difficult to break

- **Change requires several steps: first step is the desire to change**
- **Do most people understand the impact of their day-to-day activities?**
- **To explore the answer for one example situation, survey was conducted**
- **Questions involved estimating the energy consumption for normal household activities.**

Changing Human Behavior

Question 1:

"A 100-watt incandescent light bulb uses 100 units of energy in one hour. How many units of energy do you think each of the following devices typically uses in one hour?"

- **A compact fluorescent light bulb that is as bright as a 100-watt incandescent light bulb**
- **An electric clothes dryer**
- **A portable heater**
- **A room air conditioner**
- **A central air conditioner**
- **A dishwasher**

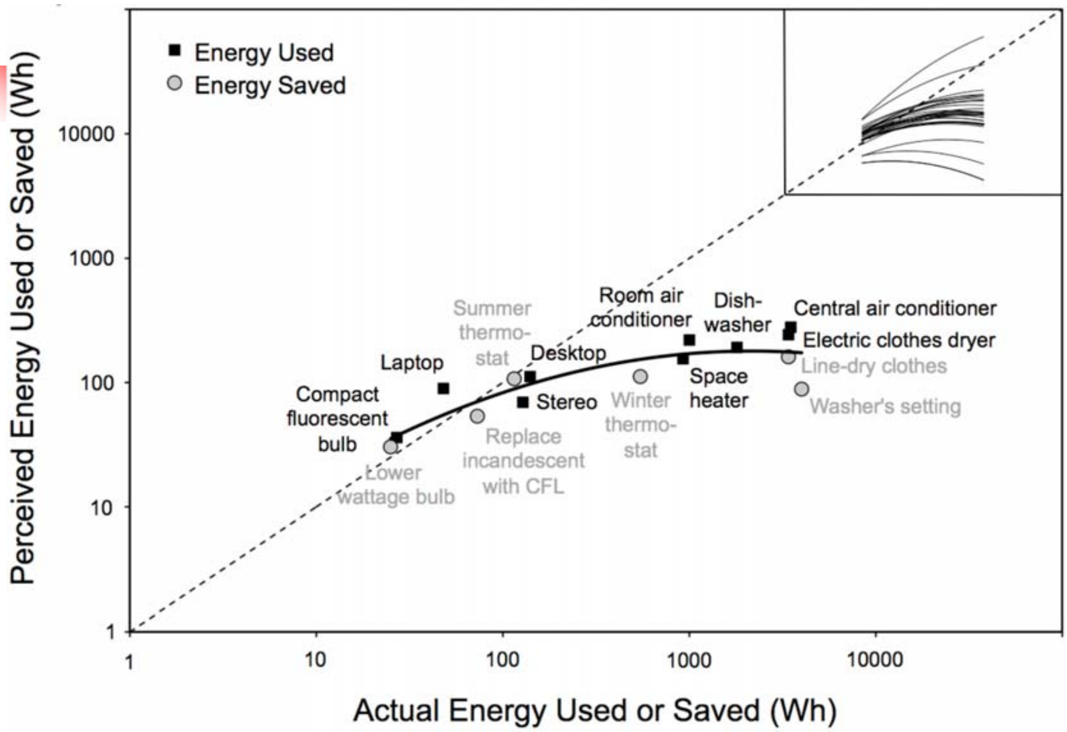
Changing Human Behavior

Question 2:

"Turning off a 100-watt incandescent light bulb for one hour saves 100 units of energy. How many units of energy do you think each of the following changes will save?"

- **Replacing one 100-watt incandescent bulb with equally bright compact fluorescent bulb that is used for one hour**
- **Replacing one 100-watt kitchen bulb with a 75-watt bulb that is used for one hour**
- **Drying clothes on a clothes line for one load**
- **Turning up the thermostat on your air conditioner by 5°F in summer**

Human perceptions of home energy use
Attari, Dekay, Davidson, Bruine de Bruin (*PNAS*, 2010)



Human perceptions of home energy use

- Perception curve is relatively flat
  - Slight overestimate for low energy appliances
  - Large underestimate for high energy appliances where perceptions are most important
- Overall perceptions show an underestimate of a factor of 2.8

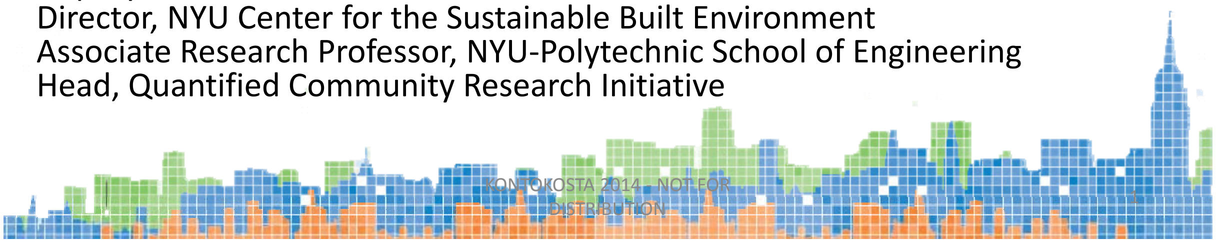
Conclusions

- We have the capability to collect large quantities of technical data, but we need to determine which technical data are most important for understanding sustainability in manufacturing and infrastructure development.
- It is much more difficult to collect data to quantify social sustainability and assess our progress.
- Achieving change in human behavior in the correct direction will require educational efforts for people understand the impacts of their activities and how to reduce them.

The Quantified Community: Measuring, Modeling, and Understanding the Urban Environment

NIST-ASCE-ASME
June 12, 2014

Dr. Constantine E. Kontokosta, PE, AICP, LEED AP, FRICS
Deputy Director, NYU-CUSP
Director, NYU Center for the Sustainable Built Environment
Associate Research Professor, NYU-Polytechnic School of Engineering
Head, Quantified Community Research Initiative



The CUSP vision includes New York City as its laboratory

The Center for Urban Science and Progress (CUSP) is a unique public-private research center that uses New York City as its laboratory and classroom to help cities around the world become more productive, livable, equitable, and resilient. CUSP observes, analyzes, and models cities to optimize outcomes, prototype new solutions, formalize new tools and processes, and develop new expertise/experts. These activities will make CUSP the world's leading authority in the emerging field of "Urban Informatics."

The CUSP Partnership

University Partners

- NYU/ NYU-Poly
- The City University of New York
- Carnegie Mellon University
- University of Toronto
- University of Warwick
- IIT-Bombay

National Laboratories

- Brookhaven
- Lawrence Livermore
- Los Alamos
- Sandia

Industrial Partners

- IBM
- Microsoft
- Xerox
- Cisco, Con Edison, Lutron, National Grid, Siemens
- AECOM, Arup, IDEO

City & State Agency Partners

- The City of New York
  - Buildings
  - City Planning
  - Citywide Administrative Services
  - Design and Construction
  - Economic Development
  - Environmental Protection
  - Finance
  - Fire Department
  - Health and Mental Hygiene
  - Information Technology and Telecommunications
  - Parks and Recreation
  - Police Department
  - Sanitation
  - Transportation
- Metropolitan Transportation Authority
- Port Authority of NY & NJ

A diverse set of other organizations have expressed interest in joining the partnership.

Urban Data Sources

- **Organic data flows**
  - Administrative records (census, permits, …)
  - Transactions (sales, communications, …)
  - Operational (traffic, transit, utilities, health system, …)
  - Twitter feeds, blog posts, Facebook, …
- **Sensors**
  - Personal (location, activity, physiological)
  - Fixed *in situ* sensors
  - Crowd sourcing (mobile phones, …)
  - Choke points (people, vehicles)
- **Opportunities for "novel" sensor technologies**
  - Visible, infrared and spectral imagery
  - RADAR, LIDAR
  - Gravity and magnetic
  - Seismic, acoustic
  - Ionizing radiation, biological, chemical
  - …

What can cities do with the data?

- **Optimize operations**
  - traffic flow, utility loads, services delivery, …
- **Monitor infrastructure conditions**
  - bridges, potholes, leaks, …
- **Infrastructure planning**
  - zoning, public transit, utilities
- **Model the dynamics of land use and neighborhood change**
- **Public health**
  - Nutrition, epidemiology, environmental impacts
- **Identify and respond to abnormal conditions and shocks**
  - Hazard detection, emergency management
- **Data-driven formulation of performance-based policies**
  - Energy use, road pricing and congestion charging, etc.
- **Improve regulatory compliance** (“nudges”, efficient enforcement)
- **Inform, empower, and engage residents**

The Quantified Community (QC)

Understanding the Patterns of Urban Life

The **CUSP “Quantified Community” (QC)** will be a fully instrumented urban neighborhood that uses an **integrated, expandable sensor network and citizen engagement** to support the measurement, integration, and analysis of neighborhood conditions. Through an **informatics overlay**, data on physical and environmental conditions and use patterns will be processed in real-time to **maximize operational efficiencies, improve quality of life for residents and visitors, and drive evidence-based planning.**

Images: Related Companies

The New York Times

Huge New York Development Project Becomes a Data Science Lab

By STEVE LOHR

April 14, 2014, 7:00 am

GreenSource
THE MAGAZINE OF SUSTAINABLE DESIGN

HOME NEWS PROJECTS BEST GREEN HOUSES CONTINUING EDUCATION FEATURES VIDEO

NEWS:

NYU's CUSP to Turn Hudson Yards into New York City's First Smart Development

By David Sokol
May 02, 2014

Buildings
Resource consumption; indoor air quality; productivity, health measures

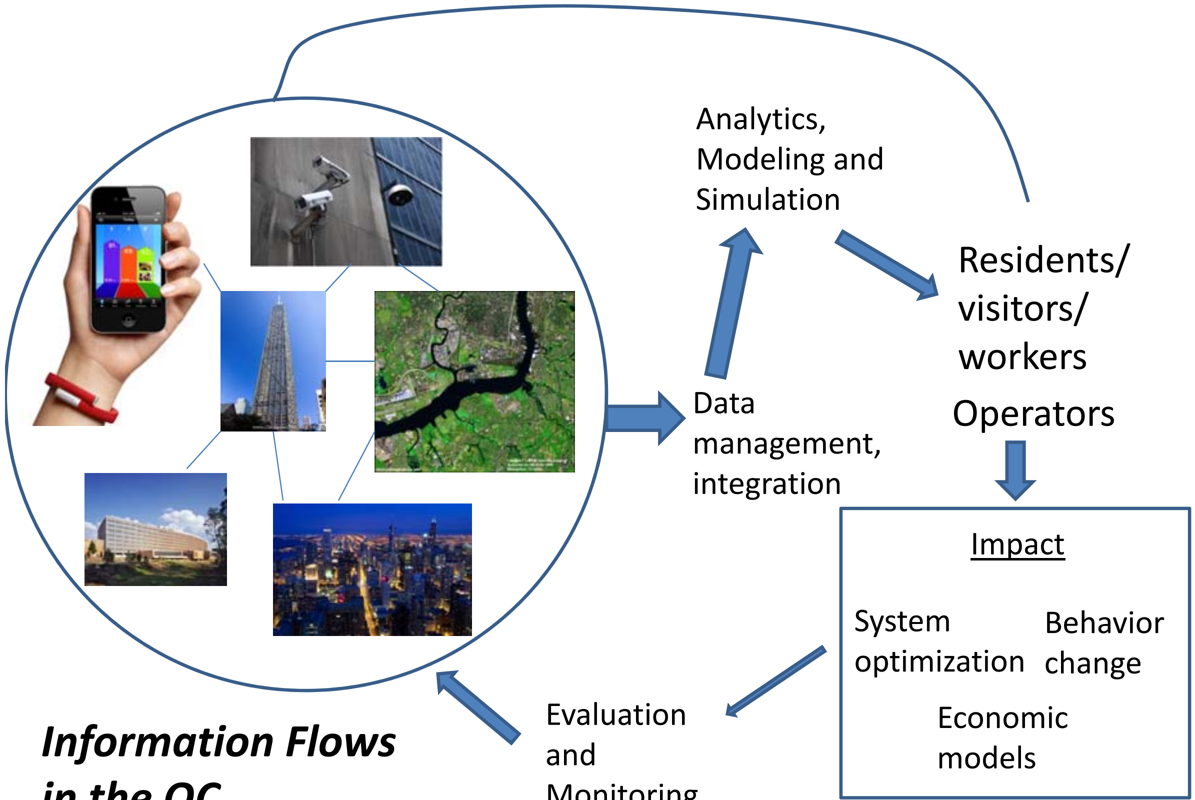
Infrastructure
Solid waste, storm-water management, power generation/distribution

Image: Related Companies

Safety and Security
Network Security, Situational Awareness, Emergency Management Integration, Event Forecasting

Environment
carbon emissions; air pollution and particulates; noise; climate

People
Behavior; mobility; health; activity; social networks, metagenomics



Information Flows in the QC Environment

Next Steps

- Pilot project underway
  - Initial data by Fall 2014; simulation and modeling by early Spring 2015
- Planning of "informatics overlay" at Hudson Yards underway
  - Focus on district infrastructure and first building to be completed
  - Data-driven construction safety, mobility, and logistics optimization project In development
- *Hiring postdocs/research scientists*

CENTER FOR URBAN SCIENCE+PROGRESS

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ckontokosta@nyu.edu

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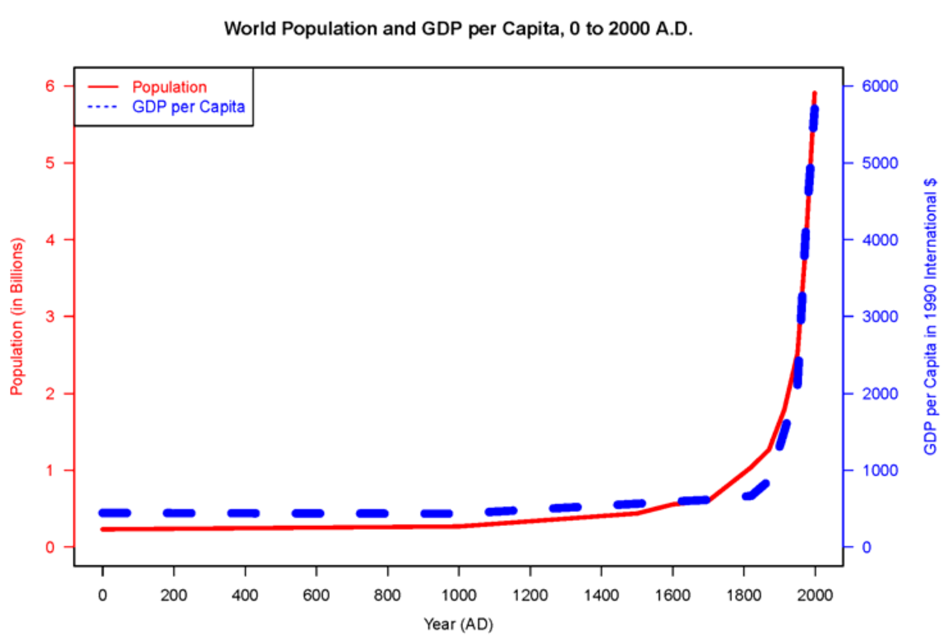
Population and Carrying Capacity: Metrics for Sustainability

Eugenia Kalnay[1], Jorge Rivas[2],
and Safa Motesharrei[1,3]
[1]University of Maryland; [2]University of Minnesota;
[3]National Socio-Environmental Synthesis Center (SEYSNC)

Presentation at the NIST-UMD Workshop on Measurement Science for Sustainable Construction and Manufacturing
June 12, 2014

Growth of Population and GDP/Capita: **Consumption of Resources is their Product!**

1AD	0.3b
1650	0.5b
1804	1.0b
1927	2.0b
1960	3.0b
1975	4.0b
1987	5.0b
1998	6.0b
2011	7.0b



Maddison, (2001)

Why was the population able to grow so fast since the 1950's?

Two reasons:

1) Sanitation and Antibiotics (Public Health → living longer)

2) Use of fossil fuels in agriculture starting in the 1950's:

- fertilizers, pesticides, irrigation, mechanization (Green Revolution).

1950 to 1984: production of grains increased by 250% and the population doubled

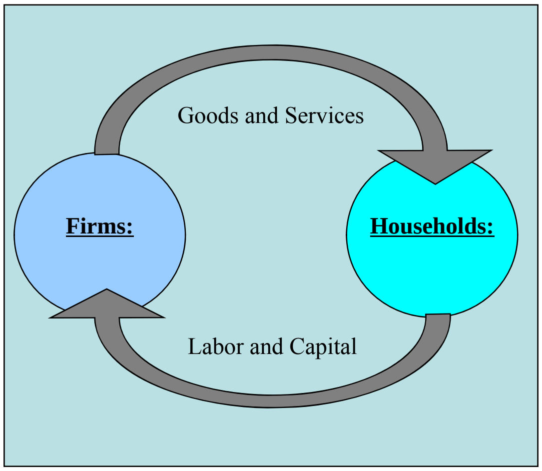
Without fossil fuels population would be much smaller!

- Growth in grain production is now flattening out
- Industrial farming is destroying forests, soil
- Urban and suburban sprawl is overrunning best farmland

This is not sustainable: "We are drawing down the stock of natural capital as if it was infinite" (Herman Daly)

Standard Neoclassical Economic Model

As Herman Daly, Robert Costanza, and other scholars in the field of Ecological Economics describe,



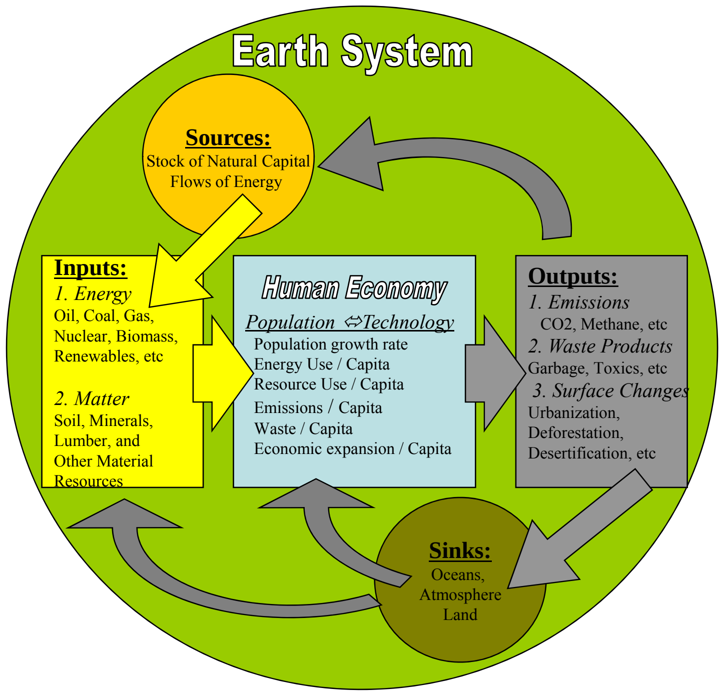
The standard Neoclassical Economic Model does not account for:

- Inputs (resources)
- Outputs (pollution)
- Stocks of Natural Capital
- Dissipation of Energy (i.e., a Perpetual Motion Machine)
- Depletion, Destruction or Transformation of Matter

Therefore, no *effects on the Earth System*, and *No Limits to Growth*.

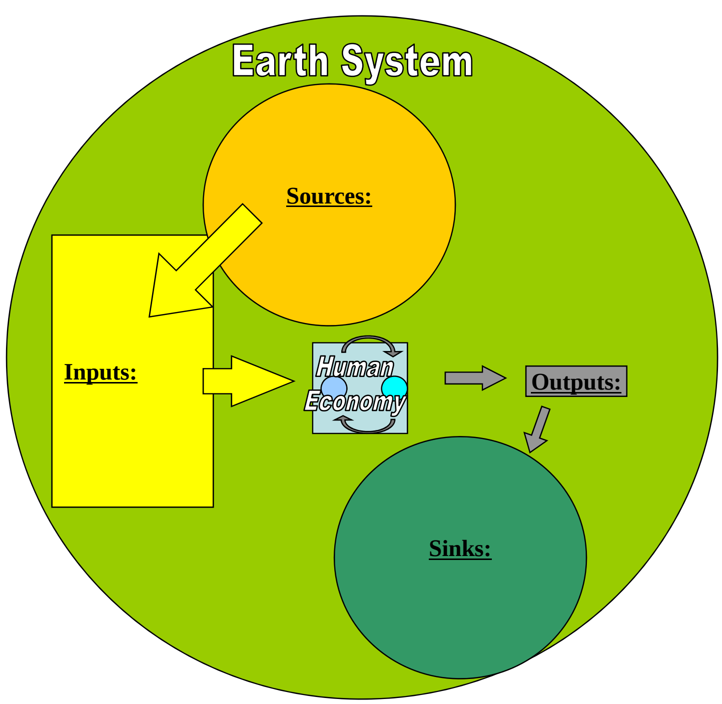
Realistic **Ecological** Economic Model (Herman Daly)

- Incorporates INPUTS, including **DEPLETION** of **SOURCES**
- Incorporates OUTPUTS, including **POLLUTION** of **SINKS**



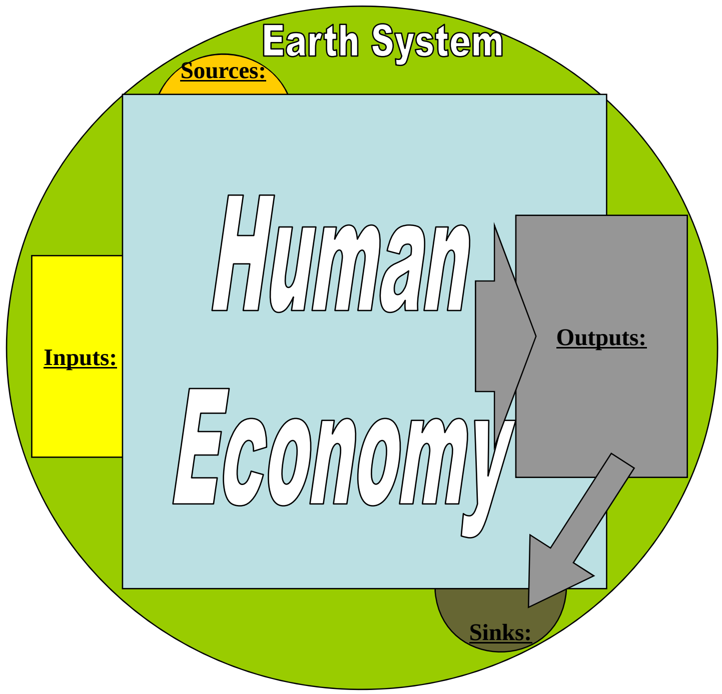
"Empty World" Model

- Throughout most of human history, the **Human Economy** was so small relative to the **Earth System**, that it had little impact on the **Sources** and **Sinks**.
- In this scenario, the standard isolated economic model might have made sense.

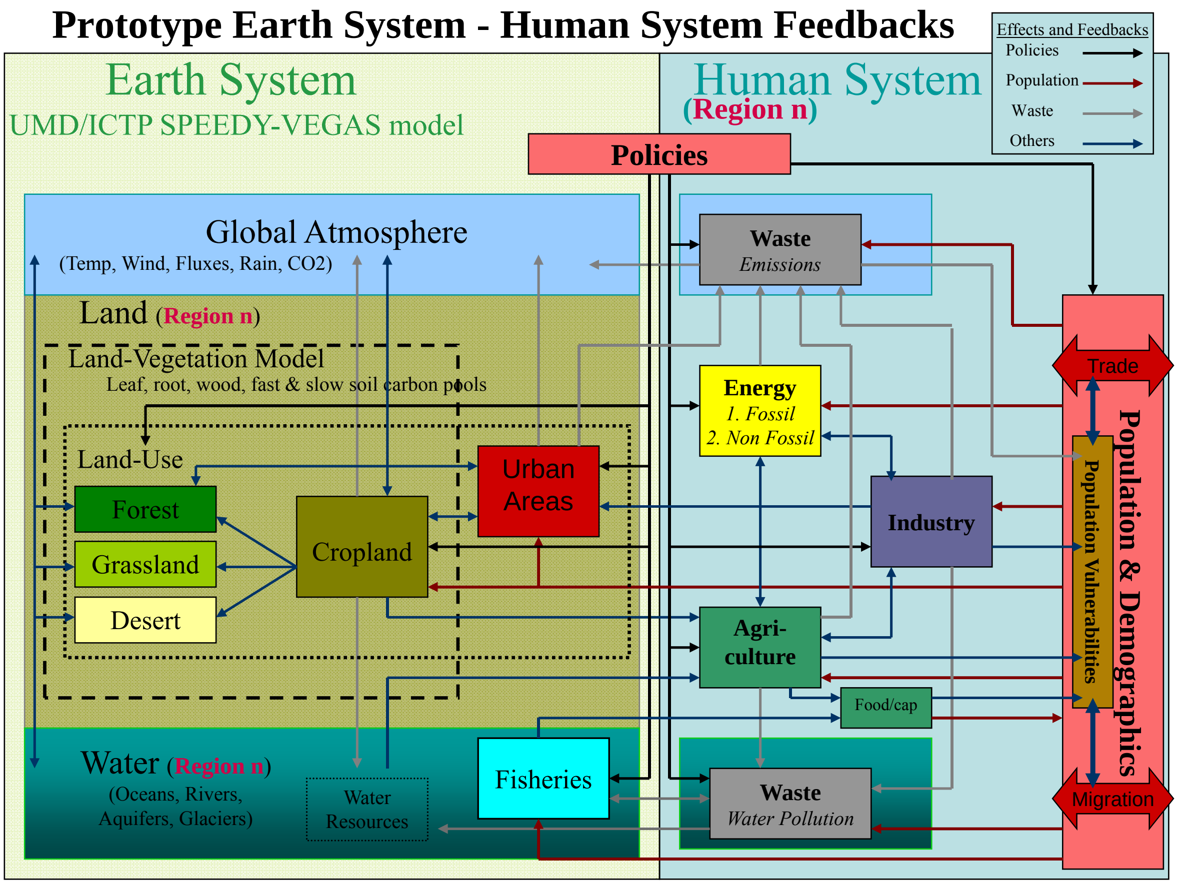


“Full World” Ecological Economic Model

- Today, the **Human Economy** has grown so large, it has very large **Effects** on the **Earth System**, ***Depleting*** the **Sources** and ***Filling*** the **Sinks**. It is clear that ***growth cannot continue forever***.



Prototype Earth System - Human System Feedbacks



Could an advanced society like ours **collapse**?

- **Collapses of many advanced societies have taken place in the last 5000 years!**
- A recent study of the many collapses that took place in Europe has excluded climate forcing, war, and disease as the root cause of such collapses, so that it concluded:
- The collapses were due to overrunning the Carrying Capacity
- We developed a "Human and Nature Dynamical model" (**HANDY**) to start understanding the nonlinear feedbacks between the Earth and the Human System.

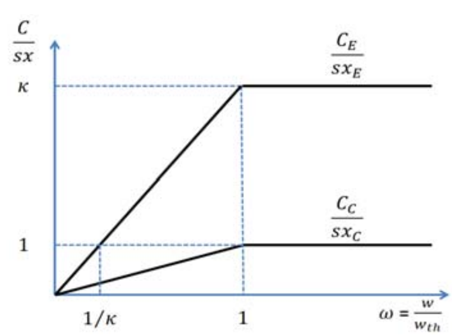
HANDY: **H**uman **a**nd **N**ature **Dy**namical model with Rich and Poor: for Thought Experiments

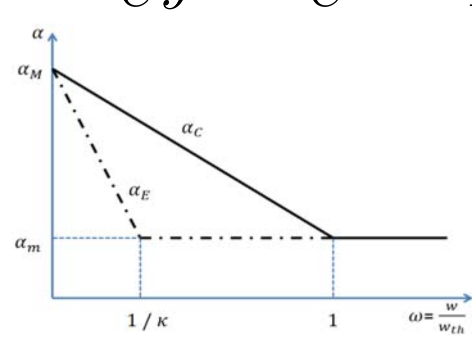
Commoner Population $$\dot{x}_C = \beta_C x_C - \alpha_C x_C$$

Elite Population $$\dot{x}_E = \beta_E x_E - \alpha_E x_E$$

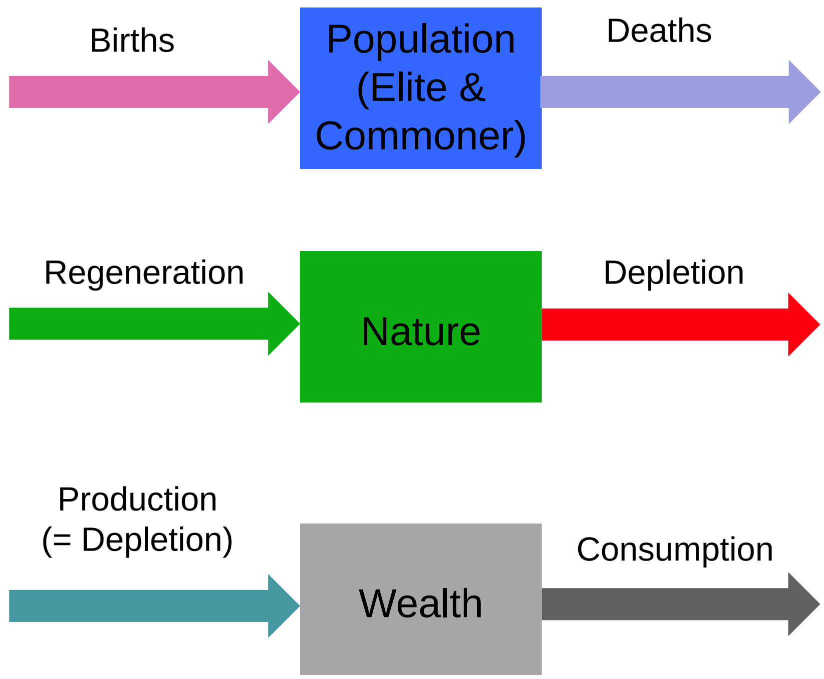
Nature $$\dot{y} = \gamma y(\lambda - y) - \delta x_C y$$

Wealth $$\dot{w} = \delta x_C y - C_C - C_E$$





State Variables (Stocks) and Flows in HANDY1



Carrying Capacity

- **Carrying Capacity:** The population level that the resources of a particular environment can sustain over the long term

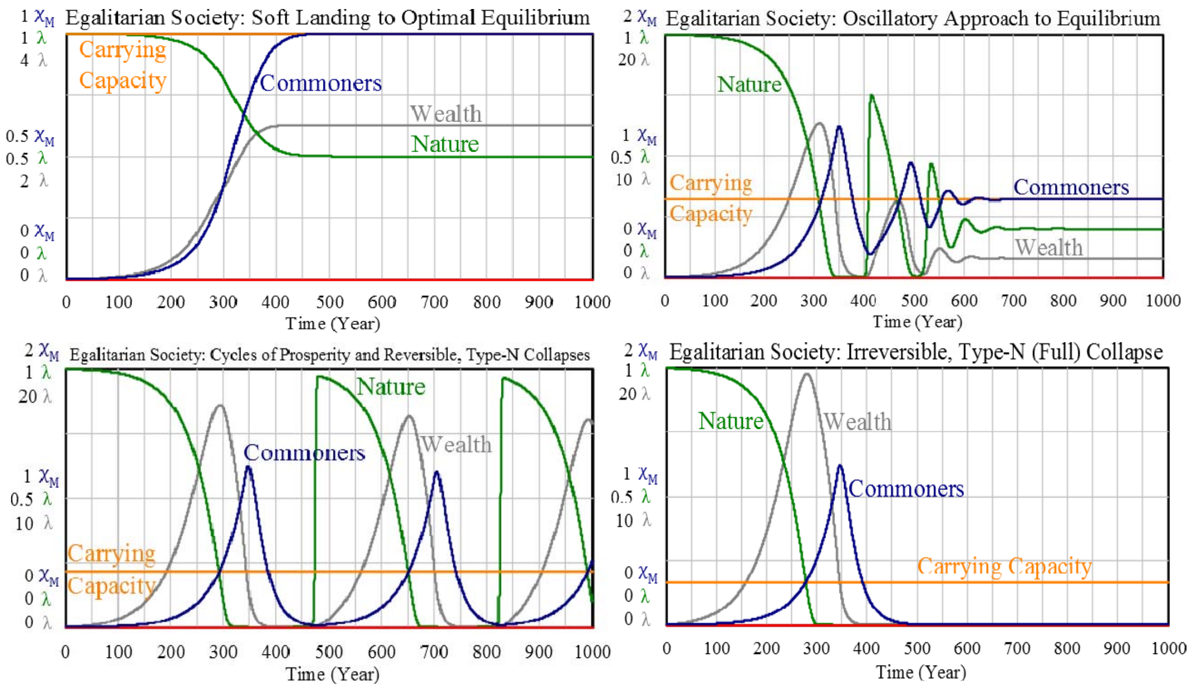
Carrying Capacity in HANDY

$$\chi = \frac{\gamma}{\delta}\left(\lambda - \eta\frac{s}{\delta}\right)$$

Maximum Carrying Capacity

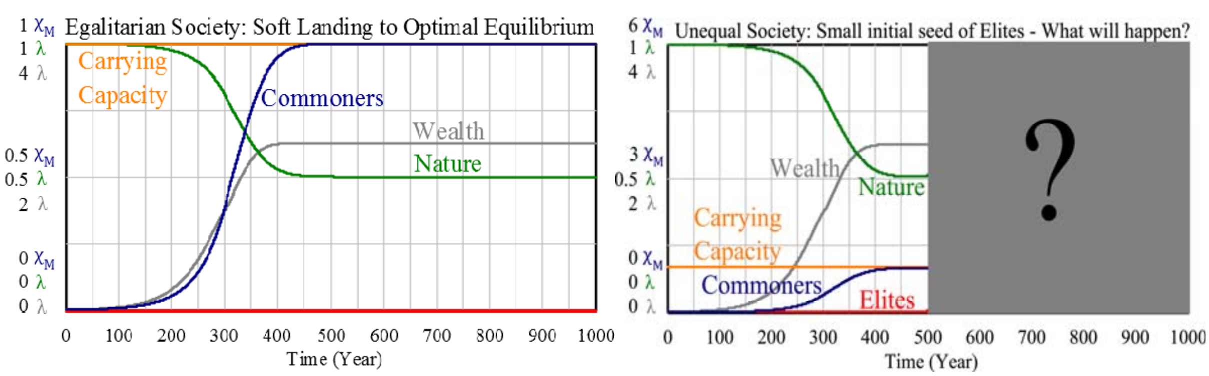
$$\chi_M = \frac{\gamma}{\eta s}\left(\frac{\lambda}{2}\right)^2$$

Experiments for an Egalitarian Society



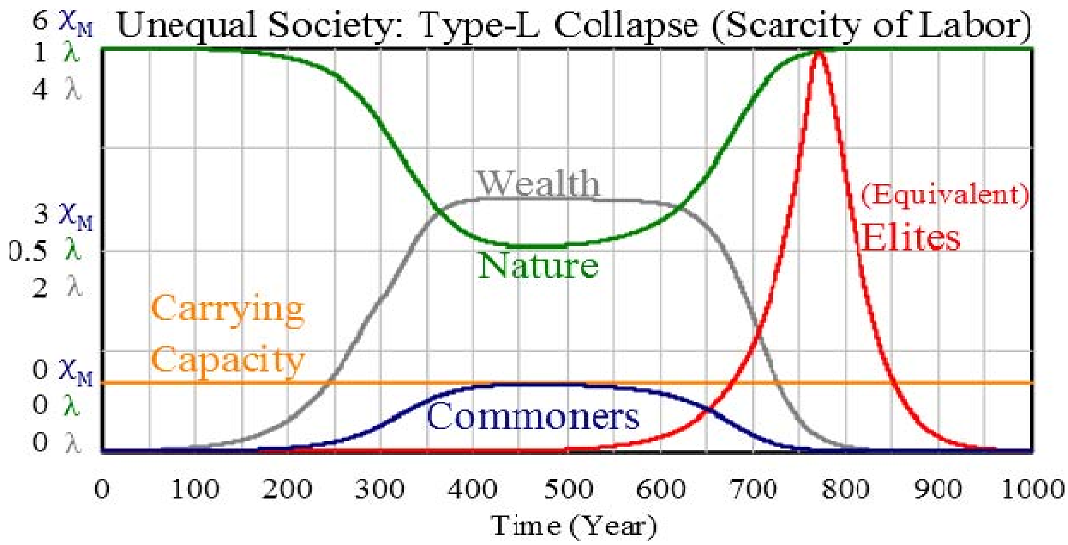
High depletion rate can lead to collapse.

What if we introduce Inequality?



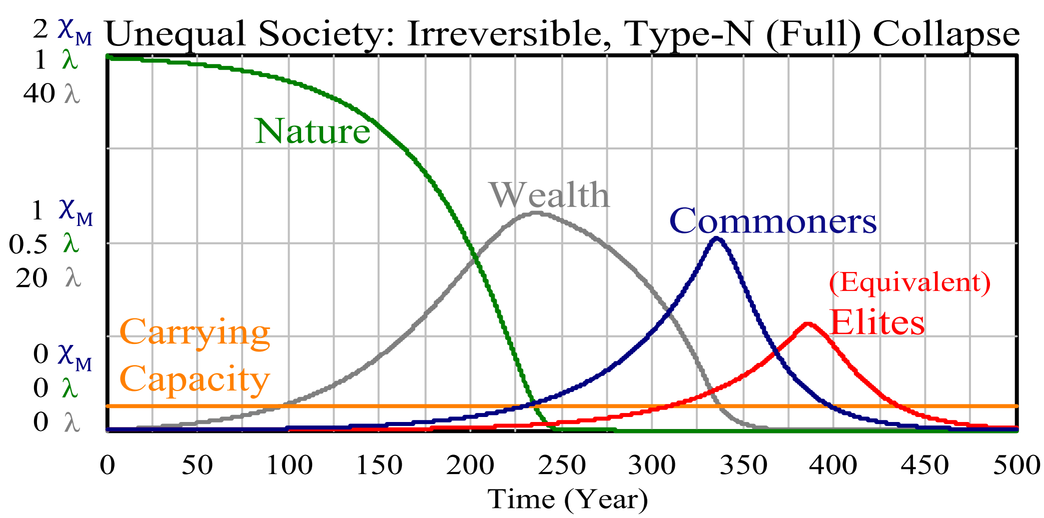
Up until t = 500,
both scenarios show the exact same dynamics.

An otherwise *sustainable* society could collapse if there is high inequality ($\kappa = 100$).



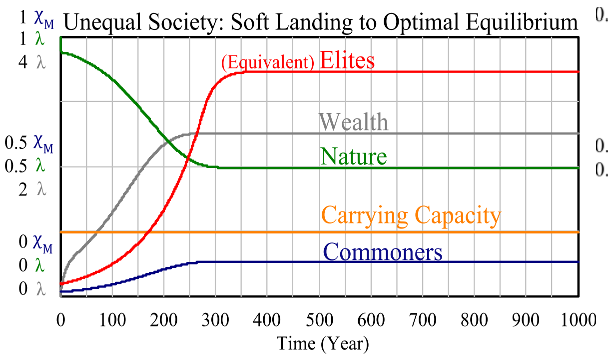
What happens if we have *both* high inequality and high depletion rate?

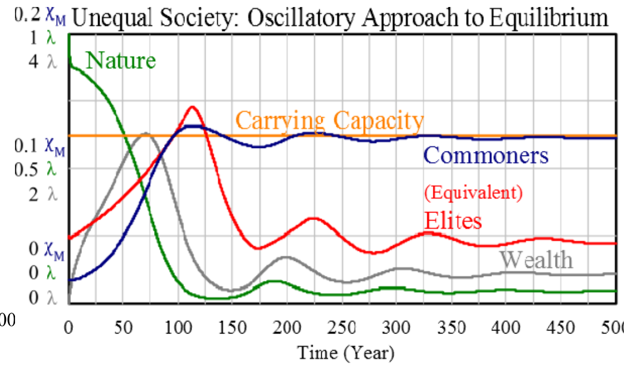
Typical Collapse: High Depletion Rates and High Inequality at the same time



Is there any hope for an unequal society to survive?

If we reduce the *depletion per capita* and *inequality*, and slow down the *population growth*, it is possible to reach a steady state and survive well.

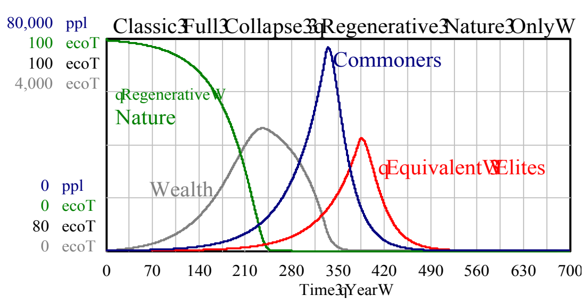




Reaching this equilibrium requires **changes in policies:**

- Reduce depletion per capita
- Reduce inequality ($\kappa = 10$)
- Reduce population growth

Could a collapse be prevented if we have large stocks of Nonrenewable Energy?



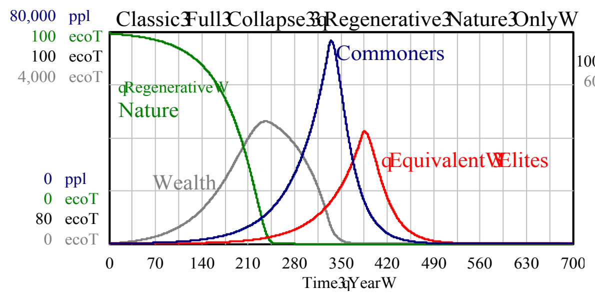
What happens when we add fossil fuels?

This is the classic HANDY1 full collapse scenario, with only regenerating Nature

We then add to the regenerating Nature a **nonrenewable Nature**

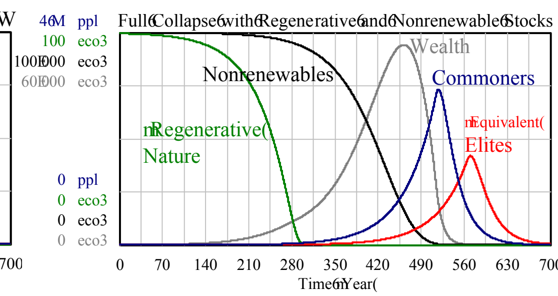
Impact of adding fossil fuels (nonrenewable energy resources)

80K



Regenerating Nature Only

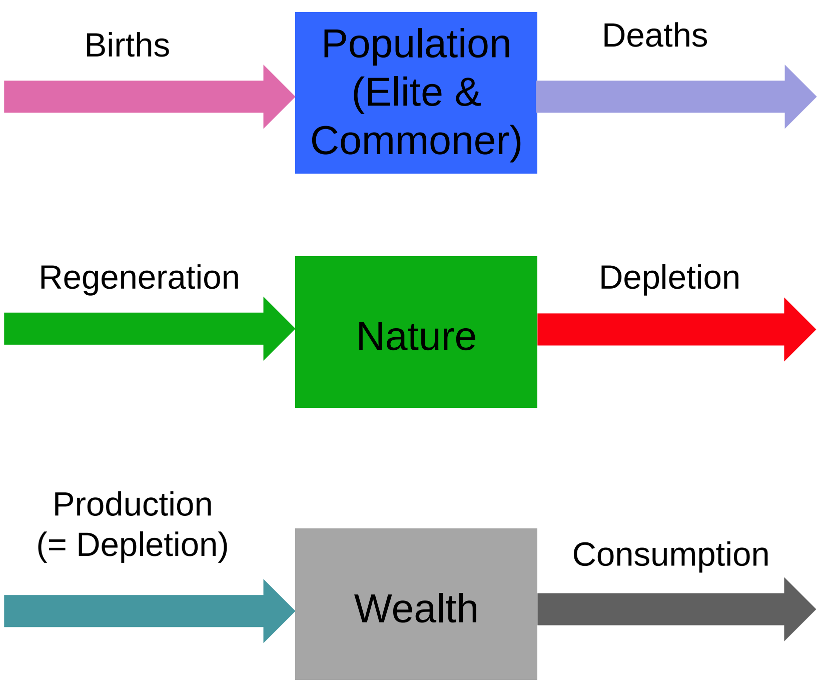
4Million



Both Regenerating and **Nonrenewable** Resources

The collapse is postponed by ~250 years and the peak population increases by a factor of ~25!

State Variables (Stocks) and Flows in HANDY1



Metrics for Sustainability

The conditions for sustainability of **resources** depend on their **type**:

1. Regenerating resources (e.g., forests, fisheries, herds):

   Total Depletion Rate ≤ Regeneration Rate

2. Renewable resources (e.g., Flows of solar and wind):

   Sustainable by definition, since the total extraction rate is always smaller than the flow rate.

Also, consumption of Accumulated Wealth must be sustainable to ensure societal sustainability, therefore:

Total Consumption ≤ Total Production

But what about *Nonrenewables*? Could their extraction be *sustainable*?

A Metric for Sustainability of Nonrenewables

We define a new metric *Time to Depletion, $T_N(t)$,* for Nonrenewable resources (e.g., fossil fuels, aquifers, minerals):

$$T_N(t) = \text{Time to Depletion} = \frac{\text{Total Nonrenewalbe Stock}}{\text{Depletion rate of Nonrenewables}} = \frac{y_N(t)}{D_N(t)}$$

For extraction of nonrenewables to be sustainable, Time to Depletion has to increase with time:

$$T_N(t+dt) \geq T_N(t)$$

It can be shown that this is equivalent to:

$$\frac{d^2}{dt^2}\Big(\log y_N(t)\Big) \geq 0$$

This also means that the net depletion rate of nonrenewables must decrease with time if their extraction is to be sustainable.

CONCLUSIONS

- The Human System **has dominated** the Earth System.
- In order to assess Societal Sustainability and issues like Climate Change, we need to couple the Earth System with Population, include bidirectional (two-way) feedbacks, and take into account the impact of policies on longer time scales (>50 years, >2 generations).
- Carrying Capacity is a widely applicable measure for societal sustainability.
- Additional sustainability metrics are also derived for all three types of resources.
- For Regenerating resources, net depletion must be within net regrowth rate of the resource.
- Extraction of Renewables is inherently sustainable.
- For Nonrenewables, **Time to Depletion** must increase with time.
- Therefore, *net depletion* of Nonrenewables **has to decrease.**
- This means if population is relatively *steady*, *depletion per capita* of nonrenewables must decrease with time.

National Institute of Standards and Technology

Measurement Science for Sustainable Construction and Manufacturing

Challenges and Metrics in Public Buildings and Infrastructure

David Dise, Director

Department of General Services

david.dise@montgomerycountymd.gov

DEPARTMENT OF GENERAL SERVICES

- Completed over 50 capital projects since 2007
- $1.2 billion in planning, design and construction costs
- Project range from $1M to $100M+
- More than 50 active projects in design or construction
- Custodian of 412 buildings, 9.5 million square feet

DEPARTMENT OF GENERAL SERVICES

Priorities for facility *performance*:

- Low environmental impact
- Durability
- Low, long-term O&M
- Long operating hours
- Flexibility for varying uses
- Resiliency

DEPARTMENT OF GENERAL SERVICES

Sustainability priorities in new capital projects:

- Passive solar design
- Daylight harvesting
- Geothermal
- Designed for future active solar
- Water capture/reuse
- Reduced impervious surface
- Use of rapidly renewable/recycled materials

Example Projects:

CHALLENGES

- Competing priorities
  - Budget vs. ROI
  - Environmental Impact
  - Durability
  - Community concerns and interests
- Regulatory requirements
- Internal client expectations

Equipment Maintenance and Transit Operations Center

Case Study: Equipment Maintenance and Transit Operations Center

- Multiple buildings
- 200+ transit buses, highway trucks and equipment, and some light duty fleet
- Fueling facility
- LEED Gold
- Tight site conditions
- Plan for future capacity
- Energy efficiency
- Light harvesting
- 400 kW of Onsite Solar – potential for expansion.
- 4 acres of vegetative roof
- Continuing measurement and verification
- On-site compressed natural gas

Future Efforts

- More aggressive solar photovoltaic/thermal
- Combined Heat and Power/Microgrids
- Expanded occupant education/engagement
- Innovative P3 opportunities

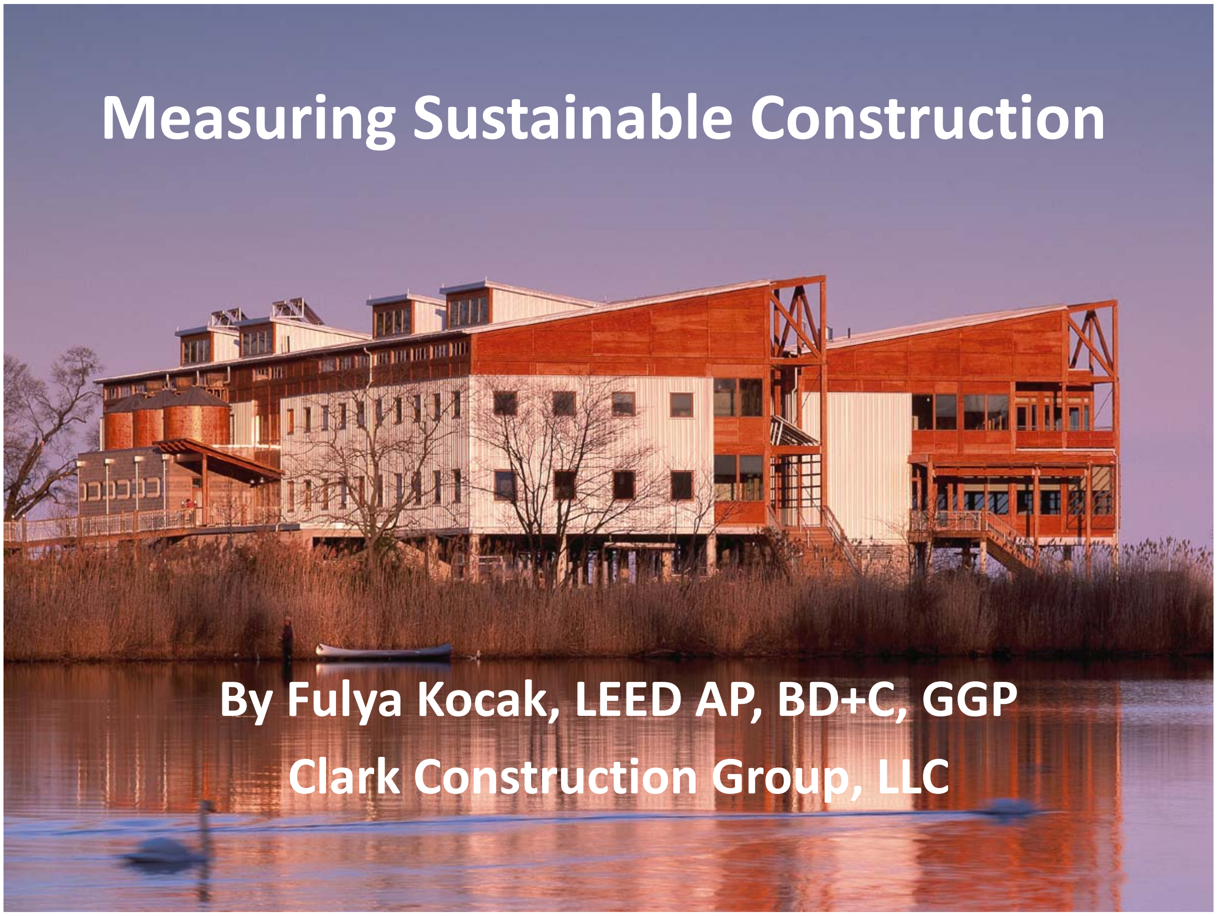
Needed Metrics to Facilitate Sustainable Construction

Contacts:

David E. Dise, Director, Department of General Services
David.Dise@montgomerycountymd.gov

Eric R. Coffman, Chief, Office of Energy and Sustainability
Eric.Coffman@montgomerycountymd.gov

Rassa Davoodpour, Manager, Office of Special Projects
Rassa.Davoodpour@montgomerycountymd.gov


Measuring Sustainable Construction
By Fulya Kocak, LEED AP, BD+C, GGP
Clark Construction Group, LLC


How do we measure Sustainability in Construction Industry?

But first…

What is Sustainable Construction?

Constructing Green Buildings?

Capabilities in LEED Certification?

CERTIFIED
40-49 points

SILVER
50-59 points

GOLD
60-79 points

PLATINUM
80+ points

Health & Well Being ?

Environmental Compliance?

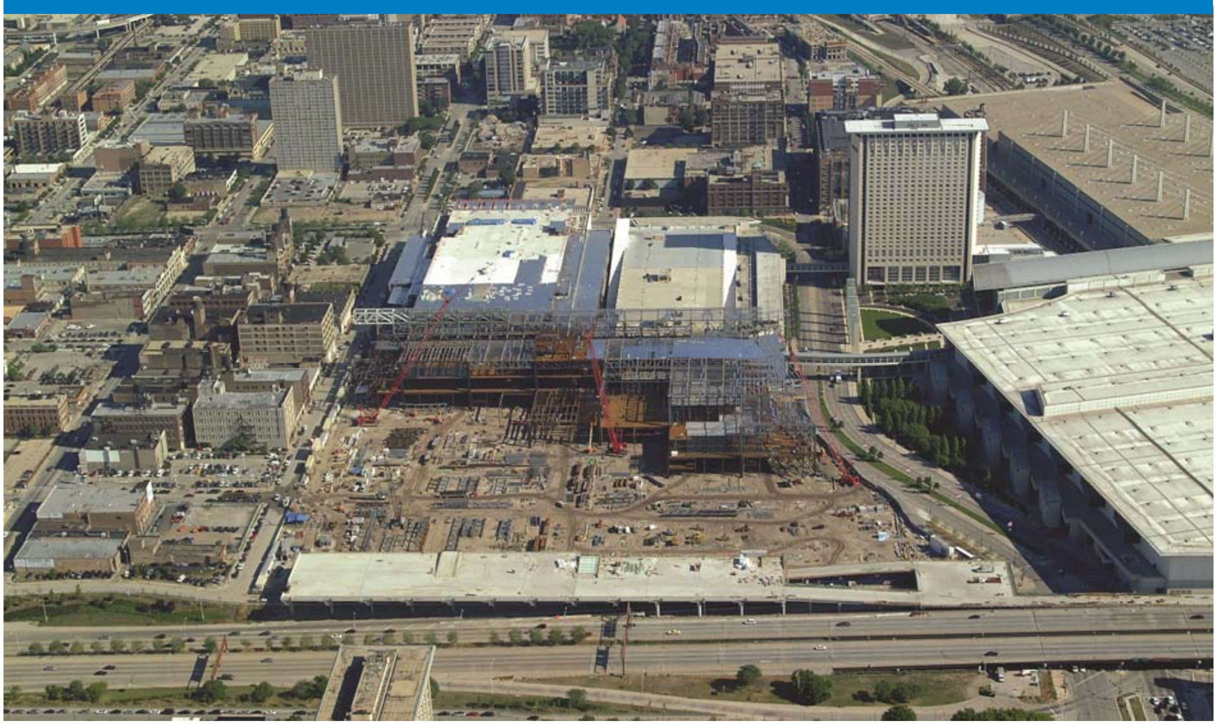
Environmental Management Systems?

Greening the Supply Chain?

Research and Innovation

Education and Awareness?

Reducing disruption to land & habitats?



Minimized transportation?

Progress in new green technologies & products?

Minimizing pollution during construction operations?

Reduce, Reuse, Recycle Construction Waste?

Making green buildings cost effective?

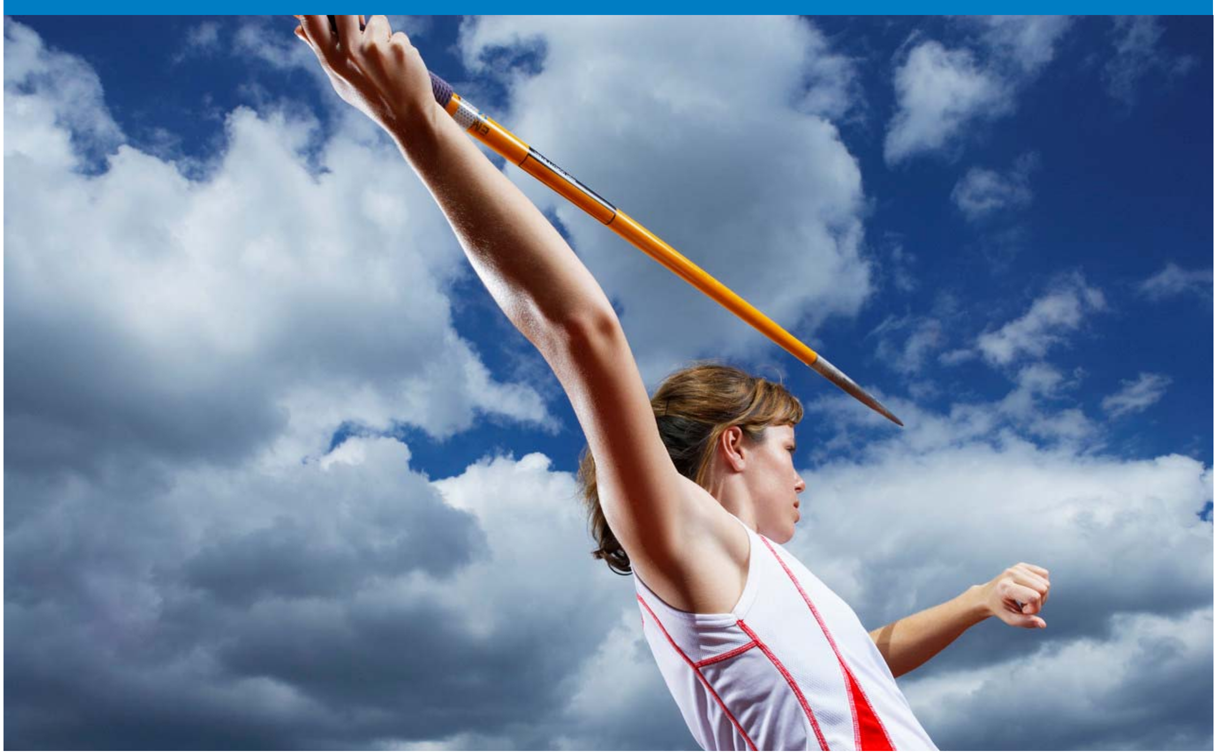
Assisting the clients build green?

Supporting local communities & businesses?

Tracking carbon emissions from construction operations?

Walking the Talk?

Competitive Advantage?

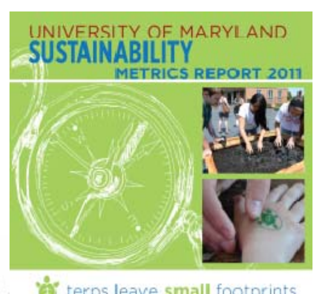


Marketing?

Profitability?

All of the above?

What metrics exist today?



Challenges?

Various meanings and priorities for sustainability

Lack of client demand

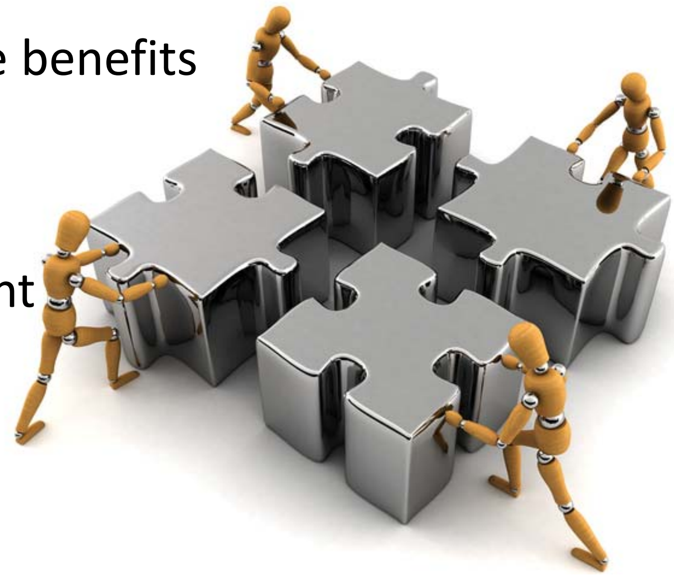
High cost, low tangible benefits

Lack of awareness

Limited resources

Long-term commitment

Slow progress



Opportunities

Profitability,

Competitive Advantage,

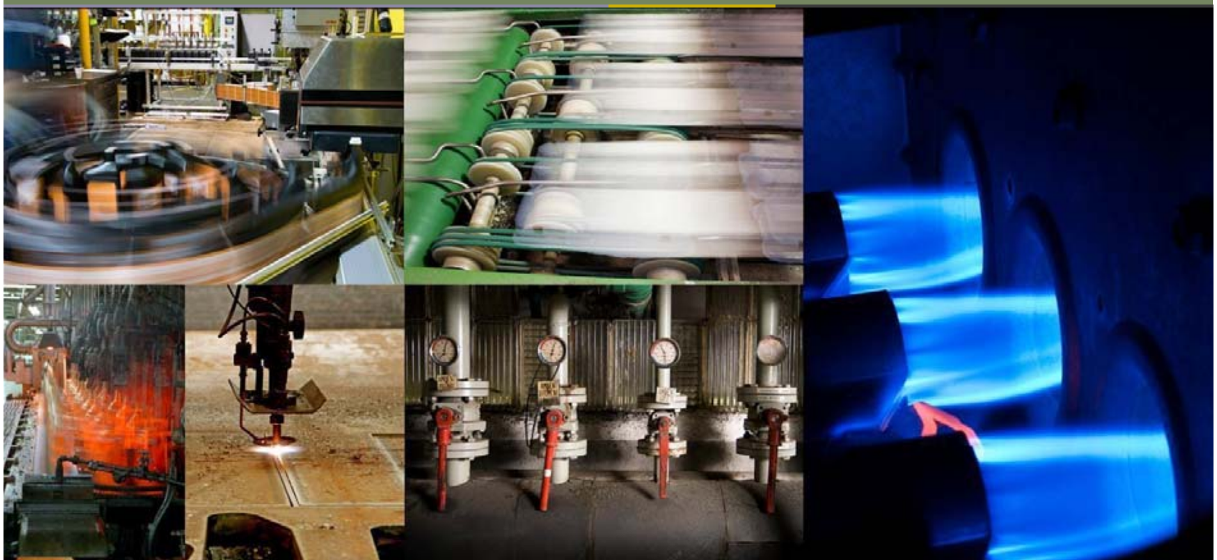
Reduced liability and risk,

Employee satisfaction.


Questions?
By Fulya Kocak, LEED AP, BD+C, GGP
Clark Construction Group, LLC
fulya.kocak@clarkconstruction.com

Technology Analysis:
Efficiency, Manufacturing, Processes & Materials

U.S. DEPARTMENT OF ENERGY



Joe Cresko, Strategic Analysis Technology Manager
Advanced Manufacturing Office
US Department of Energy

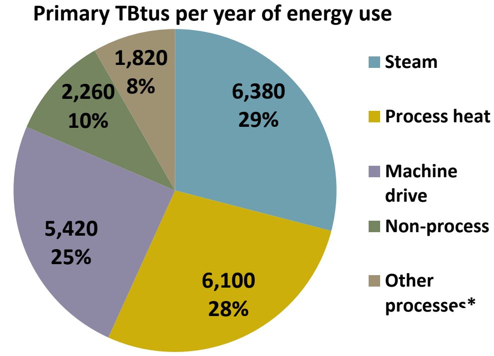
Presentation at:
NIST-ASCE-ASME Workshop on Measurement Science for Sustainable Construction and Manufacturing
June 12, 2014

United States Manufacturing Industry

Manufacturing industry

- **Constitutes 11% of GDP**
- **Employs 12 million people**
- **Employs 60% of engineers and scientists**
- **Accounts for ~30% of primary energy consumption in the United States[1]**

Primary TBtus per year of energy use



Source: *Manufacturing Energy and Carbon Footprint*, derived from 2006 MECS

AMO programs target:

- Research, Development and Demonstration of new, advanced processes and materials technologies that reduce energy consumption for manufactured products and enable life-cycle energy savings

- Efficiency opportunities through deployment of known technologies to existing manufacturing practices, especially for energy-intensive steam, process heating, and machine drive end-uses

[1]historically program has communicated in terms of site energy use; little precedent for materials flows, cross-sector impacts, economics & competitiveness.

Manufacturing and Advanced Manufacturing

"The economic evidence is increasingly clear that a strong manufacturing sector creates spillover benefits to the broader economy, making manufacturing an essential component of a competitive and innovative economy."

Gene Sperling, Director of the National Economic Council
Remarks at the Conference on the Renaissance of American Manufacturing, March 27, 2012

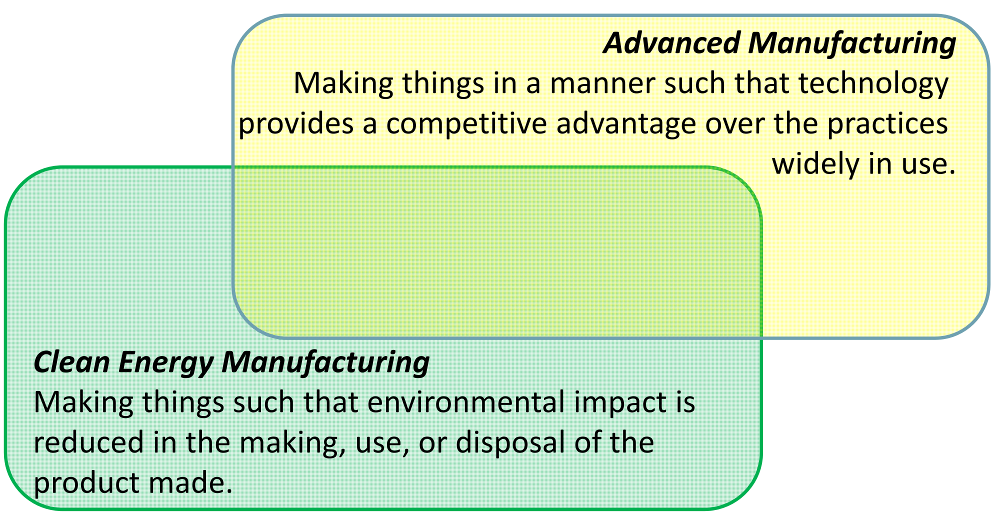
"There is a close connection between R&D and manufacturing in many of the emerging sectors ……. R&D engineers may have to stay close to manufacturing to develop new strategies for making processes more efficient. The tighter integration of innovation and production may also present opportunities to bring design closer to end users, as advanced manufacturing technologies make it possible to produce higher-value goods at lower volume."

Professor Suzanne Berger, co-chair of MIT's Production in the Innovation Economy (PIE)

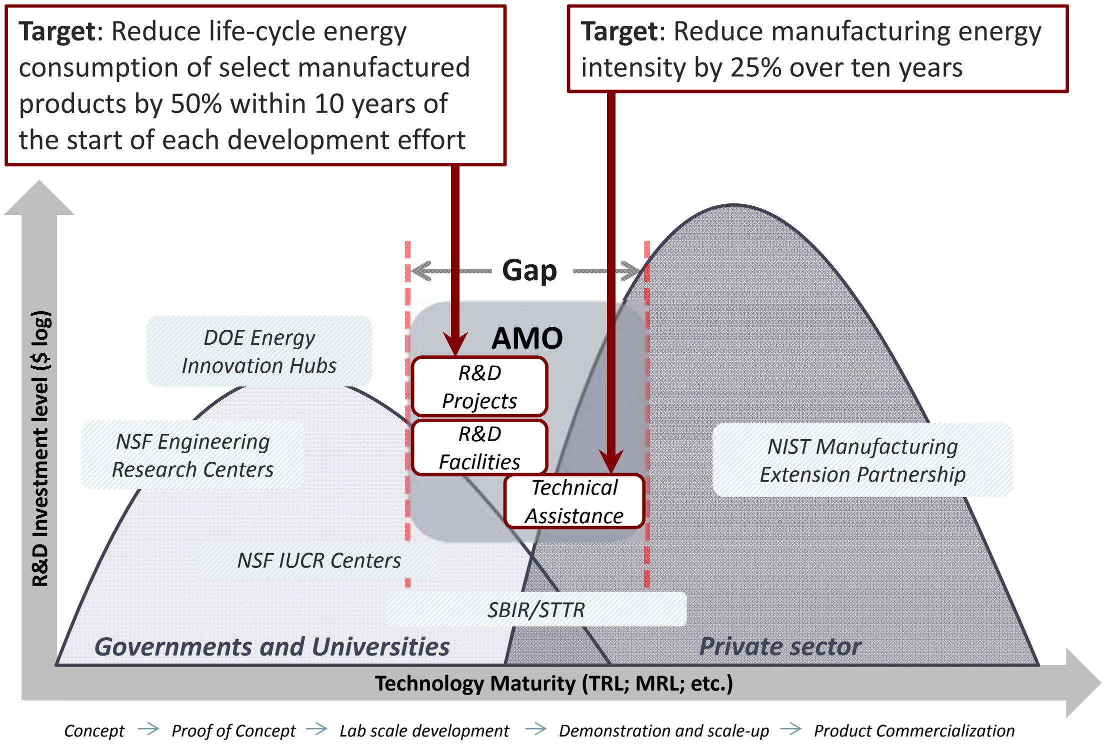
"Advanced Manufacturing involves both: new ways to manufacture existing products, and especially the manufacture of new products emerging from new advanced technologies."

President's Council of Advisors on Science and Technology,
"Report to the President on Ensuring America's Leadership in Advanced Manufacturing," June 2011

Advanced Manufacturing and Clean Energy at DOE

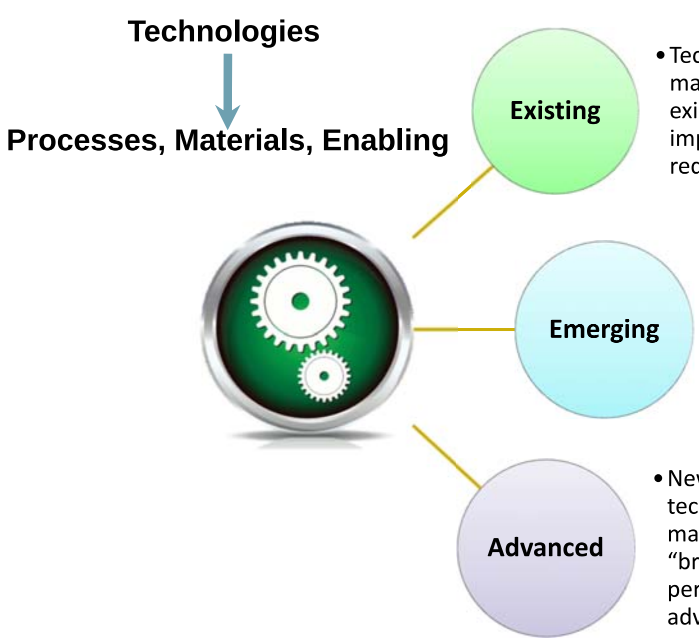


The "Missing Middle"



- *Leverage Federal support of basic research*
- *Partner with the private sector to accelerate commercialization*

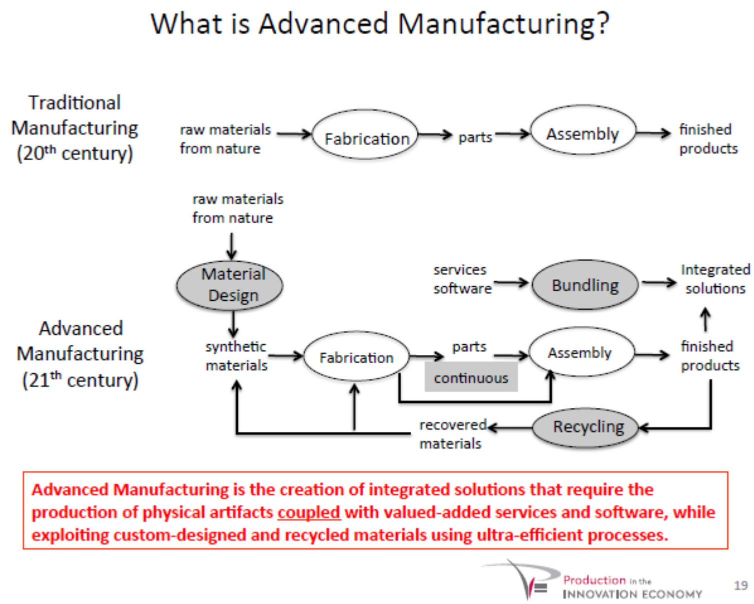
Advanced Manufacturing Office – focus on Technologies



- Technologies and materials that already exist and no further improvements are required
- Technologies and materials that are incrementally improving their performance and are under continuing improvement
- New generation technologies and materials that offer "breakthrough" performance advancements

Advanced manufacturing and supply chains

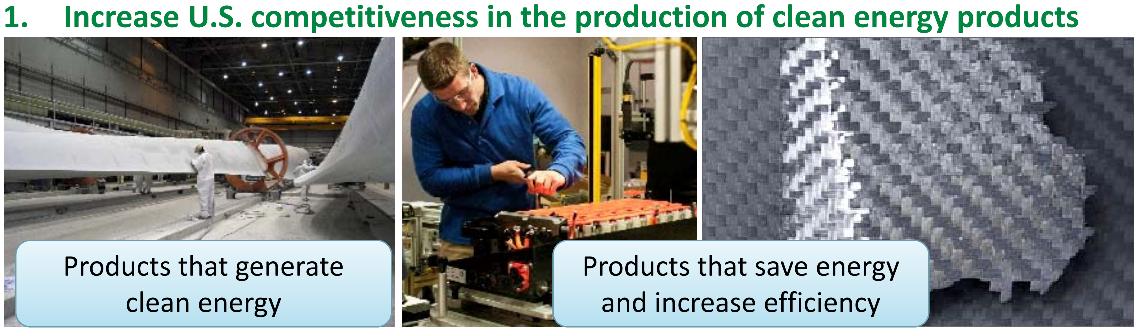
Future supply chains dependent upon advanced manufacturing technologies



Supply chains and U.S. manufacturing competitiveness

EERE's Clean Energy Manufacturing Initiative (CEMI):

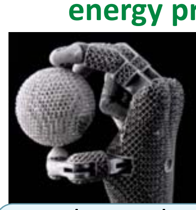
1. Increase U.S. competitiveness in the production of clean energy products



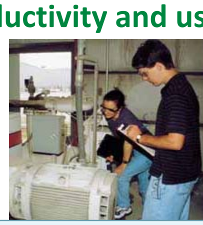
Products that generate clean energy

Products that save energy and increase efficiency

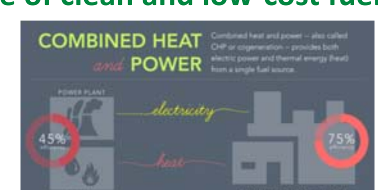
2. Increase U.S. manufacturing competitiveness across the board by increasing energy productivity and use of clean and low-cost fuels and feedstocks



Advanced Manufacturing Technologies



Industrial Energy Efficiency



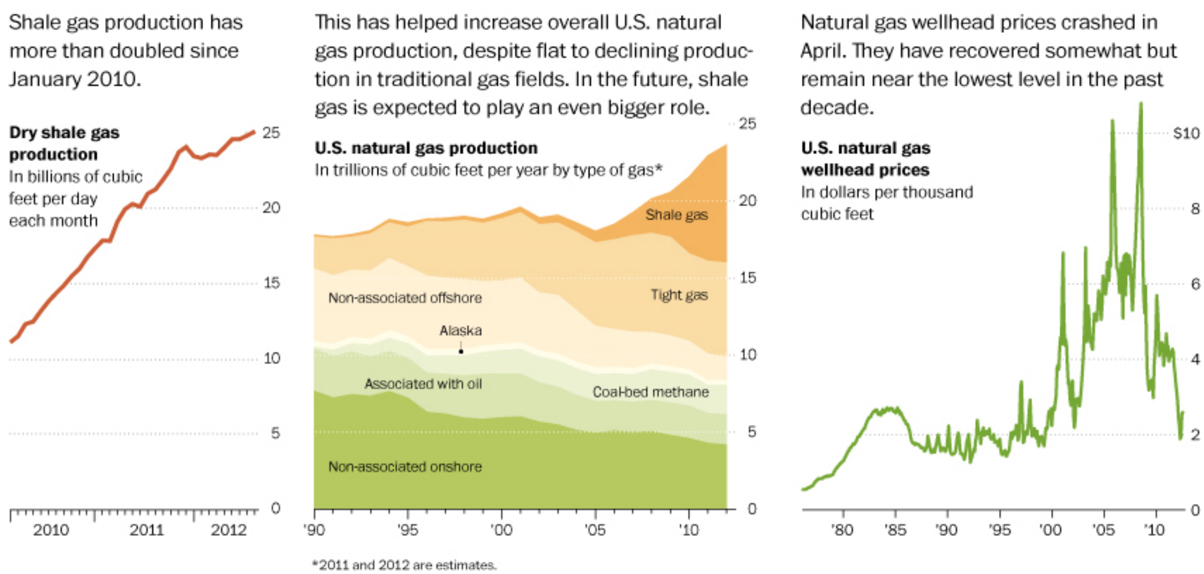
Combined Heat & Power

Low-Cost Natural Gas

Drivers affecting US Manufacturing

"…….natural gas is likely to remain 50 to 70 percent cheaper in the U.S. than in Europe and Japan … "

Boston Consulting Group analysis



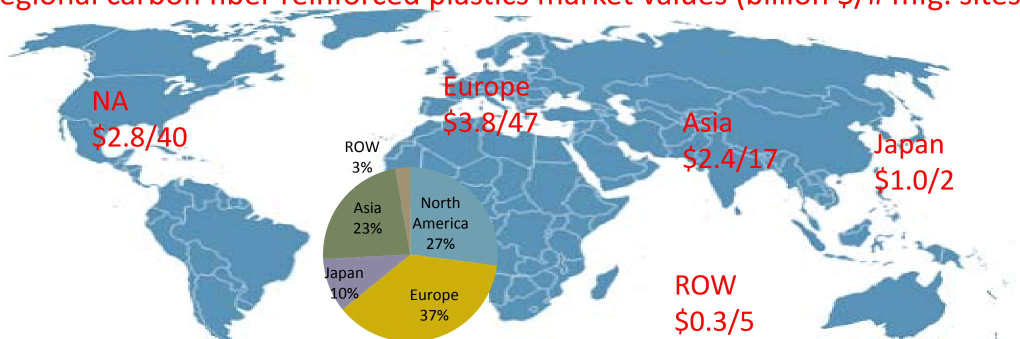
Sources: Lippman Consulting, U.S. Energy Information Administration. The Washington Post. Published on November 14, 2012, 8:00 p.m.

Evaluating US Manufacturing competitiveness

Solar, wind batteries, carbon fiber, WBG semiconductors

1. Characterize the current industry structure (develop a benchmark)
2. Map the value stream
3. Develop a high-level understanding of manufacturing cost drivers
4. Identify areas where the United States has (or may have) viable manufacturing opportunities
5. Select technologies for analytical "deep dive"
   - Refine market analysis
   - Develop cost models
   - Assess qualitative factors driving factory location decisions

Regional carbon fiber reinforced plastics market values (billion $/# mfg. sites)



Market Value Distribution

Source: Industry Experts (2013). Carbon Fiber & Carbon Fiber Reinforced Plastics (CFRP) – A Global Market Overview

Evaluating competitiveness starts with technologies

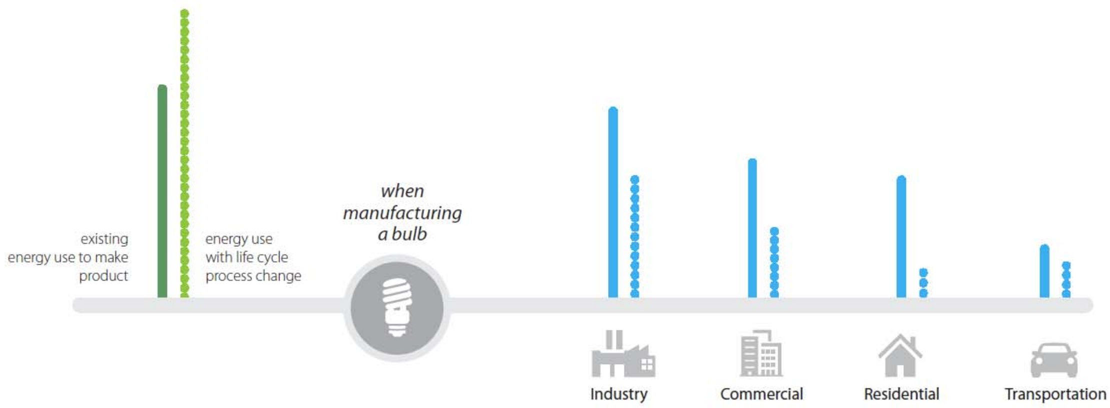
AMO targets investments in high impact technologies

- **Transformative:** Results in significant change in the life-cycle impact (energetic or economic) of manufactured products
- **Pervasive**: Creates value in multiple supply chains, diversifies the end use/markets, applies to many industrial/use domains in both existing and new products and markets
- **Globally Competitive**: Represents a competitive/strategic capability for the United States
- **Significant in Clean Energy Industry**: Has a quantifiable energetic or economic value (increase in value-added, increase in export value, increase in jobs created)

Wide range of metrics

Relevant Technology Characteristics	**High level drivers:** Enabling? Add-value? Add quality? Reduce energy use? Reduce materials waste? Improve production speed? Others?	**More detailed metrics:** Production volume (units per year) Process cycle time (time per unit) Percent cost reduction (relative to current) Percent weight reduction (relative to current) Energy cost savings target? Others?
Barriers	Technology risks/uncertainties Availability of verifiable testing capabilities High capital cost High material cost Material supply chain insecurity Lack of customer demand	Technical limitations Lack of knowledge Insufficient tools Workforce availability Other?
Existing Approaches	Internal assets (R&D; technology experts, etc.) Consultants Commercial labs Technology vendors	Universities Shared R&D facility (capable of precompetitive and protected work) Other?

Life cycle approach to better understand system-wide impacts



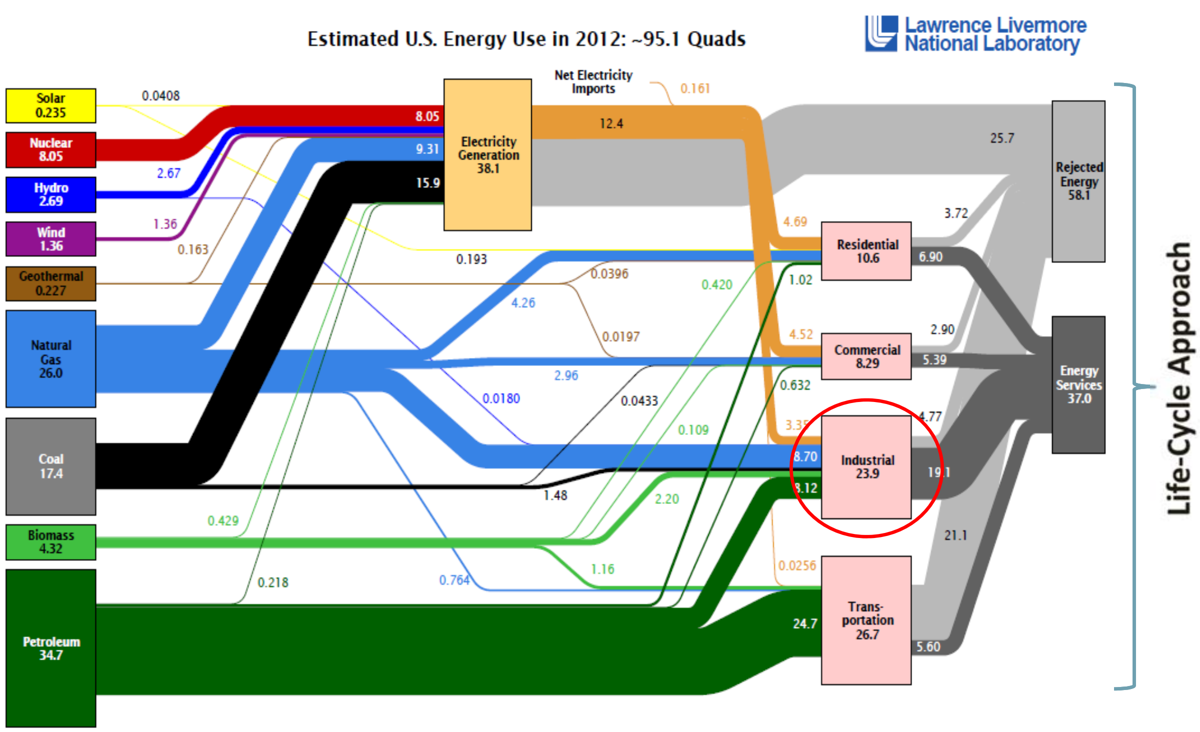
Energy Use in Manufacturing Process

New products or processes may lead to change in energy use in manufacturing sector.

Energy Use in Environment

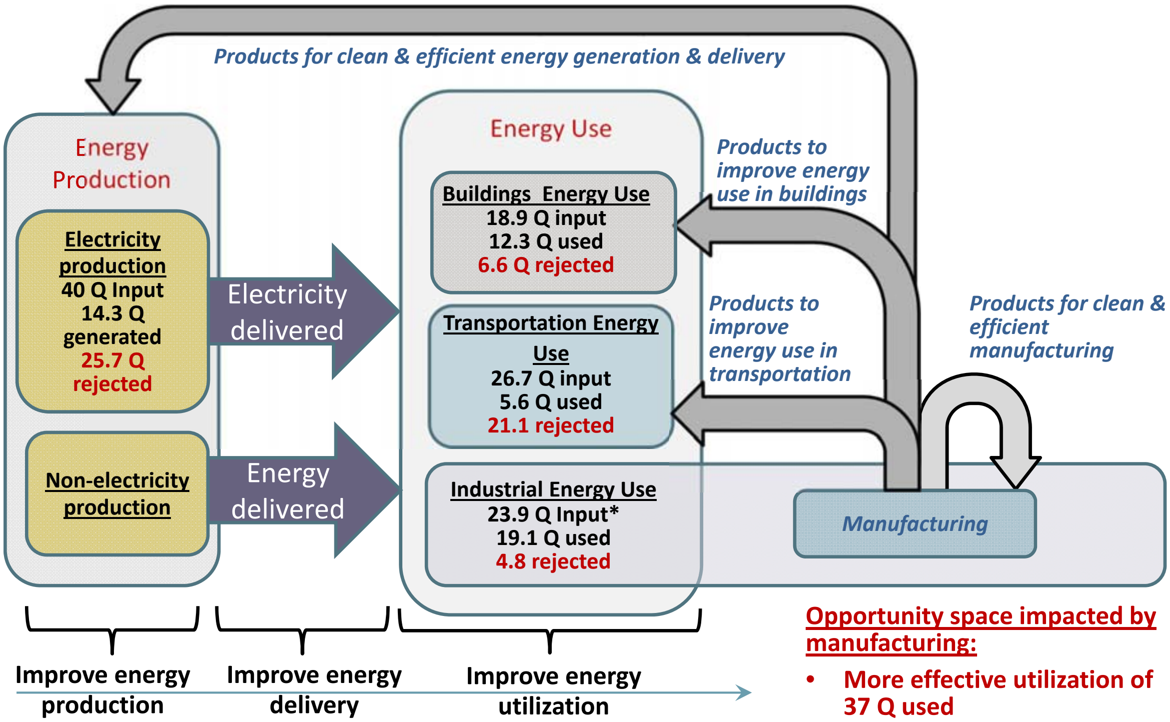
Change occurs in energy use across sectors as a result of deployment of new product.

Flow of Energy through the U.S. Economy



Source: LLNL 2013. Data is based on DOE/EIA-0035(2013-05), May, 2013. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

The opportunity space: economy-wide energy impacts resulting from clean energy manufacturing.



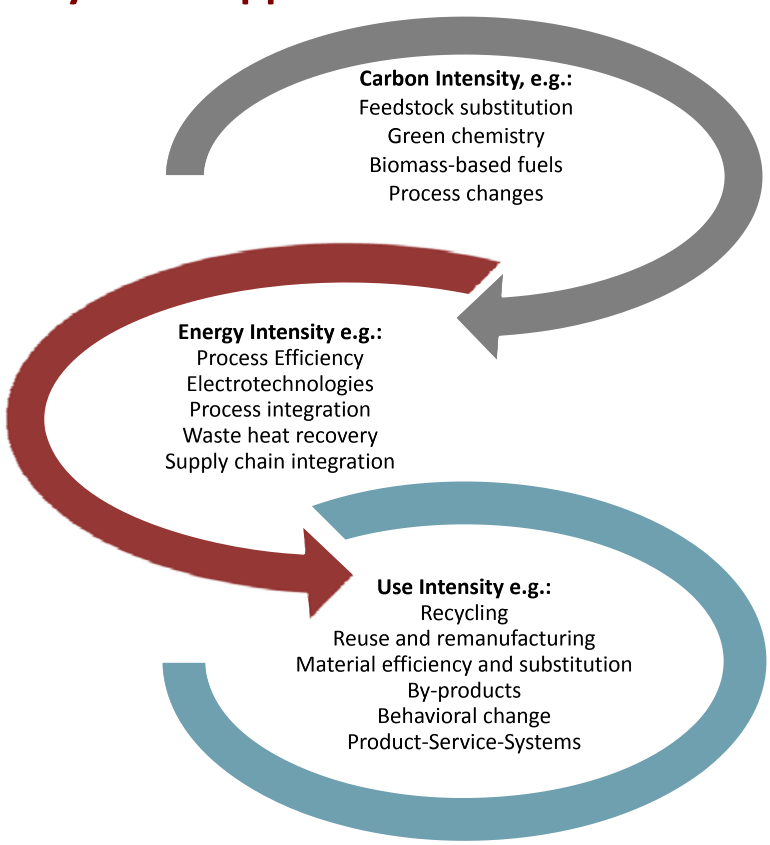
Opportunity space impacted by manufacturing:

- More effective utilization of 37 Q used
- Reduction of the 58 Quads wasted

* >30% is feedstock

Primary Energy Consumption by sectors, 2012 (Total 95 Quads)

Systems Approach – What affects the system?

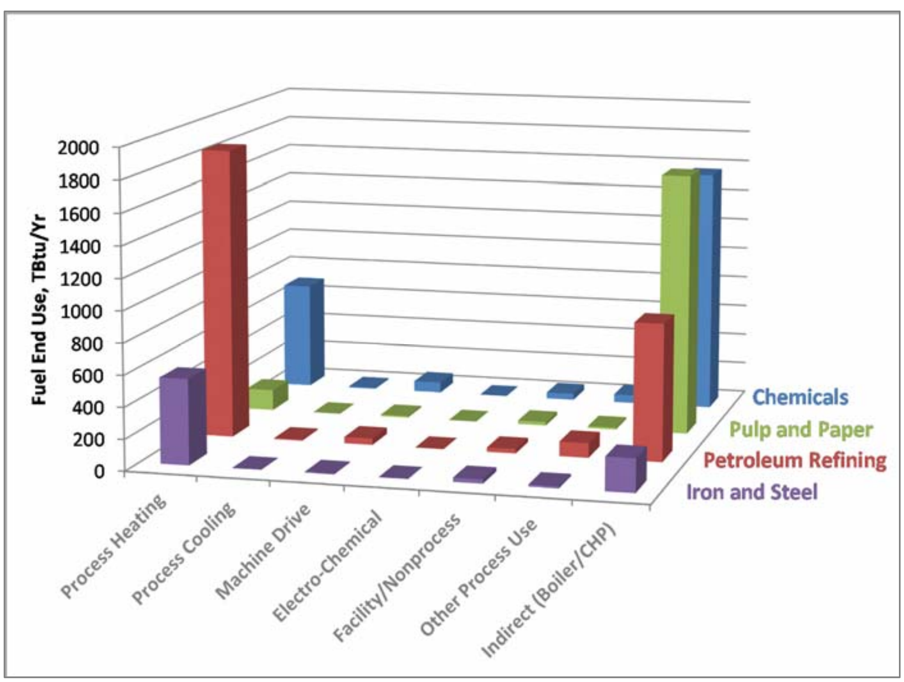


Drivers to reduce energy & emissions through the product lifecycle

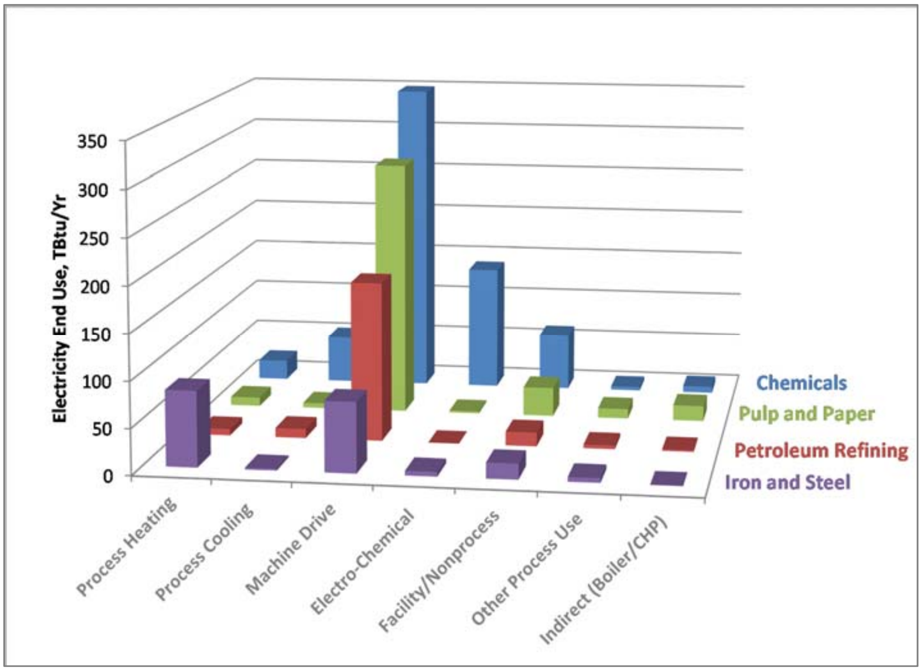
Where do we start? Energy data…

- National sample survey that collects information on the stock of U.S. manufacturing establishment, their energy-related building characteristics, and their energy consumption and expenditures.
  - 250,000 U.S. manufacturing plants
  - Statistical sample of approximately 15,500 establishments are surveyed representing 97% - 98% of U.S. manufacturing payroll and energy consumption
- MECS data released every four years
  - Past footprints (1998, 2002, 2006)
  - Current footprint (2010)

Fuel End Use by Sector

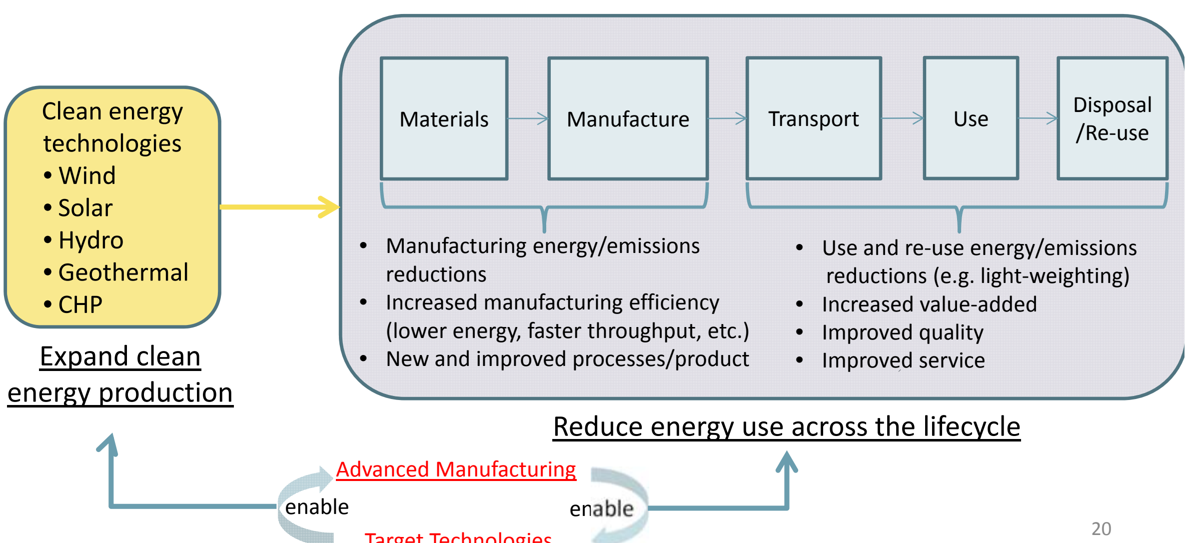


Electrical End Use by Sector



Economy-wide lifecycle energy impacts – starts with technology

- Identify opportunities for manufacturing impacts in clean energy production and use.
- Target timely, high-impact, foundational clean energy technologies with the potential to transform energy use and accelerate their introduction into the US economy.



Illustrative

Economy-wide lifecycle energy impacts – starts with technology

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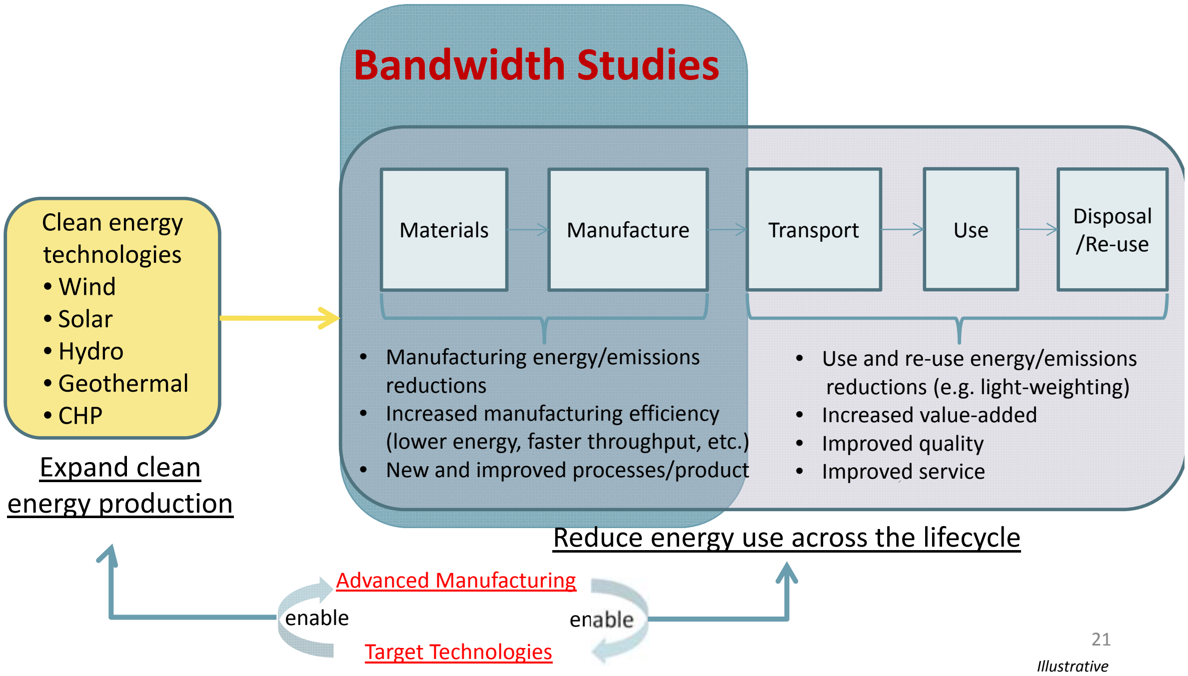

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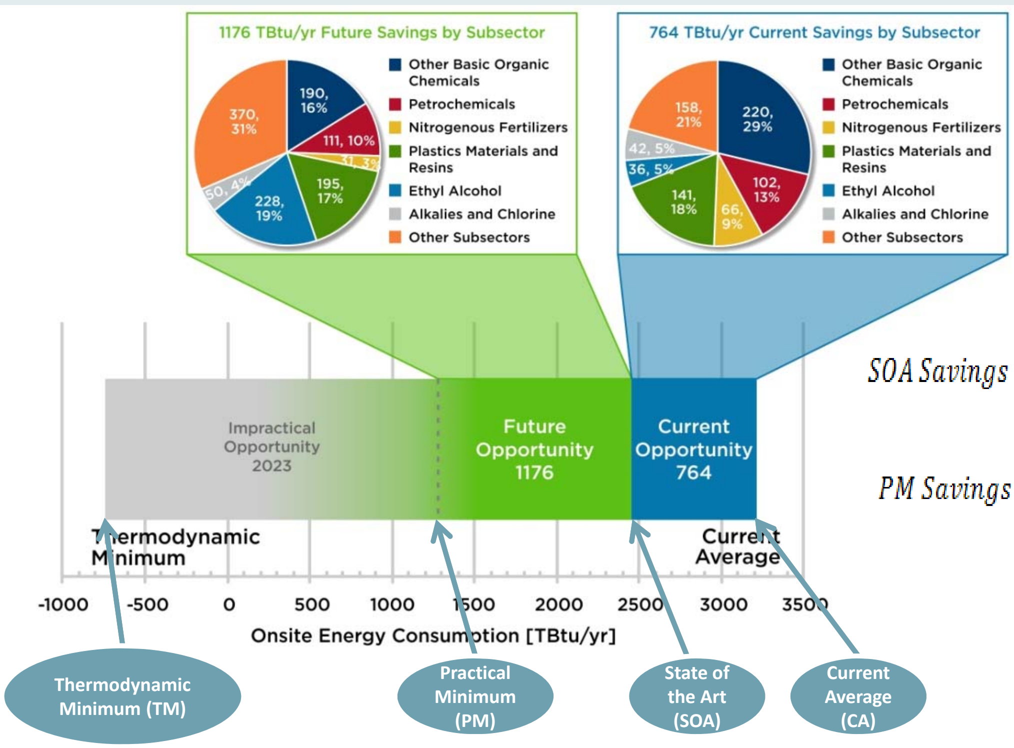
SB1

Chemical Bandwidths - CA, SOA, PM and TM



$$SOA\ Savings\ \% = \frac{CA-SOA}{CA-TM}$$

$$PM\ Savings\ \% = \frac{CA-PM}{CA-TM}.$$

Slide 22

SB1 Julie,
I would like to create a new slide before this one that helps viewers understand this figure.

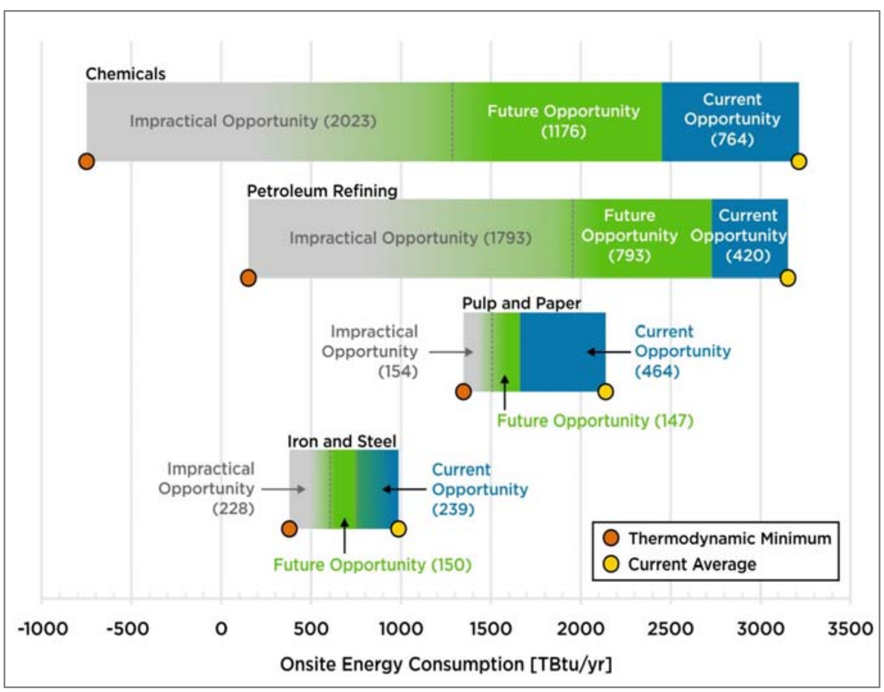
I would like to show the single pie chart first, maybe start with one generic colored pie labeled Current Savings by Process Area with Process Area 1, Process Area 2...thru 6.

Then show the bar showing generic current opp, future opp, impr opp, no numbers in generic version.

Finally link the two pies with the bar, maybe animation showing connecting expansion lines.

All generic, no sector, no numbers. You can just use one of existing to mock up numbers.
Sabine Brueske, 5/18/2014

Energy Intensive Industries - Bandwidths



Expanding the perspective… Materials Flows through Industry (MFI)

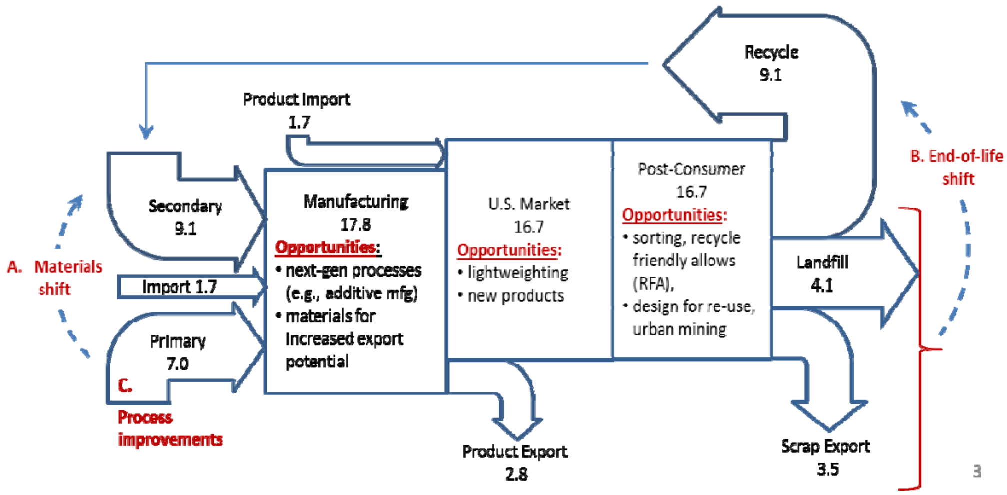
Aluminum Materials Flows – U.S. and Canada, 2009 Billions of Pounds

btu/lb	primary	secondary
Current average	26,000	2,200
Practically achievable	20,000	925
Current savings potential	6,000 btu/lb Process improvement	1,275
Theoretical minimum	10,200	510

23,800 btu/lb Materials shift

Key Opportunities:
- **A. Materials shift** - Technologies to enable increase in secondary aluminum use by manufacturing sector.
- **B. End-of-life shift** - Technologies to enable greater capture and use of 7.6 billion pounds aluminum (landfill + scrap export).
- **C. Process Improvements**- Technologies to improve primary aluminum processing.

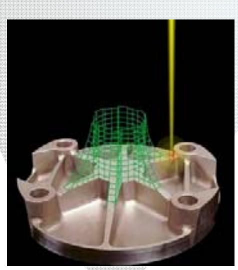
New opportunities throughout the system – in materials design, product design, manufacturing, use and re-use.



Economy-wide lifecycle energy impacts – starts with technology

Industry Energy Use

- Dramatically increased buy:fly for complex components
- Less process heating



AeroMet process. Boeing, Northrup Grumman, NavAir W. Coblenz, DARPA/DSO 2000

Lifecycle Impact

Non-Industry Energy Use

- Lighter components
- Novel, energy-efficient designs

Reduces material use and costs by up to 90%

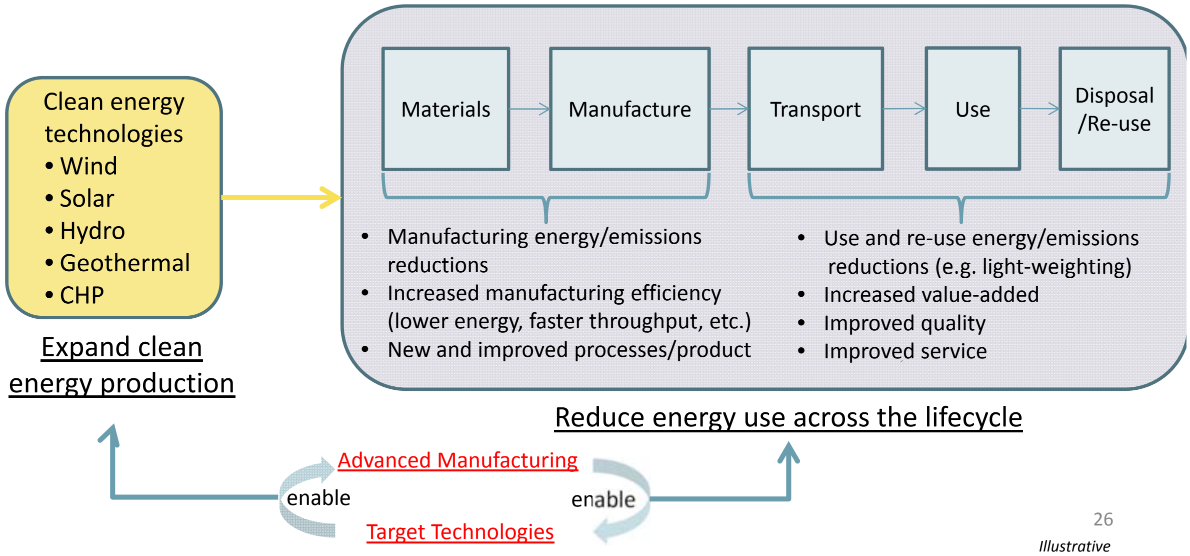
Source: The Economist.
www.economist.com/node/18114221

"…in our lifetime at least 50% of the engine will be made by additive manufacturing"

– Robert McEwan GE

Economy-wide lifecycle energy impacts – continues with technology

- Identify opportunities for manufacturing impacts in clean energy production and use.
- Target timely, high-impact, foundational clean energy technologies with the potential to transform energy use and accelerate their introduction into the US economy.



Illustrative

Economy-wide lifecycle energy impacts – continues with technology

- Identify opportunities for manufacturing impacts in clean energy production and use.
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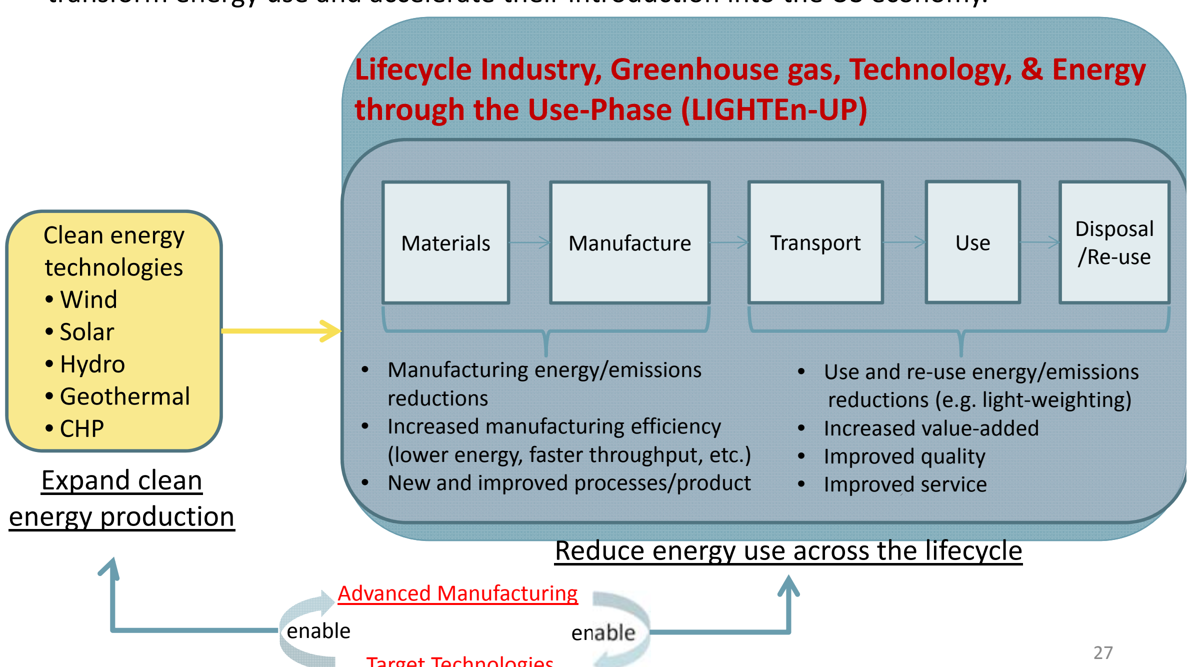

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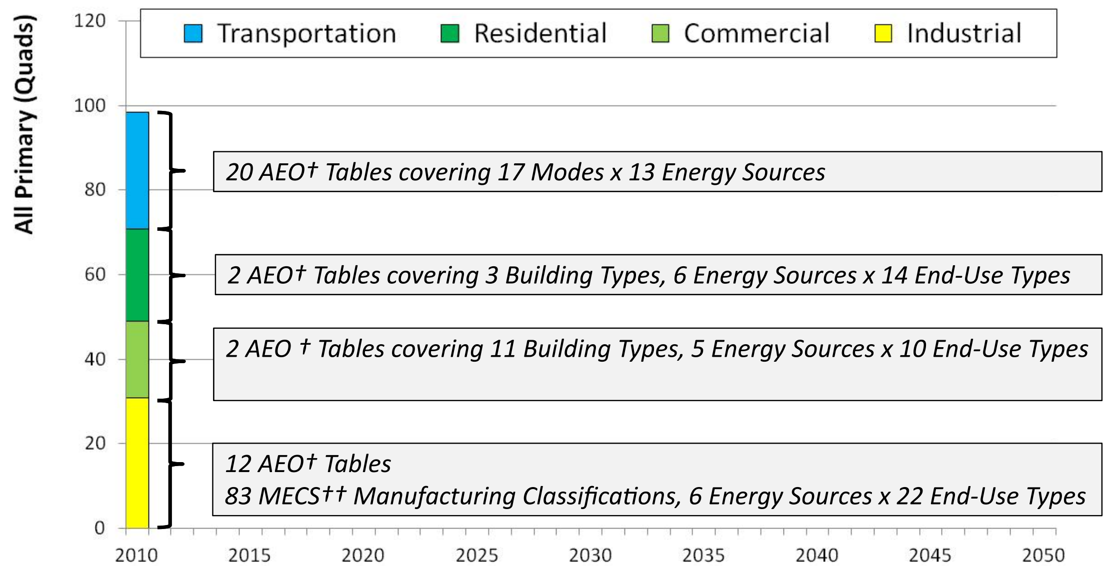
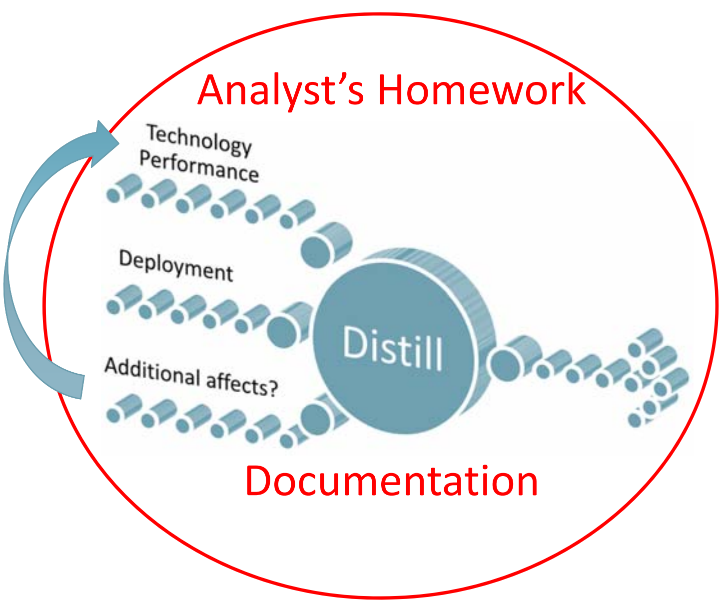
LIGHTEn-UP Tool – Publically Available U.S. Energy Consumption Data



† Annual Energy Outlook (AEO) Tables
†† Manufacturing Energy Consumption Survey

Protocol – Distilling scenarios to Three Key Variables



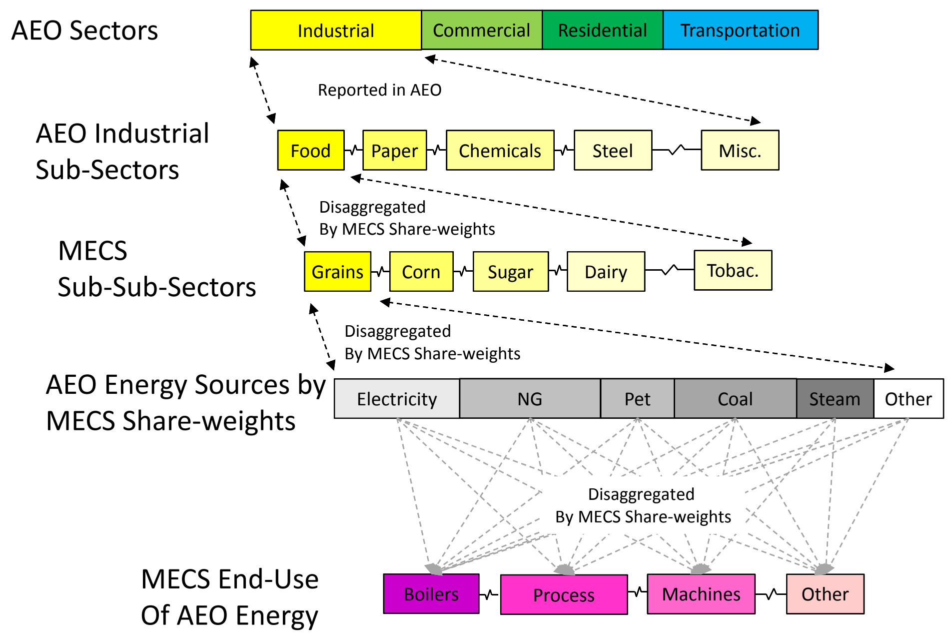
Three Key Variables For LIGHTEn-UP Tool

Where?
(Sector & end-use)

What?
(Energy Impact)

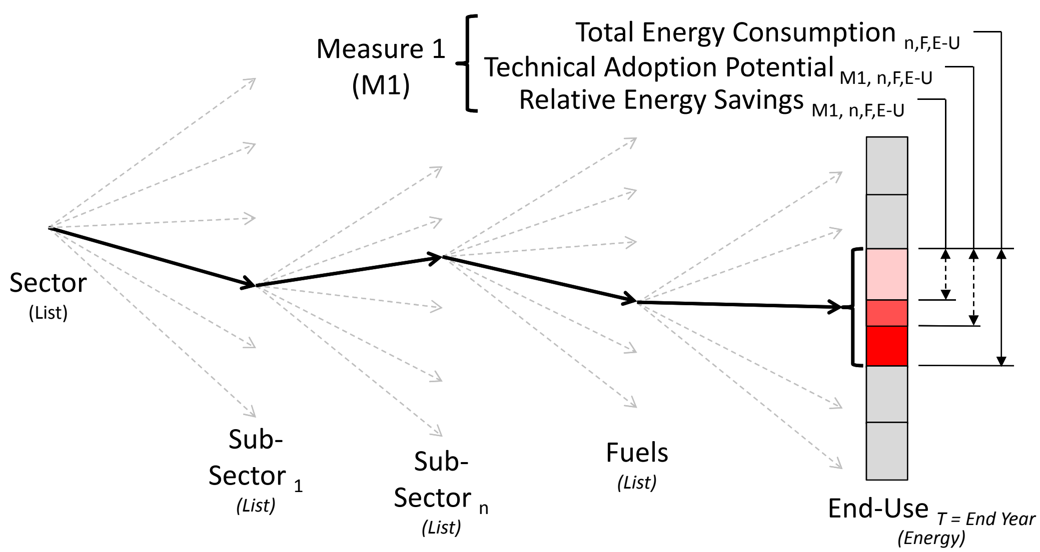
When?
(Start & End years)

Where will the impact be?



What will the impact be?

Technical Adoption Potential % & Relative Energy Savings %



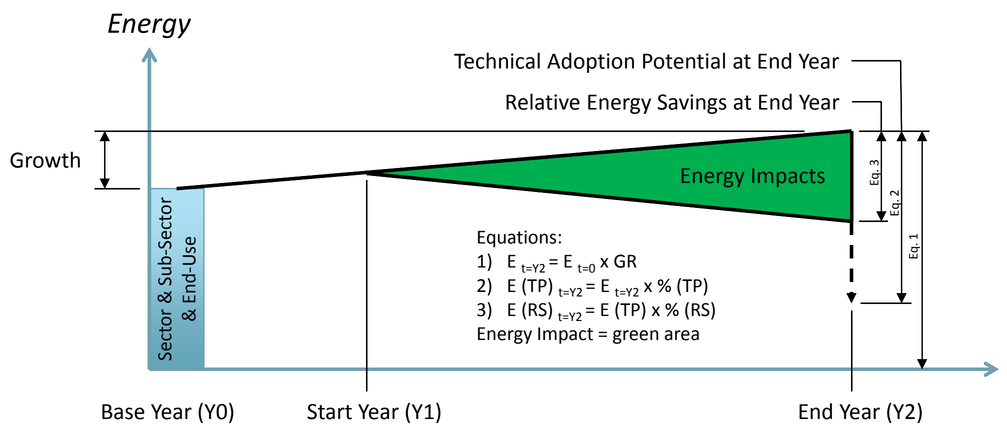
$$Technical\ Adoption\ Potential\ \% = \frac{Technical\ Adoption\ Potential_{M1,n,F,E-U}}{Total\ Energy\ Consumption_{n,F,E-U}}$$

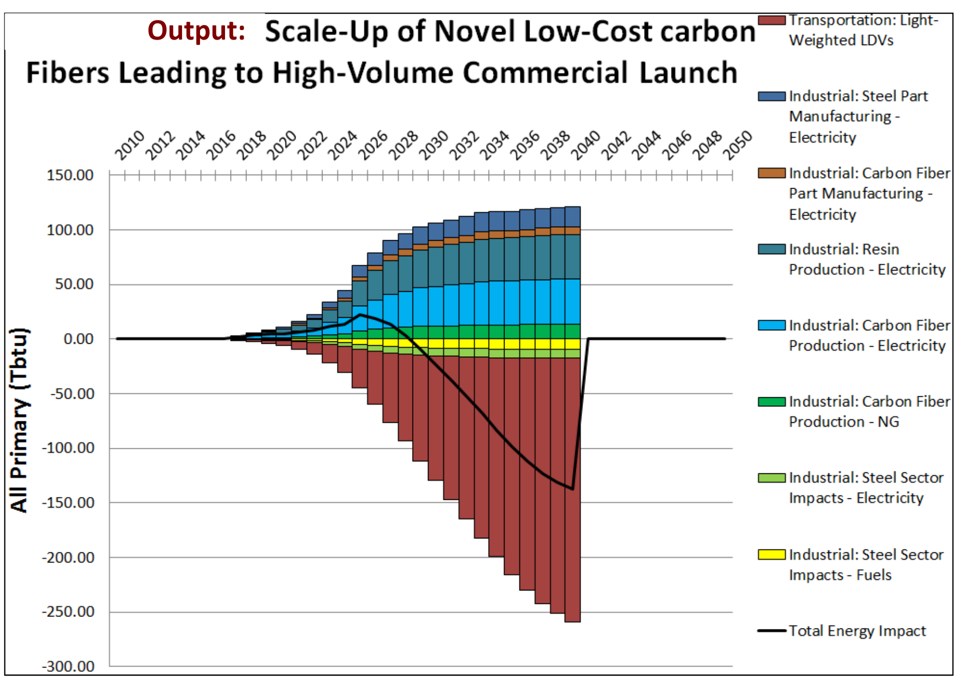
$$Relative\ Energy\ Savings\ \% = \frac{Relative\ Energy\ Savings_{M1,n,F,E-U}}{Technical\ Adoption\ Potential_{M1,n,F,E-U}}$$

Time – and when will the impact occur…?

Where? What? When?

Where: Which Sector & End-Use?			What Impact at End Year			When?	
Industrial Commercial Residential Transportation	Sub-Sector	End-Use	Technical Adoption Potential %	Relative Energy Savings %	Growth Rate Assumption	Start Year	End Year

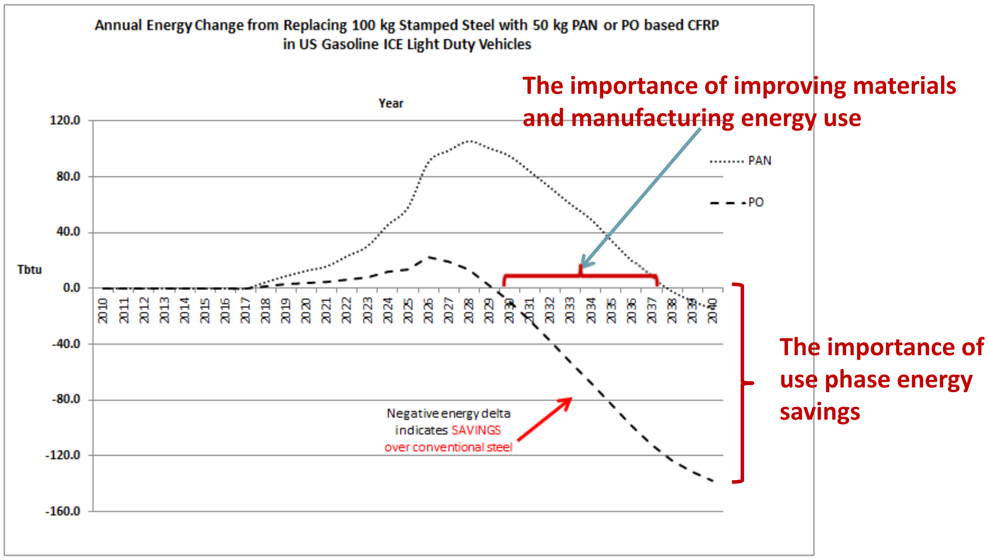




- LIGHTEn_UP shows fleet annual net energy impact (black line) increasing in initial years as CFRP production ramps up
- Beyond year 2030, net energy savings are realized as use phase benefits accrue (i.e. black line falls below x-axis)
- Within industrial sector:
  - Energy increases in carbon fiber and resin sectors due to increased CFRP production
  - Energy decrease in steel sector due to avoided steel production

Energy Consumption Savings from Lightweighting
Carbon Fiber Reinforced Plastics (CFRP) vs. Steel;
Improved CF (polyolefin) vs. current CF (polyacrylonotrile)

Why manufacturing energy use matters – accounting for vehicle turnover.



- Per vehicle savings of 2600 MJ per PAN vehicle and 11,500 MJ per PO vehicle
- Net energy impact of PO (dashed line) in US LDV fleet also compared with PAN (dotted line)
- Significantly greater materials and manufacturing energy investment with PAN – net energy savings temporally delayed and lesser magnitude

Thank You!

Joe Cresko
Joe.cresko@ee.doe.gov

Team:
Alberta Carpenter – NREL
Sujit Das – ORNL
Diane Graziano -ANL
Maggie Mann – NREL
William Morrow – LBNL
Eric Masanet - Northwestern
Sachin Nimbalkar - ORNL
Arman Shehabi - LBNL

Metrics for Sustainable Products and Processes

I. S. Jawahir
Professor of Mechanical Engineering,
James F. Hardymon Endowed Chair in Manufacturing Systems, and
Director of Institute for Sustainable Manufacturing (ISM)

www.ism.uky.edu

Introduction: *Sustainability as the Basis for Sustainable Growth and Value Creation*

- Sustainability is a ***global phenomenon***
- Sustainability ***IS NOT*** Sustainment, but is the basis for ***sustainable growth and value creation***

- Designing ***sustainable products*** and developing ***sustainable manufacturing processes*** have been a major research focus in ***sustainable manufacturing***

Innovation-based Sustainable Manufacturing

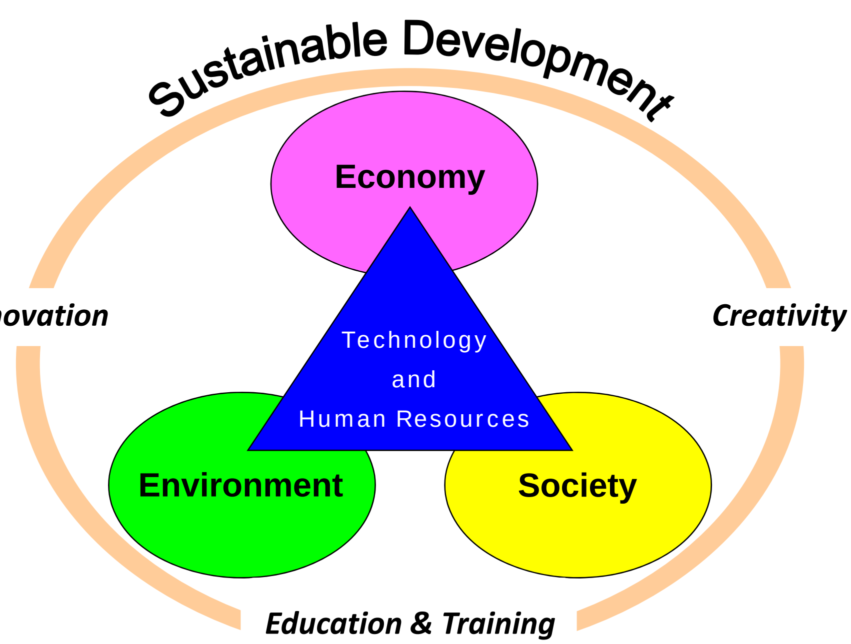
Sustainability is the driver for innovation

Innovation promotes accelerated growth in manufacturing

Manufacturing is the engine for wealth generation and societal well-being

Societal well-being and economic growth heavily depend on the level and quality of education and training

The Foundation of Sustainable Development



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Sustainable Manufacturing: Definitions

- ***Numerous definitions*** and descriptions exist for sustainable manufacturing:
  - US Department of Commerce, 2009
  - NACFAM, 2009
  - NIST, 2010
  - ASME, 2011, 2013
  - NSF 2013
- Almost all definitions fall short of showing the connectivity among the integral elements – ***No connectivity shown between sustainability and innovation or value creation***
- Sustainable manufacturing offers a new way of ***producing functionally superior products innovative sustainable technologies and manufacturing methods*** through the coordination of capabilities ***across the entire supply chain, not just the process chain***
- Sustainable manufacturing must enable ***sustainable value creation for all stakeholders.***

Sustainable Manufacturing: Revised Definition

Sustainable manufacturing must:

- demonstrate reduced ***negative environmental impact,***
- offer improved ***energy and resource efficiency,***
- generate ***minimum quantity of wastes***,
- provide ***operational safety,*** and
- offer improved ***personal health***

while maintaining and/or improving the ***product and process quality***

Source: Jayal et al. (201o) and Jawahir (2012) – Adapted from US Department of Commerce (2009)

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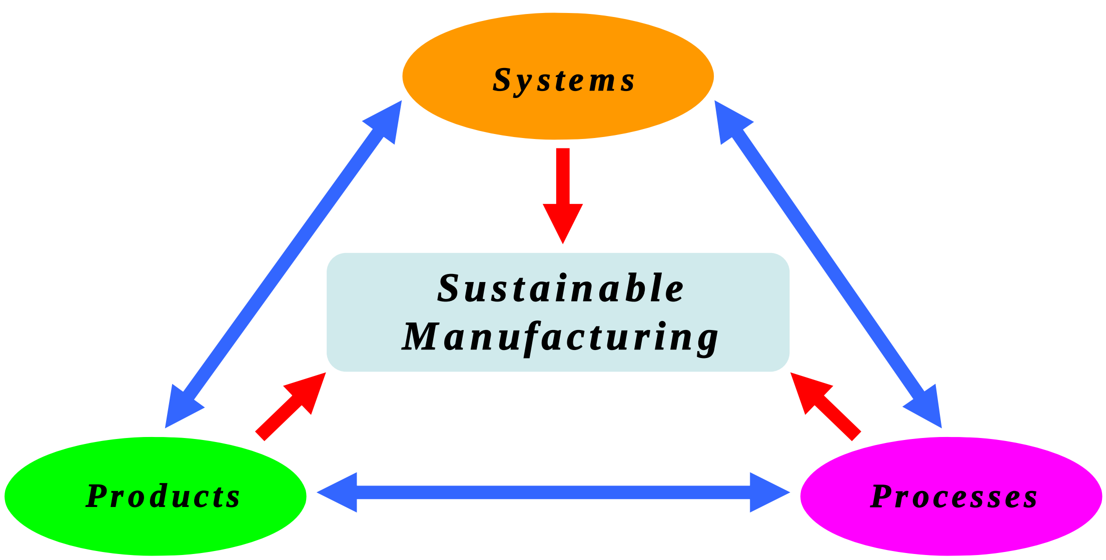
Sustainable Manufacturing: *Basic Elements*

Expectations:

- Reducing ***energy consumption***
- Reducing ***waste***
- Reducing ***material utilization***
- Enhancing ***product durability***
- Increasing ***operational safety***
- Reducing ***toxic dispersion***
- Reducing ***health hazards/Improving health conditions***
- Consistently improving ***manufacturing quality***
- Improving ***recycling, reuse and remanufacturing***
- Maximizing ***sustainable sources of renewable energy***

ISM Focus



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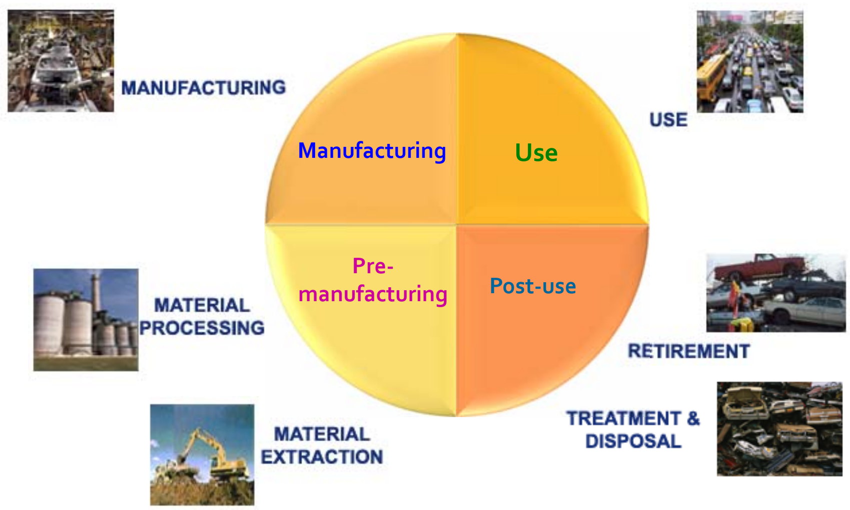
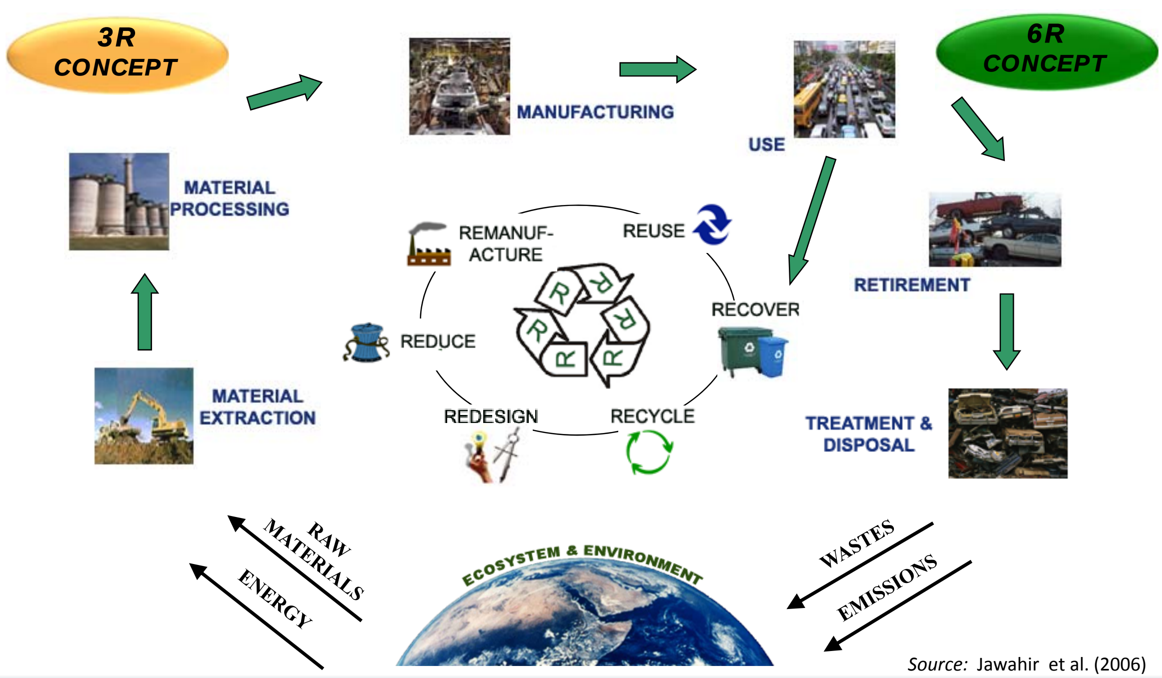
Holistic and Total Life-cycle Approach

Emphasis on all four product life-cycle stages

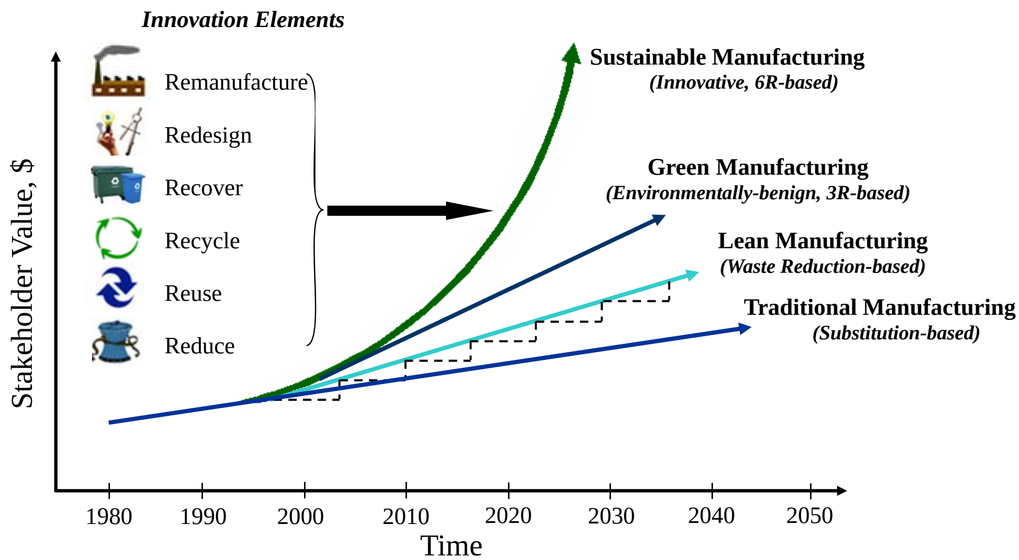


Closed-loop Material Flow – The 6R Approach

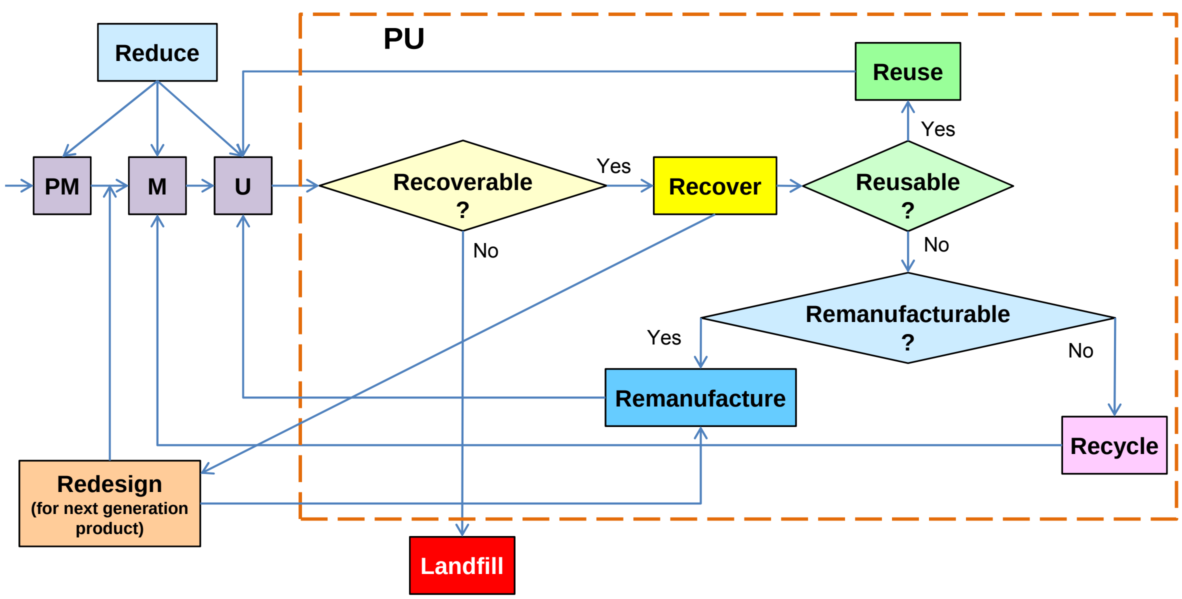


Source: Jawahir et al. (2006)

Evolution of Sustainable Manufacturing



Total Life-cycle 6R Applications for Sustainable Products



Overview of Existing Sustainability Measurement Systems

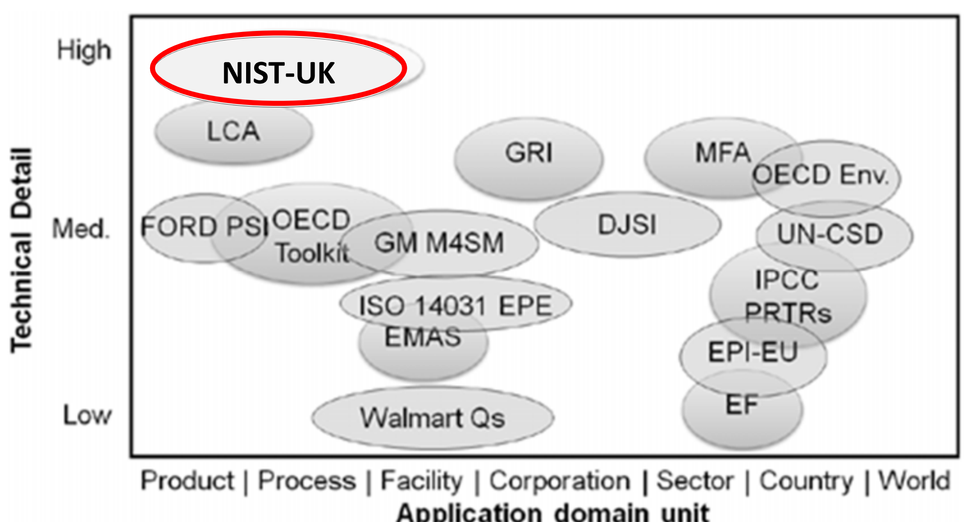
A list of existing measurement systems

Indicator Set	components
Global Reporting Initiative (GRI)	70 indicators
Dow Jones Sustainability Index (DJSI)	12 criteria based single indicator
2005 Environmental Sustainability Indicators	76 building blocks
2006 Environment Performance Indicators	19 Indicators
United Nations Committee on Sustainable Development Indicators	50 indicators
OECD Core indicators	46 indicators
Indicator database	409 indicators
Ford Product Sustainability Index	8 indicators
GM Metrics for Sustainable Manufacturing	46 Metrics
ISO 14031 environmental performance evaluation	155 example indicators
Wal-Mart Sustainability Product Index	15 questions
Environmental Indicators for European Union	60 indicators
Eco-Indicators 1999	3 main factors based single indicator

(Feng et al. 2010)

Overview of Existing Sustainability Measurement Systems (Cont.)

Comparison of the existing measurement systems



(Feng et al. 2010)

Product and Process Metrics for Sustainable Manufacturing: NIST-sponsored Project

Project Title: Development of Metrics, Metrology and a Framework for Product-Process Ontology for Interoperability in Model-Based Sustainable Manufacturing

Project Team: **Faculty:** Dr. I.S. Jawahir, Dr. F. Badurdeen, Dr. O.W. Dillon, Jr., Dr. K. Rouch
Graduate Students: T. Lu, M. Shuaib, X. Zhang, A. Huang, C. Stovall

Sponsor: NIST ***Industry partners:*** TOYOTA GE LEXMARK

Project Objective: To develop and implement tools and principles for quantitative evaluation of manufactured products and their manufacturing processes from the aspect of sustainable manufacturing

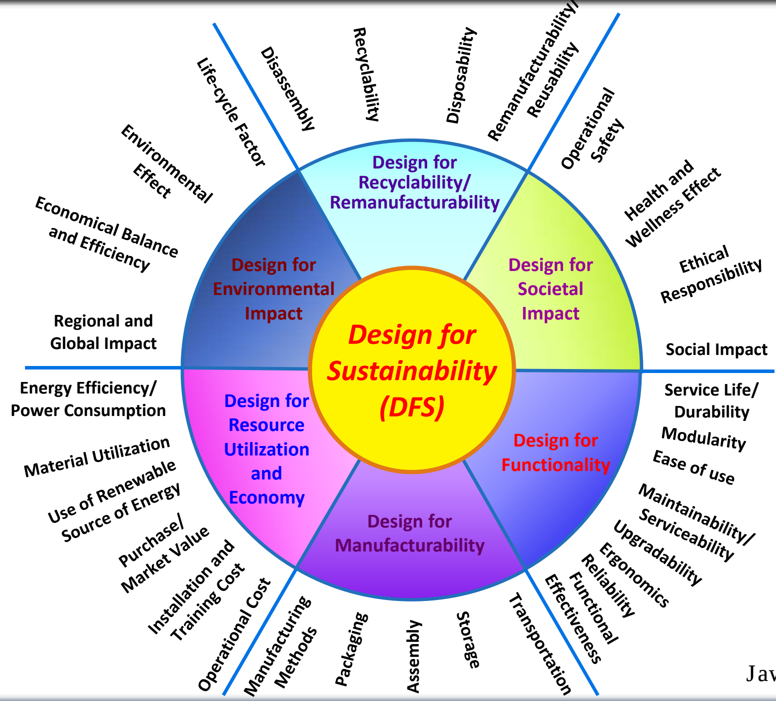
Metrics for Sustainable Manufacturing

- ***Manufacturing is an engine for wealth generation,*** and achieving sustainability in manufacturing is crucial to economy
- There is a ***critical need for developing improved metrics*** to evaluate the sustainability performance of a product and its manufacturing processes
- Metrics can help ***to improve decision-making with optimized product and process design*** for sustainable manufacturing

Project Summary

- The major sustainability elements and metrics of ***products and processes for sustainable manufacturing*** identified
- A framework for developing ***comprehensive product and process metrics*** for sustainable manufacturing developed

Product Design for Sustainability



Jawahir et al., 2006

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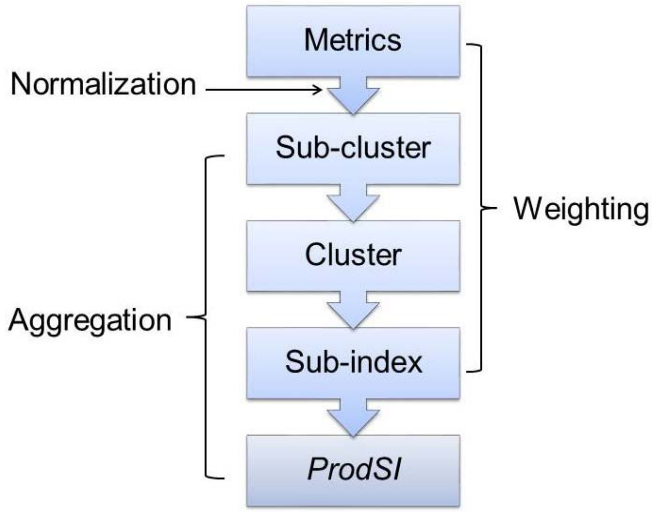
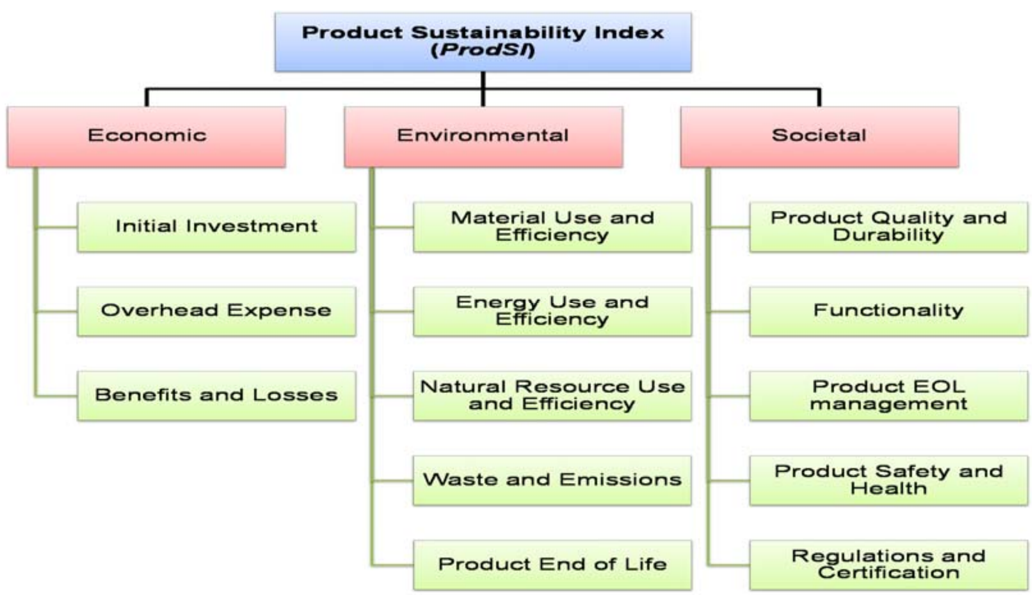
Hierarchical Structure of Product Sustainability Evaluation Method



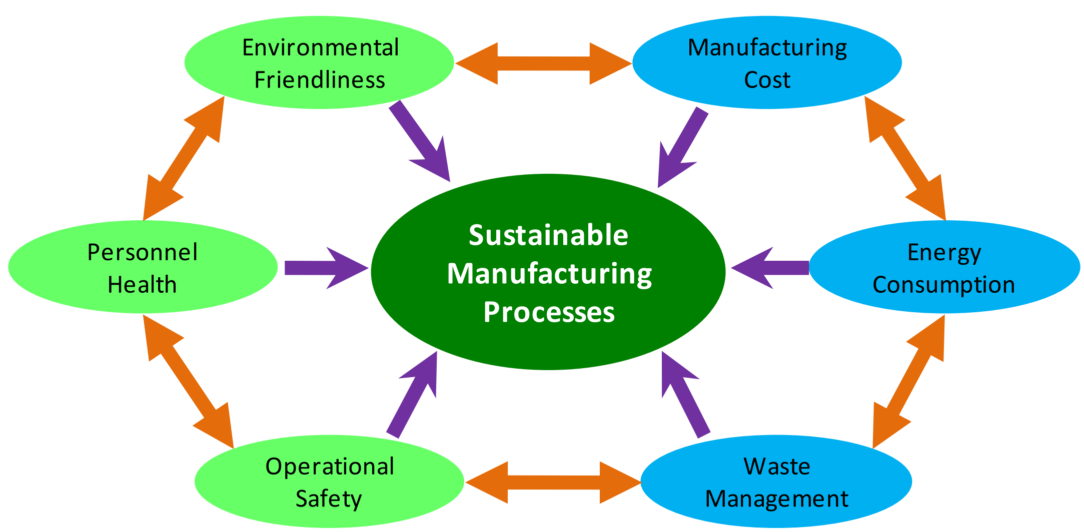
Product Clusters



Example Metrics for Product Clusters and Life-cycle Stages

Metrics Clusters	Example Metrics	Unit (D/L dimensionless)	PM (pre-mfg.)	M (mfg.)	U (use)	PU (post-use)
Residues	Emissions Rate (carbon-dioxide, sulphur-oxides, nitrous-oxides etc.)	mass/unit	√	√	√	√
Energy Use and Efficiency	Remanufactured Product Energy	kWh/unit		√	√	√
	Maintenance/ Repair Energy	kWh/unit			√	
Product End-of-Life Management	Design-for-Environment Expenditure	$/$ (D/L)		√		
Material Use and efficiency	Restricted Material Usage Rate	mass/unit	√	√		√
Water Use and Efficiency	Recycled Water Usage Rate	gallons/unit	√	√		√
Cost	Product Operational Cost	$/unit			√	
Innovation	Average Disassembly Cost	$/unit				√
Profitability	Profit	$/unit		√		
Product Quality	Defective Products Loss	$/unit		√		
	Warranty Cost Ratio	$/unit			√	
Education	Employee Training	Hours/unit	√	√		√
Customer Satisfaction	Repeat Customer Ratio	(D/L)		√	√	
	Post-Sale Service Effectiveness	(D/L)			√	
Product End-of-Life Management	Ease of Sustainable Product Disposal	$/unit			√	
Product Safety and Societal Well-being	Product Processing Injury Rate	incidents/unit	√	√		√
	Landfill Reduction	mass/unit	√	√	√	√

Process Sustainability Elements



(Wanigarathne et al., 2004)

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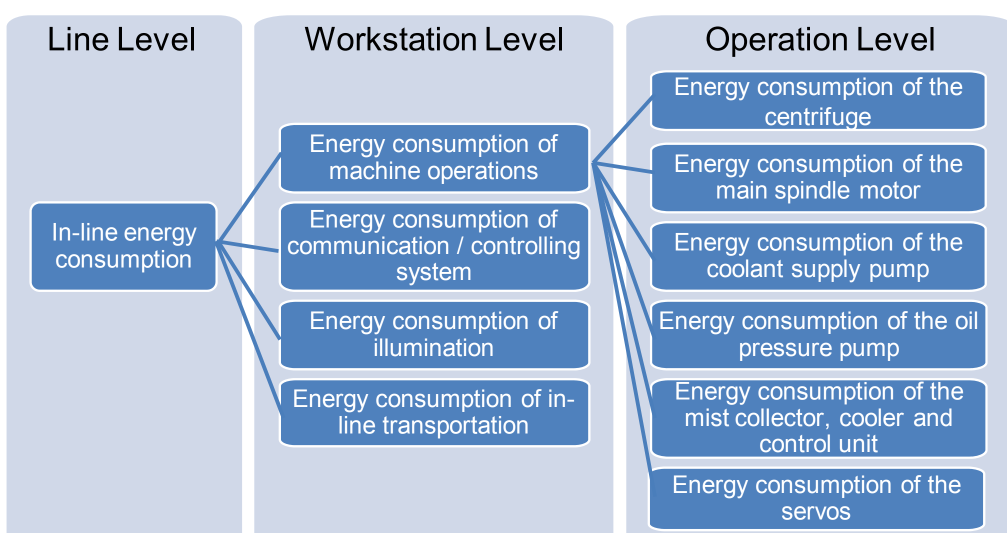
Process Sustainability Metrics

Environmental Impact	Energy Consumption	Cost
GHG emission from energy consumption of the line (ton CO_2 eq./unit) Ratio of renewable energy used (%) Total water consumption (ton/unit) Mass of restricted disposals (kg/unit) Noise level outside the factory (dB)	In-line energy consumption (kWh/unit) Energy consumption on maintaining facility environment (kWh/unit) Energy consumption on transportation into/out of the line (kWh/unit) Ratio of use of renewable energy (%)	Labor cost ($/unit) Cost for use of energy ($/unit) Cost of consumables ($/unit) Maintenance cost ($/unit) Cost of by-product treatment ($/unit) Indirect labor cost ($/unit)
Operator Safety	**Personnel Health**	**Waste Management**
Exposure to Corrosive/toxic chemicals (points/person) Exposure to high energy components (points/person) Injury rate (injuries/unit)	Chemical contamination of working environment (mg/m^3) Mist/dust level (mg/m^3) Noise level (dB) Physical load index (dimensionless) Health related absenteeism rate (%)	Mass of disposed consumables (kg/unit) Consumables reuse ratio (%) Mass of mist generation (kg/unit) Mass of disposed chips and scraps (kg/unit) Ratio of recycled chips and scraps (%)

Three-level Process Sustainability Metrics for Energy Consumption



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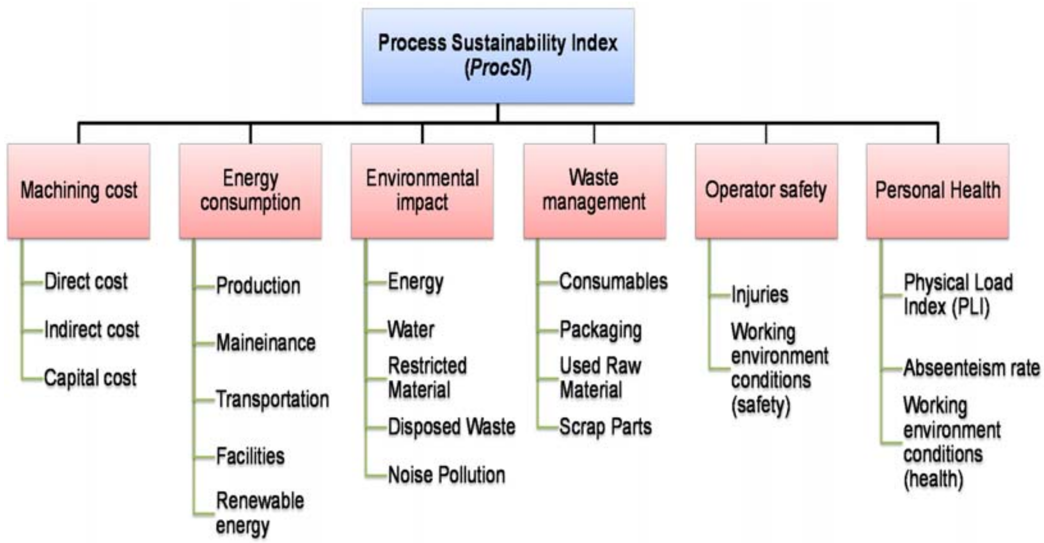
Process Sustainability Clusters and Sub-clusters



ProdSI and ProcSI Evaluation

$$ProdSI = \frac{1}{3}\left(Ec + Ev + So\right) = \frac{1}{3}\left(\sum_{i=1}^{3} w_i^C C_i + \sum_{i=4}^{8} w_i^C C_i + \sum_{i=9}^{13} w_i^C C_i\right) \quad C_m = \sum SC_j w_j^{sc} \ \forall j \quad SC_n = \sum M_k w_k^m \ \forall j$$

$$ProcSI = \frac{1}{6}\sum_{i=1}^{6} C_i = \frac{1}{6}\left(C_1 + C_2 + \frac{1}{5}\sum_{i=10}^{14} w_i^{sc} SC_i + \frac{1}{4}\sum_{i=15}^{18} w_i^{sc} SC_i + \frac{1}{3}\sum_{i=19}^{21} w_i^{sc} SC_i + \frac{1}{2}\sum_{i=22}^{23} w_i^{sc} SC_i\right)$$

$$SC_n = \sum w_j^m M_j \forall j$$

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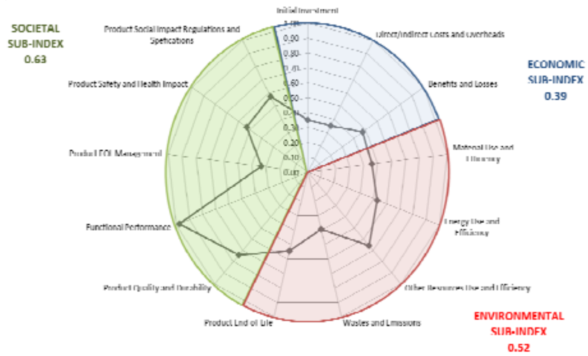
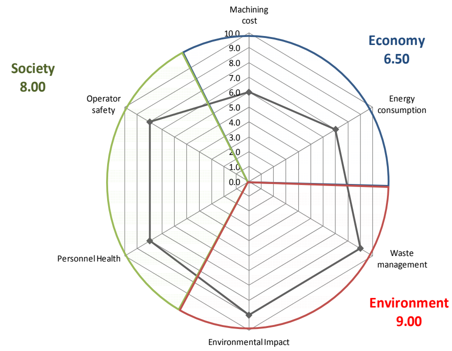
Examples of ProdSI and ProcSI



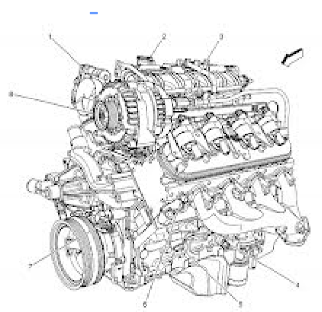
(a) *ProdSI*

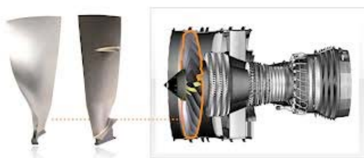


(b) *ProcSI*

Sustainability Improvement in Products and Processes

Case studies were conducted on three major manufactured products





Implementing Product and Process Sustainability Metrics

Current State:

- Considerable effort in the manufacturing industry, with corporate commitment to sustainability
- Promotion of dedicated educational and training programs and workforce development

Limitations:

- Slow progress and limited effectiveness in implementing sustainable practices --- No economic benefits shown, and no standards despite significant push for regulatory measures
- Difficulty in identifying relevant tools and techniques for evaluation
- Complexity in measuring and quantifying sustainability elements in manufactured products and manufacturing processes

Outlook and Opportunity:

- Metrics-based evaluation of sustainable products and processes offers an new opportunity for quantitative evaluation of sustainability in manufacturing
- Sustainability is the driver for innovation
- Significantly improved manufacturing productivity through product/process innovation

Acknowledgements

- Project Sponsor: NIST (Award No: 60NANB10D009) 2010-13
- Industry Participants:
  - GE-Aviation
  - Toyota Motor Manufacturing
  - Lexmark International

Perspectives of an Owner & Builder on Metrics

June 12, 2014

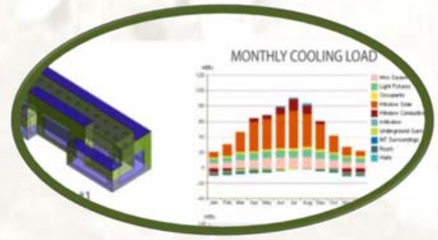
James Dalton, P.E., SES
Chief, Engineering & Construction
US Army Corps of Engineers

An Owner-Builder Perspective

As we design and build…

- Data measured from prior project informs new design efforts
- Energy models are not predictive of energy use
- Holding designers, builders and users to a meter reading is difficult
- Smart Meters and digital control system architectures can be a challenge
- Maintaining new technologies is difficult
  - Struggling with mechanical systems

An Owner-Builder Perspective (continued)



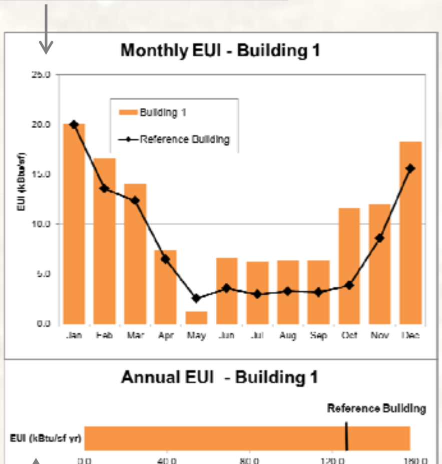
Some additional thoughts ……

- ➔ Measure only what we need to know
  - ➔ How are we informed what that is?
  - ➔ Are dashboards more effective than meters?
  - ➔ Is there a role for BIM?
- ➔ Require measures that hold a designer/builder accountable
  - ➔ We have had success with air tightness and infrared testing
  - ➔ Help us discern Designer/Building/User affects on building performance
  - ➔ Need something more….

Sample Army MDMS Display work in progress

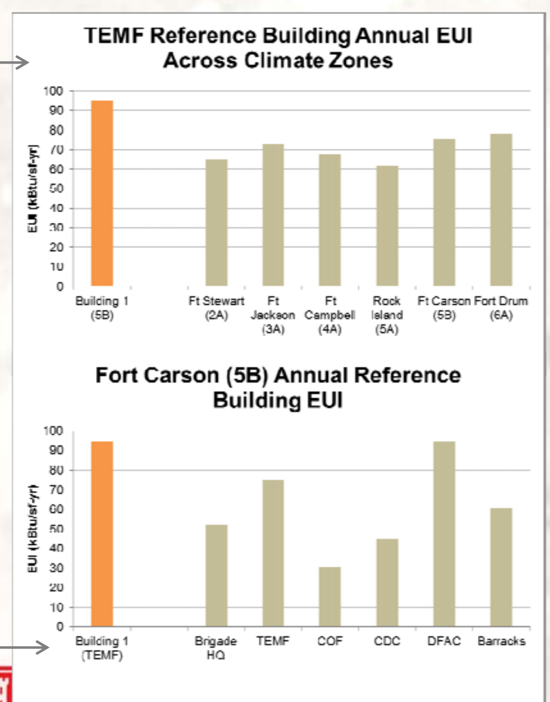
Compare against reference building monthly consumption to detect seasonal trends

Compare across climate zones for same building type



Compare annual EUI of 'your' building with reference building

Compare across building types in same climate zone



Questions?

Workshop on Measurement Science for Sustainable Construction and Manufacturing
International perspectives on metrics

Bo Kasal,
Fraunhofer WKI, Braunschweig,
Germany

The Fraunhofer-Gesellschaft

Research and development

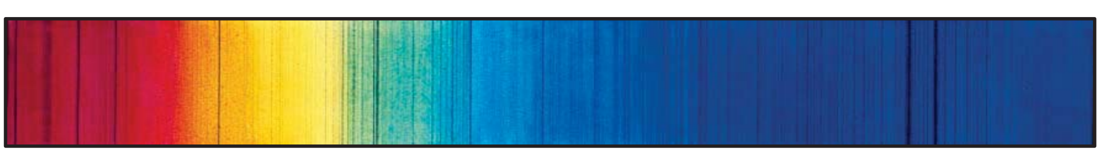
- Application-oriented research of direct use to businesses and for the benefit to society
- Application-oriented basic research
- Departmental research for the German Federal Ministry of Defense

Business community

- Institutes work as profit centers
- One-third of the budget consists of income from industrial projects
- Spinoffs by Fraunhofer researchers are encouraged

Contracting partners/clients

- Industrial and service companies
- Public sector



Fraunhofer is the largest organization for applied research in Europe

- 66 Fraunhofer institutes and independent research units
- More than 24,000 employees, the majority educated in the natural sciences or engineering
- An annual research volume of 2.1 billion euros, of which 1.7 billion euros is generated through contract research.
  - 2/3 of this research revenue derives from contracts with industry and from publicly financed research projects.
  - 1/3 is contributed by the German federal government and the *Länder* governments in the form of institutional financing.
- International collaboration through representative offices in Europe, the US, Asia and the Middle East

Fraunhofer WKI

Joseph von Fraunhofer

The Fraunhofer-Gesellschaft

Joseph von Fraunhofer		The Fraunhofer-Gesellschaft
Discovery of the "Fraunhofer lines" in the solar spectrum	Researcher	Research and development on behalf of industry and state
New methods for processing lenses	Inventor	mp3 music format, white LED, high-resolution thermal camera
Director and partner in a glassworks	Entrepreneur	Research volume: approx. 2.0 billion euros annually

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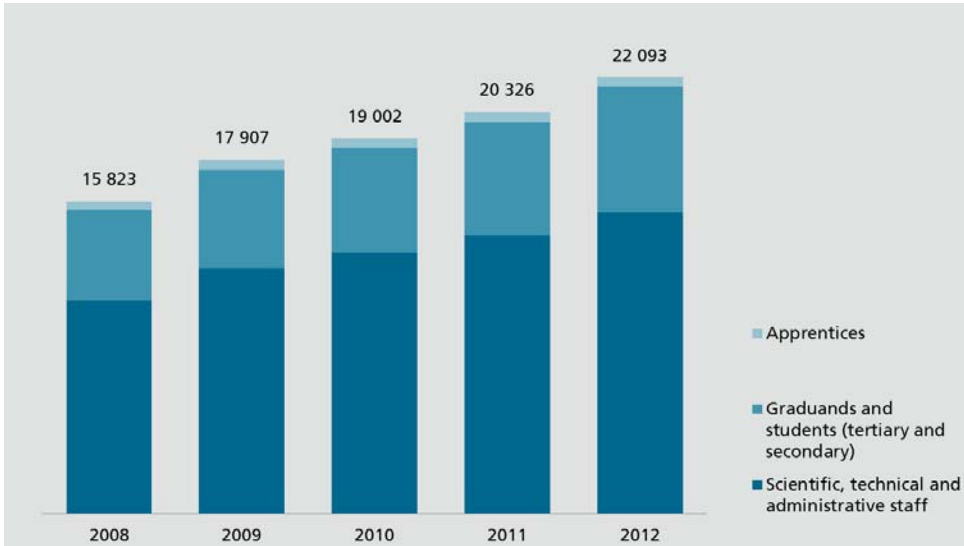
Fraunhofer-Gesellschaft Human Resources
2008 - 2012



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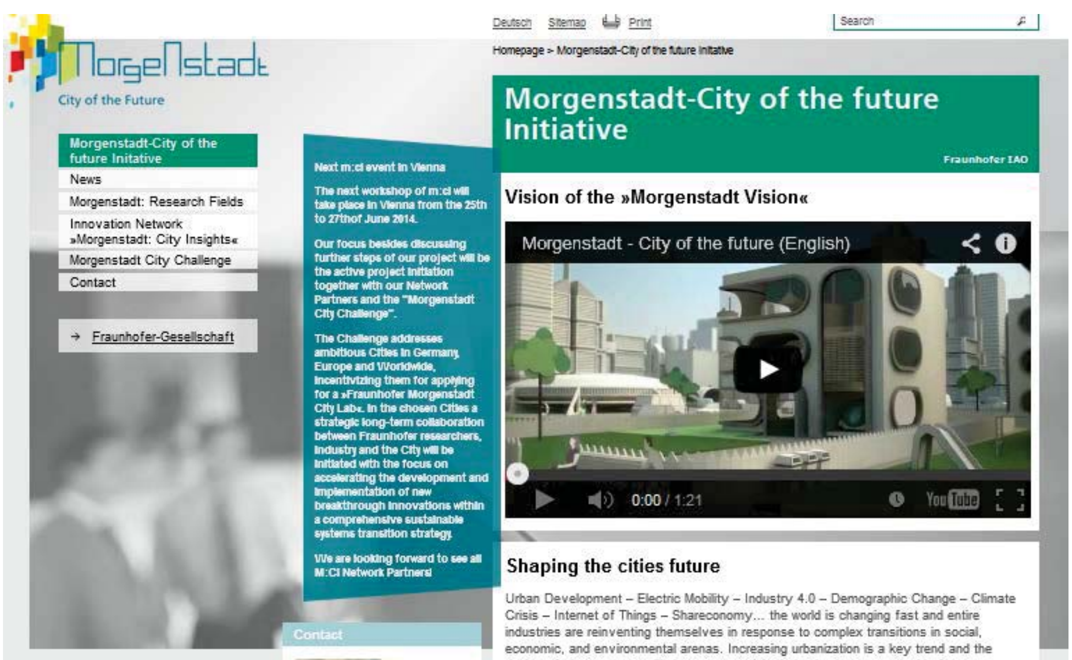
Fraunhofer Alliances

- Adaptronics
- Additive Manufacturing
- Advancer
- Ambient Assisted Living AAL
- Automobile Production
- Building Innovation
- Cleaning Technology
- Cloud Computing
- Digital Cinema
- E-Government
- Embedded Systems
- Energy
- Food Chain Management
- Lightweight Structures
- Nanotechnology
- Optic Surfaces
- Photocatalysis
- Polymer Surfaces POLO
- Simulation
- Traffic and Transportation
- Vision
- Water Systems (SysWasser)

Fraunhofer WKI


Fraunhofer
Hans Carl von Carlowitz - Discoverer of the principle of sustained yield forestry
* 14th December 1645, Oberrabenstein
† 3rd March 1714, Freiberg, Saxony
SUSTAINABILITY AND RESEARCH
Wavelength in nm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Fraunhofer-Gesellschaft
Next m:ci event in Vienna
The next workshop of m:ci will take place in Vienna from the 25th to 27thof June 2014.
Our focus besides discussing further steps of our project will be the active project initiation together with our Network Partners and the "Morgenstadt City Challenge".
The Challenge addresses ambitious Cities in Germany, Europe and Worldwide, incentivizing them for applying for a »Fraunhofer Morgenstadt City Lab«. In the chosen Cities a strategic long-term collaboration between Fraunhofer researchers, industry and the City will be initiated with the focus on accelerating the development and implementation of new breakthrough innovations within a comprehensive sustainable systems transition strategy.
We are looking forward to see all M:CI Network Partners!
Contact
Morgenstadt-City of the future Initiative
Fraunhofer IAO
Vision of the »Morgenstadt Vision«
Morgenstadt - City of the future (English)
0:00 / 1:21
YouTube
Shaping the cities future
Urban Development – Electric Mobility – Industry 4.0 – Demographic Change – Climate Crisis – Internet of Things – Shareconomy... the world is changing fast and entire industries are reinventing themselves in response to complex transitions in social, economic, and environmental arenas. Increasing urbanization is a key trend and the

Braunschweig

Phases of construction

- land development phase
- material production phase
- construction phase
- building function/use phase
- maintenance and repair phase
- deconstruction and recycling phase

Land development

- parcel into lots
- storm water management
- roads
- sewer, water, power
- communication

Material production phase

- production of building materials
- can be speculative if not defined for a specific project with known suppliers

http://www.dw-world.de/dw/article/0,,5988100,00.html

Construction phase

- can be speculative if not defined for a specific project with known suppliers and manufacturers of goods

Building function/use phase

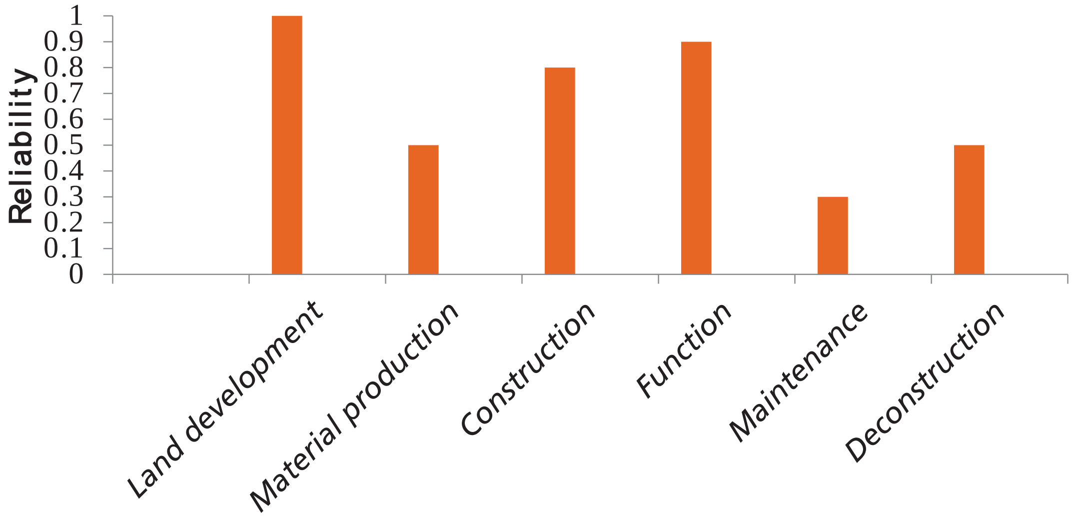
- can be measured/quantified
- building can be instrumented and data collected
  - energy use
  - water use
  - building comfort parameters.......

Maintenance and repair phase

- speculative
- no good data available
- hard to predict

Deconstruction

- speculative
- no good data avaiable
- hard to predict



Sources of uncertainty

- Random error and statistical variation (measurement error)
- Systematic error and subjective judgment
- Linguistic imprecision (Assigning quantitative parameter estimates based on qualitative descriptors)
- Variability (data variability)
- Inherent randomness and unpredictability
- Expert uncertainty and disagreement
- Approximation

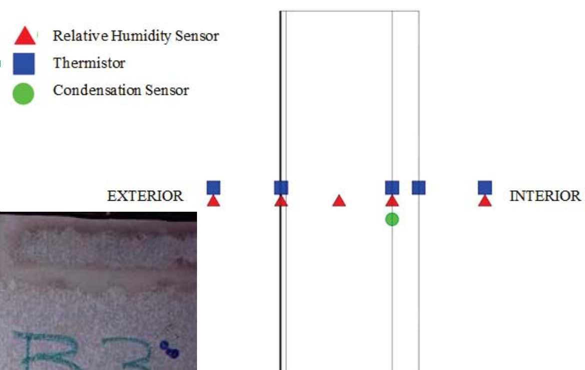
1 Shannon M. Lloyd and Robert Ries. (2007) Characterizing, Propagating, and Analyzing Uncertainty in Life-Cycle Assessment A Survey of Quantitative Approaches. Journal of Industrial Ecology. Vil. 11.1.

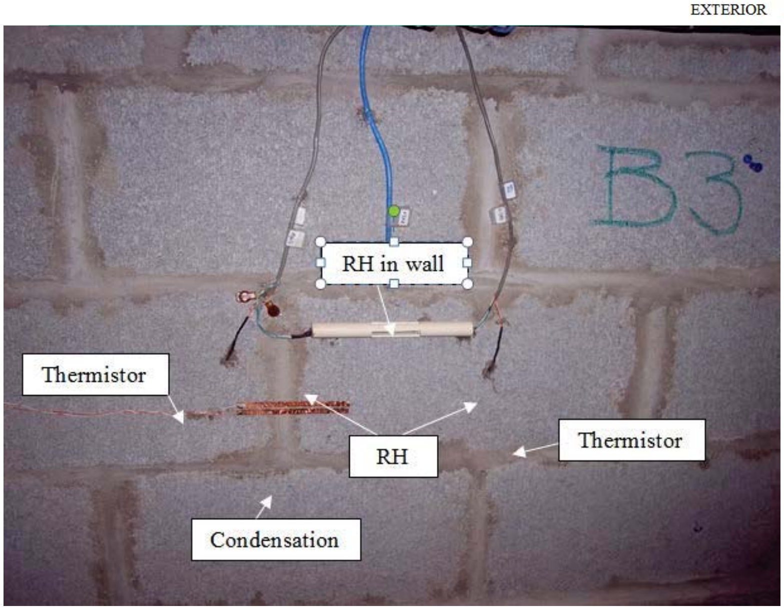
Parameters and frequency of measurements – building envelope

Component/Parameter		Parameters measured Frequency							
		Temperature	*RWVP*	*Acceleration/ Vibrations*	*Noise intensity*	*Formaldehyd concentration*	*VOC concentration*	*Light intensity*	*Air exchange*
		continuously	continuously	triggered	triggered	daily/weekly or random	daily/weekly or random	hourly	random
Building envelope	Walls	x	x						
	Openings	x						x	
	Roof	x	x						
Interior partitions				x					
Ceilings/Floors		x	x	x					
Indoor climate	Rooms	x	x		x	x	x	x	x
Energy consumption/mechanical systems (HVAC)	Rooms Mech. systems	x	x					x	x
Ageing of materials		x	x			x	x	x	
Water consumption Wastewater discharge	Building	continuously							
Exterior environment (weather station)	wind, rain, snow fall, sun radiation	x	x		x		x	x	

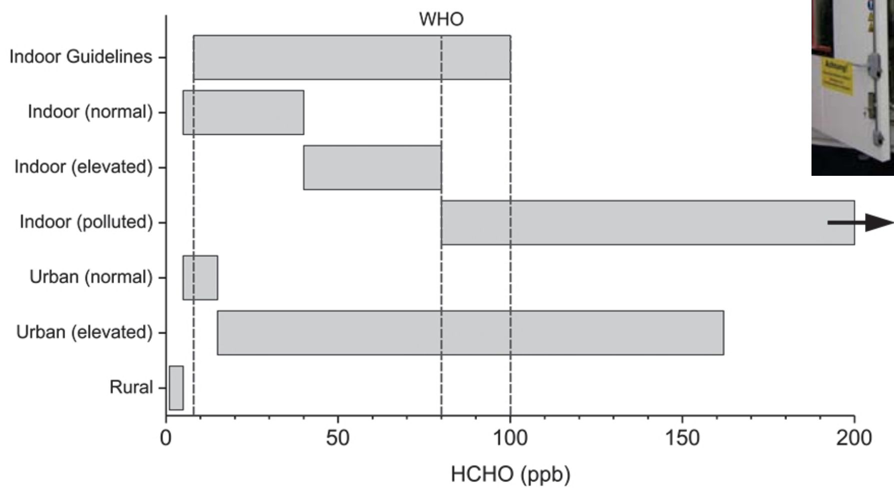
		warm side room climate	cold side outside climate
Temperature	[°C]	0 … 35	-40 … 60
Humidity	[% r.H.]	30 … 95	20 … 95
Volume main chamber	[m³]	73	35
auxiliary chamber	[m³]	2 x 13	(2 x 7)*
Heating power	[kW]	6 x 3	6 x 4,5
Cooling power	[kW]	6 x 5	6 x 6
condensation temperature	[°C]	45	45
vaporization temperature	[°C]	-10	-35

* Standby chambers for sun- and rain simulators





Indoor air quality



Salthammer (2013) Angew. Chem. Int. Ed. 52, 3320-3327

Indoor air quality-example of inconsistencies (HCHO)

➢ California / USA	CARB Phase 2	PB: 0.09 ppm MDF: 0.11 ppm Thin MDF: 0.13 ppm PLY: 0.05 ppm
➢ Japan	F☆… F☆☆☆☆	F☆☆☆☆ (JIS chamber): 0.005 µg/h·m³ F☆☆☆☆ (JIS desiccator): 0.3 mg/L F☆☆☆☆ can be used indoor without any restriction
➢ Russia	E1	coated PB: 0.1 ppm *probably new (July 1st, 2014): 0.01 ppm* PLY: 0.1 ppm PB: 8 mg/100 g dry board
➢ China	E1 E2	E1: ≤ 0.1 ppm ≤ 9.0 mg/100 g dry board E2*: ≤ 30 mg/100 g dry board *use for indoor air only after surface treatment

Indoor air quality-example of inconsistencies (HCHO)

- Europe — E1 E2

EN 13986 building products
(reference chamber method EN 717-1):
E1: ≤ 0.1 ppm (≙ 0.124 mg/m³)
E2: > 0.1 ppm (≙ 0.124 mg/m³)
< 0.24 ppm (≙ 0.3 mg/m³)

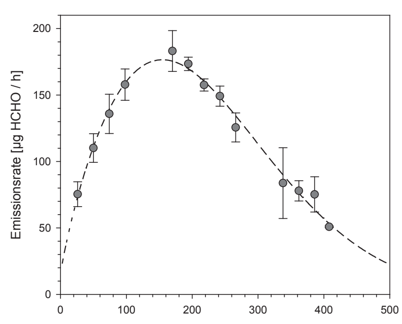
- Germany
- Austria
- Czech Republic
- Denmark
- Italy
- Sweden

} E1

Mandatory for building products and furniture

Assesment of building sustainability

- considered „soft science“
- number of standards available
- many parameters subjective or speculative[1]
- using of materials from renewable resources makes the building not automatically sustainable
- stochastic approaches desirable[1,2]



1. Shannon M. Lloyd and Robert Ries. (2007) Characterizing, Propagating, and Analyzing Uncertainty in Life-Cycle Assessment A Survey of Quantitative Approaches. Journal of Industrial Ecology. Vil. 11.1.
2. 2. Miller, Shelie A., Stephen Moysey, Benjamin Sharp and Jose Alfaro. (2013) “A Stochastic Approach to Model Dynamic Systems in Life Cycle Assessment.” Journal of Industrial Ecology 17(3): 352–362.

International prospective

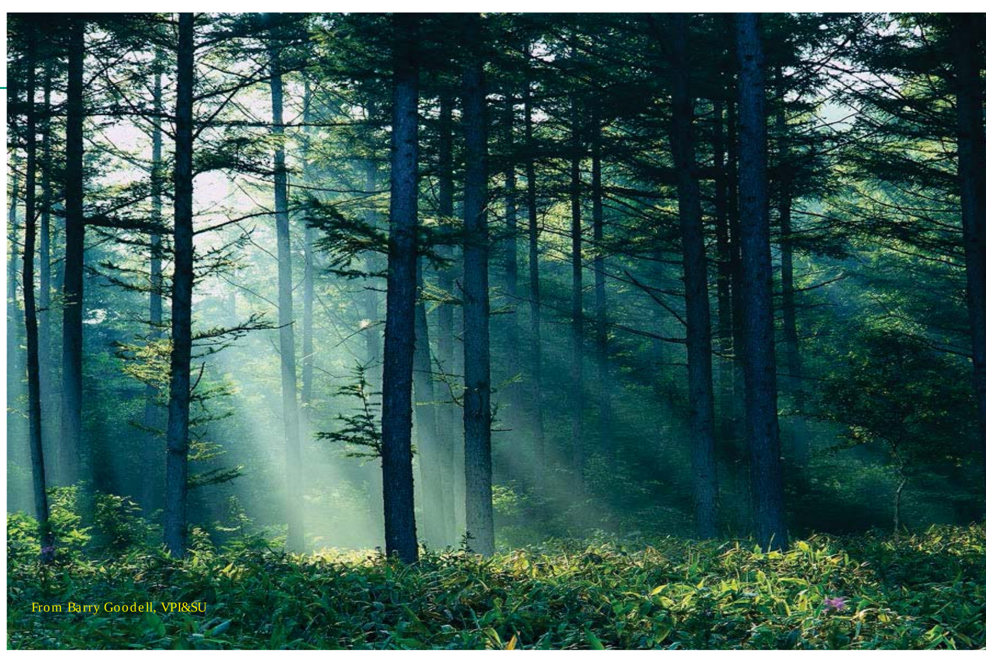
- 7 billion people on the planet
- 5.9 billion living in developing world
- 44% (3 billion) no access to sanitation
- 24% of people living under $1.25/day
- 80% of people living under $10/day
- people in rich countries use 10x more natural resources than those in poor countries

Our ability to move towards sustainability may be limited.

Perhaps, our solutions should be adjusted to the needs of the 80% of the population

Sources: http://unstats.un.org/unsd/demographic/products/dyb/dyb2011/Table01.pdf; http://unstats.un.org/unsd/demographic/products/socind/default.htm (table 1c); http://mdgs.un.org/unsd/mdg/Resources/Static/Products/Progress2012/English2012.pdf; http://www.fao.org/docrep/016/i3010e/i3010e.pdf (State of the World's Forests 2012); Williams, M. 2002. Deforesting the earth: from prehistory to global crisis. Chicago, USA, University of Chicago Press.

http://www.fao.org/docrep/013/i1757e/i1757e.pdf; https://www.cia.gov/library/publications/the-world-factbook/rankorder/2004rank.html; http://iresearch.worldbank.org/PovcalNet/index.htm?1; http://www.prb.org/pdf12/2012-population-data-sheet_eng.pdf



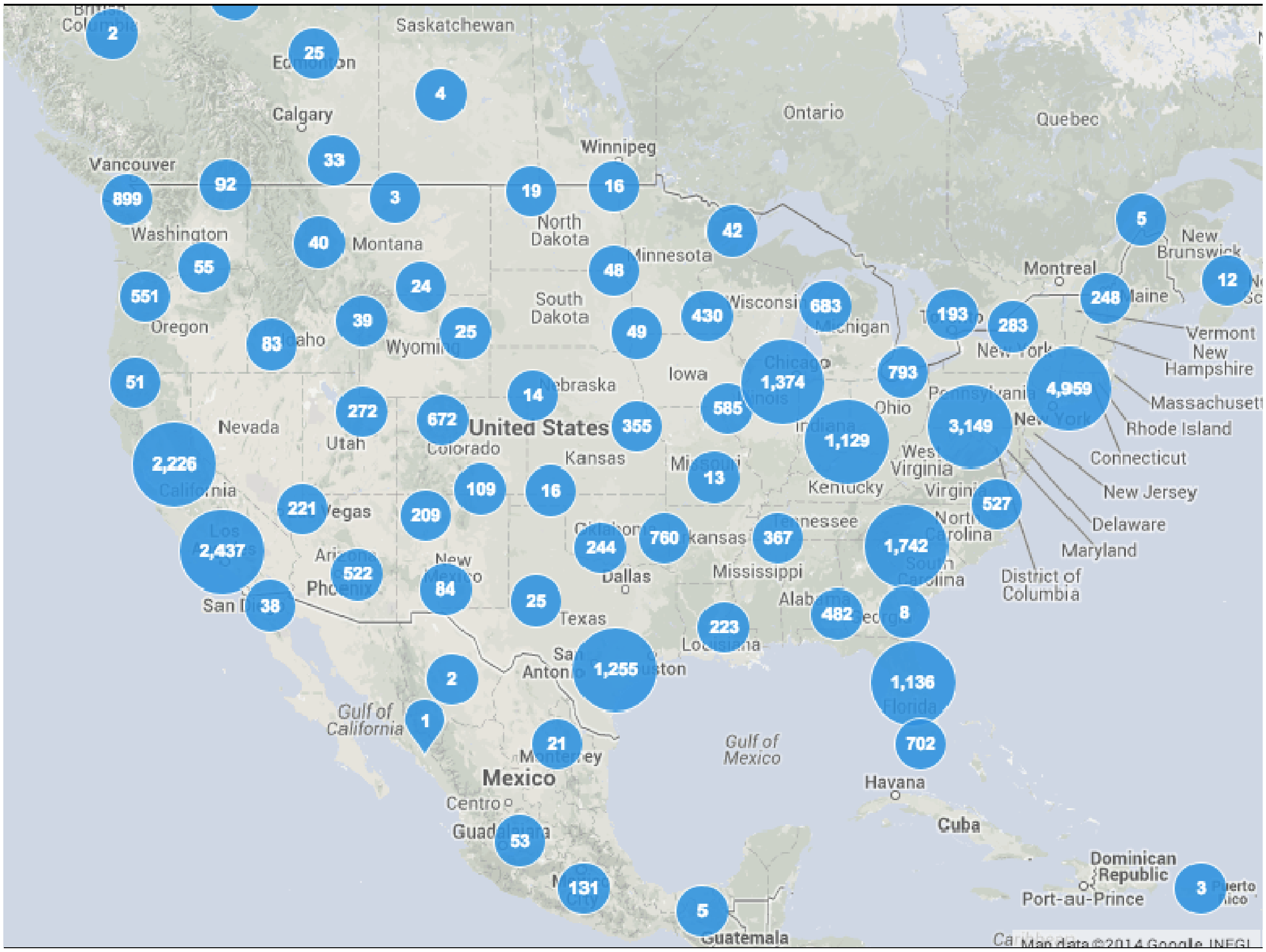
From Barry Goodell, VPI&SU

CURRENT & FUTURE OPPORTUNITIES FOR MEASURES OF

HIGH PERFORMANCE GREEN BUILDINGS

A DECADE OF GREEN BUILDING

RESULTS ON THE GROUND



LEED AND ENERGY STAR: 74,265 BUILDINGS WITH

>2,000 GREEN ATTRIBUTES AND PERFORMANCE MEASURES

ENERGY

ASHRAE 90.1
TITLE 24
ENERGY STAR
RENEWABLE ENERGY
GREEN POWER

WATER

FIXTURE EFFICIENCY
LANDSCAPING
PROCESS

SITE DESIGN

ACCESSIBILITY
STORMWATER
HEAT ISLAND

MATERIALS

SOURCE
RECYCLED CONTENT
END-OF-LIFE

OCCUPANTS

SATISFACTION
COMFORT
CONTROL

IMPLIED VALUE OF METRICS

RANK	RATING SYSTEMS
1	OPERATIONAL ENERGY
2	OPERATIONAL WATER
3	MATERIALS
4	OCCUPANT BEHAVIOR & PERFORMANCE

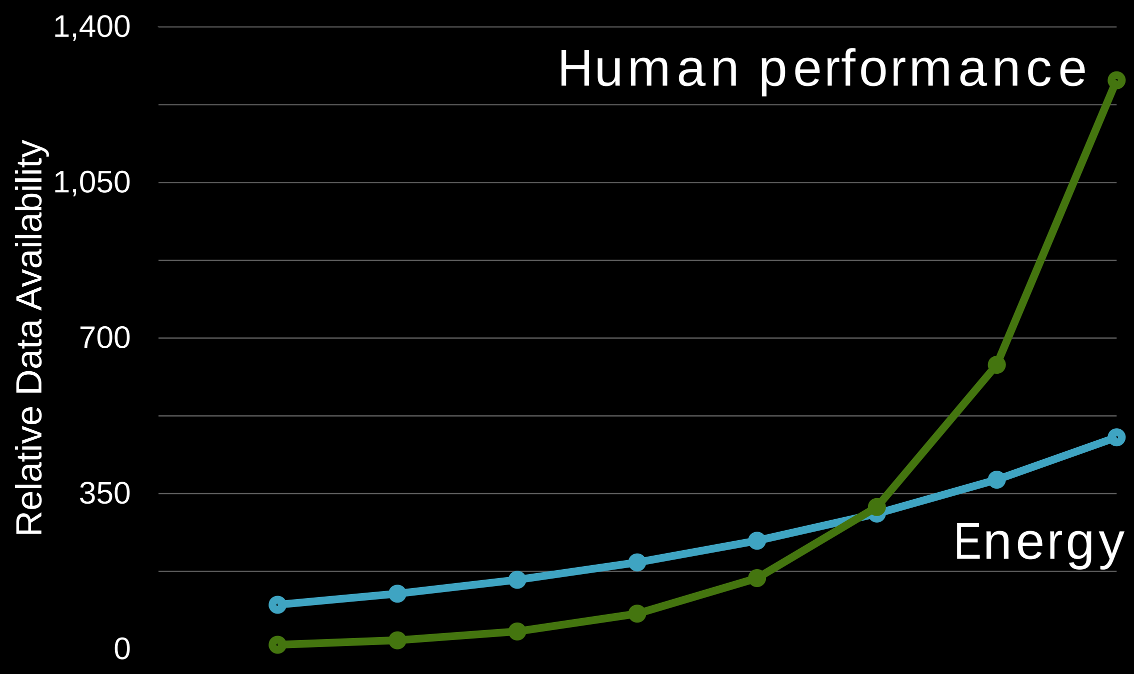
IMPLIED VALUE OF METRICS

RANK	RATING SYSTEMS	ENV IMPACT
1	OPERATIONAL ENERGY	OCCUPANT BEHAVIOR & PERFORMANCE
2	OPERATIONAL WATER	OPERATIONAL ENERGY
3	MATERIALS	MATERIALS
4	BEHAVIOR & SATISFACTION	OPERATIONAL WATER

IMPLIED VALUE OF METRICS

RANK	RATING SYSTEMS	ENV IMPACT	FINANCIAL IMPACT
1	OPERATIONAL ENERGY	OCCUPANT BEHAVIOR & PERFORMANCE	OCCUPANT BEHAVIOR & PERFORMANCE
2	OPERATIONAL WATER	OPERATIONAL ENERGY	OPERATIONAL ENERGY
3	MATERIALS	MATERIALS	OPERATIONAL WATER
4	BEHAVIOR & SATISFACTION	OPERATIONAL WATER	MATERIALS

A SCENARIO OF FUTURE DATA AVAILABILITY



INTERESTED IN THIS CHALLENGE?

EXPLORE: INSIGHT.GBIG.ORG

CONTACT: CPYKE@USGBC.ORG

FOLLOW @CHRISPYKE

Introduction to Breakout Sessions

Richard N. Wright, Dist.M.ASCE, NAE

June 12, 2014

Sustainability in Construction and Manufacturing

- No separation between construction and manufacturing because constructed facilities are manufactured products.
- For both, we are interested in sustainability over their whole life cycles.
- Generally similar measurement issues are expected, but distinctions should be noted as they occur to a breakout session team.

Objectives of Breakout Sessions

- Identify knowledge gaps and research needs relating to measurement science for sustainable construction and manufacturing
- Provide suggestions in the form of problems, descriptions, analyses, recommendations and actions for the consideration of NIST

Breakout Sessions

1. Measurement science (definition, standards, metrics, indicators and ratings)
2. Systems (aggregation, linkages, system of systems, sustainability-resilience synergy and interdependencies)
3. Planning, design and supply chain (lifecycle analyses and treatments, and material and energy efficiency)
4. Economic, environmental and social aspects (valuation, impacts and behavior).

Breakouts Are Not Silos

We expect synergies to arise as similar or identical issues/problems are identified and dealt with in two or more breakouts.

Breakouts do provide different starting foci.

We hope this helps capture the most important measurement science needs.

Draw upon the workshop papers and presentations and your own experiences.

Breakout Forms

1. Problem Definition: Problem Name, Problem Description (Drafted in advance by the co-moderators)

2. Recommendation: Name, Root Cause, Recommendation, Action Plan, Roles

3. Breakout Team: Name, Affiliation, Email, Phone

1. Problem Description

Problem Title	Problem Description

2. Problem Analysis		
Problem or Issue:		
Root Cause:		
Recommendation:		
Action Plan: *Possible steps towards the goal*		**Roles**
		Industry
		Government
		Academia
		NGO
		Software/Hardware

3. Breakout Team

Name/Affiliation	Email/Phone

Breakout Schedule

In advance, co-moderators select a person to provide a summary of outcomes at the closing session.

8:45: Problem definitions -identify, describe and assign key problems/issues to working groups (one or more participants)

9:15: Problems analysis - working groups analyze individual problems/issues

9:45: Break

10:00: Presentation/discussion of analyses

10:45: Working groups complete analyses responding to discussions.

11:00: Breakouts end.

engineering laboratory

NIST-UMD Workshop on Measurement Science for Sustainable Construction and Manufacturing

Charge to the Breakout Groups

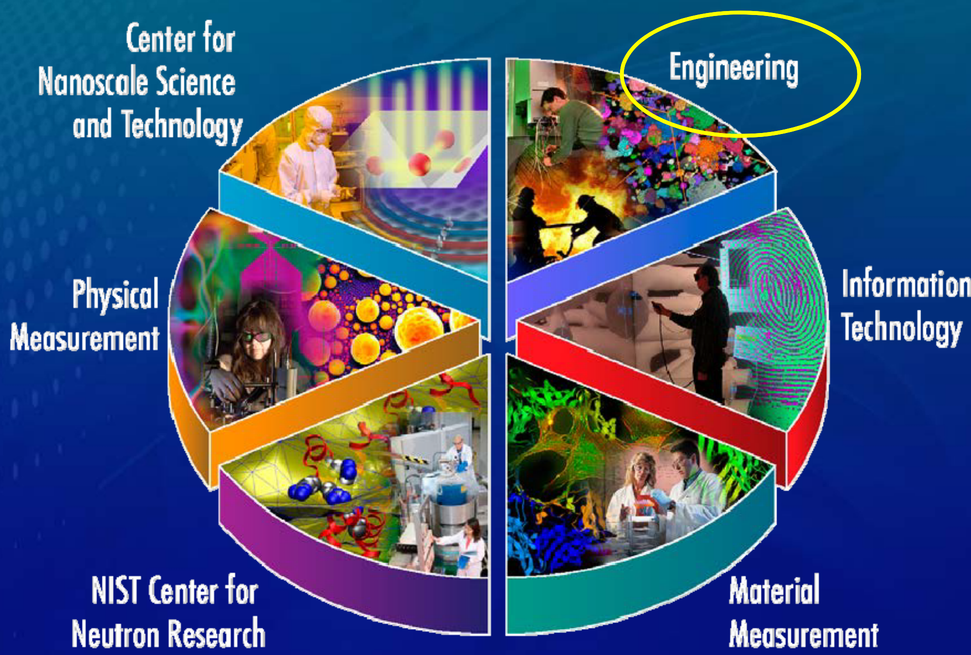
Dr. Joannie Chin
Acting Deputy Director
Engineering Laboratory
NIST

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

NIST's Mission

To promote U.S. innovation and industrial competitiveness by advancing **measurement science, standards, and technology** in ways that enhance economic security and improve our quality of life

NIST Laboratories



Engineering Lab (EL) Mission

To promote U.S. *innovation* and *industrial competitiveness* in areas of critical national priority **by anticipating and meeting the measurement science and standards needs for technology-intensive manufacturing, construction, and cyber-physical systems** in ways that enhance *economic prosperity* and improve the *quality of life.*

EL Core Capabilities

Fire protection, fire physics, materials flammability

Structural analysis, disaster and failure studies

Building and renewable energy, indoor environment, and building systems performance measurement

Intelligent sensing, control, robotics and automation

Sustainability, durability, and service life prediction of engineered materials

Systems integration, information modeling, model-based engineering

Partnering Strategies with Industry, Academia and Other Federal Agencies

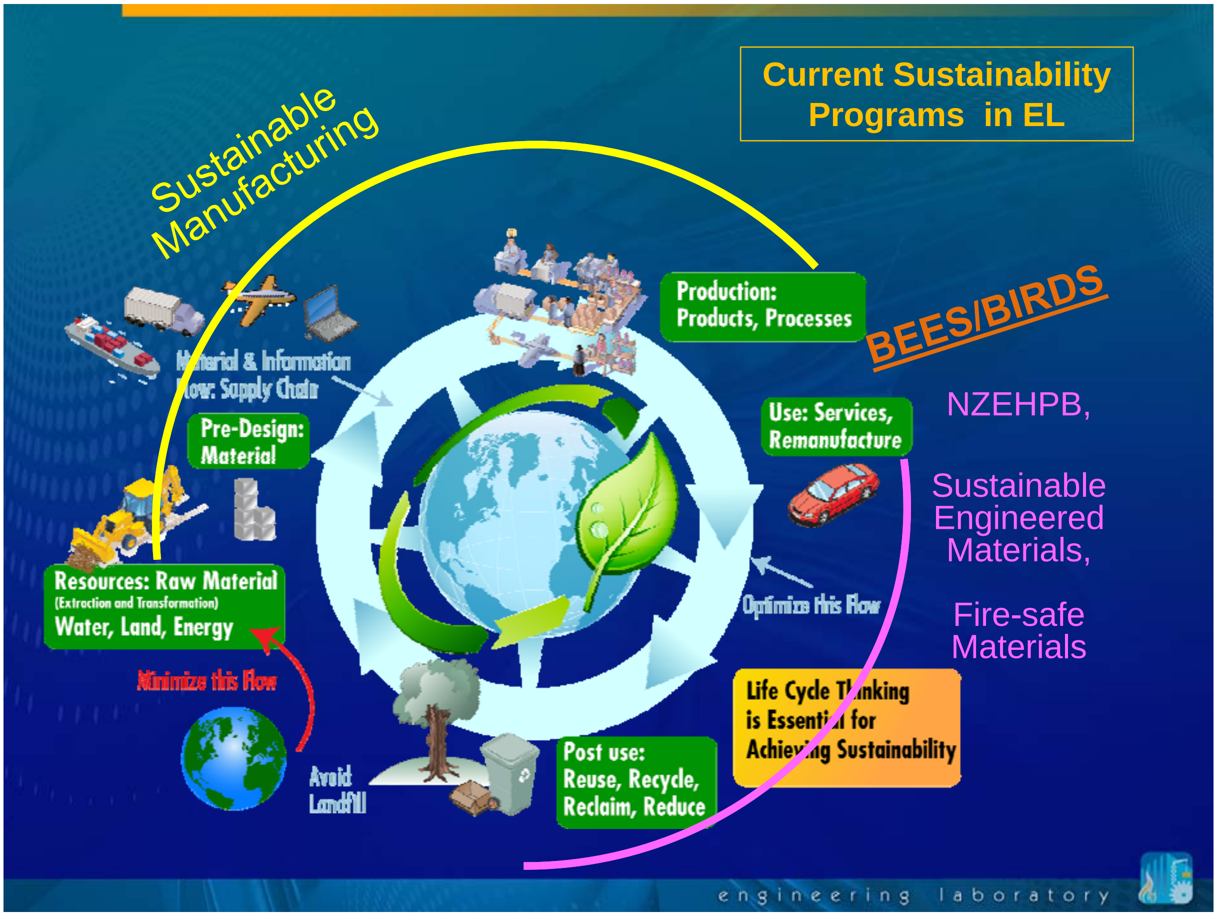
- Planning and Roadmapping Workshops
- Testbeds, Facilities, and Tools
- Codes and Standards Engagement
- Cooperation Mechanisms
- NIST Sponsored Events

Engineering Laboratory Strategic Goals

- Smart Manufacturing, Construction, and Cyber-Physical Systems
- Sustainable and Energy-Efficient Manufacturing, Materials, and Infrastructure
- Disaster-Resilient Buildings, Infrastructure, and Communities

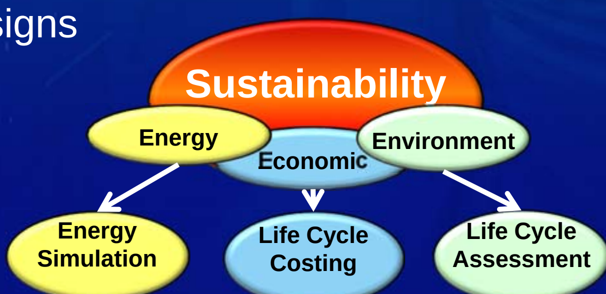
Sustainable and Energy-Efficient Manufacturing, Materials, and Infrastructure

- Sustainable Manufacturing
- Sustainable Engineered Materials
- Net-Zero Energy, High-Performance Buildings
- Embedded Intelligence in Buildings



BEES and BIRDS

- Building for Environmental and Economic Sustainability (BEES)
  - Sustainability Performance of Similar Building Products
- Building Industry Reporting and Design for Sustainability (BIRDS)
  - Sustainability Performance of Whole Building Designs



BIRDS
Building Industry Reporting and Design *for* Sustainability

Research Facilities and Testbeds

- Virtual Cement and Concrete Testing Laboratory
- Integrating Sphere for Service Life Prediction of Materials
- Virtual Cybernetic Building Testbed
- Smart Grid Testbed Facility
- Solar Photovoltaic Systems

Net-Zero Energy Residential Test Facility

- Demonstrate net-zero energy for residence similar in appearance to surrounding homes
- Provide a test bed for in-situ measurements of advanced components and systems
- Quantify energy use reductions using embedded intelligence
- Compare actual installed performance to controlled laboratory measurements

Breakout Groups

- **Workshop Objective:**

  Identify knowledge gaps and research needs in measurement science for sustainable construction and manufacturing.

- **Measurement Science:**
  - Scientific and technical basis for standards, codes, and practices
  - Includes: performance metrics; measurement and testing methods; predictive modeling and simulation tools; test and calibration protocols; reference materials, artifacts and data; evaluation of technologies, systems, and practices (including uncertainty analysis); devices and instruments

Breakout Groups

- Breakout Categories:
  - *Measurement science* (definition, standards, metrics, indicators and ratings)
  - *Systems* (aggregation, linkages, system of systems, sustainability-resilience synergy and interdependencies)
  - *Planning, design and supply chain* (lifecycle analyses and treatments, and material and energy efficiency)
  - *Economic, environmental and social aspects* (valuation, impacts and behavior).

Anticipated Outcomes

- Guidance document that will serve as a roadmap for NIST's future programs in sustainability, and help facilitate our technology transfer and implementation mission.
- Document will include:
  - Definition of sustainability relevant to construction and manufacturing
  - Appropriate sustainability metrics
  - Systems level considerations
  - Economic valuation and impacts
  - Research gaps and needs

1. Measurement science (definition, standards, metrics, indicators and ratings)

Problem Title	Problem Description
Sustainability science is unclear	Bring together physical, natural, and social sciences and engineering for defining sustainability
Measuring is challenging (2a) Not all things we care about are measurable (2b)	Identify metrics and requirements for assessing sustainability Find ways of introducing weights of these things we care about
Value issues need further vetting	Develop a framework for incorporating different value judgments
Uncertainty in measurement	Develop methodologies for assessing uncertainty

Breakout Team 1	Measurement science (definition, standards, metrics, indicators and ratings)	
Problem or Issue:	Sustainability science is unclear	Bring together physical, natural, and social sciences and engineering for defining sustainability
Root Cause:	Not all aspects of sustainability is measurable Multi-facets of sustainability exist Subjectivity and selectivity involved	
Recommendation:	Integration of multi-disciplinary aspects Develop quantitative methodologies for evaluating sustainability	

Action Plan: *Possible steps towards the goal*	**Roles**
1. Identify experts in social, economic and behavioral sciences along with urban planners(e.g. dedicated workshops, meetings, etc.) 2. Integrate deterministic and non-deterministic methodologies 3. Promote educational and training programs (need for new knowledge and data)	**Industry** All stakeholders to collaborate. All segments of construction and manufacturing industries must be engaged. **Government** **Academia** **NGO** **Software/Hardware**

Breakout Team 1	Measurement science (definition, standards, metrics, indicators and ratings)	
Problem or Issue:	Value issues need further vetting	Identify or develop a framework for incorporating different value judgments Value judgments quantify the relative importance of components of sustainability Science needs to include and quantify consequences of impact of those components; combining disciplines to accomplish this task is hard because of disciplinary norms
Root Cause:	Sustainability & decisions are a combination of science and value judgments. It is critical to assure that these are distinguished.	
Recommendation:	Provide frameworks for prioritizing and valuing the relative importance of the components or elements of sustainability.	

Action Plan: *Possible steps towards the goal*	**Roles**
Assess the state of the science and application as well as identify research gaps needed by industries Fund research on value framework that is translational, multidisciplinary and includes elements of sustainability that are challenging to measure and prioritize Demonstrate and apply the framework in construction and manufacturing	**Industry**
	Collaborate with researchers, fund, define challenges
	Government
	Fund, prioritize, conduct assessment
	Academia
	Conduct research, assess, demonstrate, and disseminate
	NGO
	Fund, collaborate and demonstrate
	Software/Hardware
	Develop algorithms, measurement/data collection

Breakout Team 1	Measurement science (definition, standards, metrics, indicators and ratings)	
Problem or Issue:	Measuring is challenging (2a) Not all things we care about are measurable (2b)	Identify measurements and requirements for assessing sustainability Find ways of introducing weights of these things we care about
Root Cause:	Dynamics of the multidimensional nature of issues Values are relative and not easily quantifiable	
Recommendation:	Create a framework for system identification Identify metrics and indicators Identify or create methodology for assigning relative weights to values that we care about Identify or create assessment methodology for decision making	

Action Plan: *Possible steps towards the goal*	**Roles**
Create a framework for system identification Identify metrics and indicators Identify or create methodology for assigning relative weights to values that we care about Identify or create assessment methodology for decision making	**Industry**
	All stakeholders to collaborate
	Government
	Academia
	NGO
	Software/Hardware

Breakout Team 1	Measurement science (definition, standards, metrics, indicators and ratings)	
Problem or Issue:	Uncertainty in measurement	Develop methodologies for assessing uncertainty
Root Cause:	Sources: Definition, time horizon, interactions (systems) Types: Variability, lack of information, approximations Quantification methods: Probabilistic & non-probabilistic frameworks	
Recommendation:	Identify sources, Identify types, Develop frameworks/methods to assess uncertainty	

Action Plan: *Possible steps towards the goal*	**Primary Roles**
1. Identify high-value problem areas as anchors for uncertainty-related tasks. 2. For each problem area, follow recommendation above. 3. Generalize Step 2 outcomes. 4. Formalize best practices, guidelines and standards. 5. Disseminate and educate. 6. Obtain feedback and improve steps 1 to 5.	**Industry** Establish relevance, feasibility **Government** Provide leadership, policy, investment and incentives **Academia** Fundamental research, training Human resource development **NGO** Provide liaison among society, researchers and practitioners **Software/Hardware** Software needed to implement methods

Breakout Team 1. Measurement science

Name/Affiliation	Email/Phone
Anne Caldas/ANSI	acaldas@ansi.org/212-642-4914
Subhas Sikdar/EPA	Sikdar.subhas@epa.gov/513-569-7528
Daniel Castro/Georgia Tech	dcastro@gatech.edu/404-385-6964
I.S. Jawahir/University of Kentucky	is.Jawahir@uky.edu/859-323-3239
Bilal Ayyub/University of Maryland	ba@umd.edu/301-405-1956
Stephen Mawn/ASTM	smawn@astm.org/610-832-9726
Sankaran Mahadevan/Vanderbilt	Sankaran.mahadevan@Vanderbilt.edu/ 615-322-3040
Melissa Kenney/University of Maryland	Melissa.kenney@noaa.gov/202-419-3477
Nasim Uddin/University of Alabama	nuddin@uab.edu/205-934-8432
Mohammad Heidarinejad/University of Maryland	muh182@umd.edu/301-405-1624
Joannie Chin/NIST	Joannie.chin@nist.gov/301-975-6815

2. Systems Break-Out Session: Selected 3 Problems

Problem Title	Problem Description
System boundary setting	Since all systems are connected from micro to macro scale, how can one establish boundaries for analysis?
Loss of fidelity in aggregation	How can one perform aggregated, high-level system-level analysis without losing important fine-grain details?
Coupling of human and natural processes	What methods are useful for characterizing the linkages among mechanistic processes designed by humans and organic processes that have evolved in nature?
Predictive assessment for sustainability and resilience	How can decision makers assess the potential ecological, economic, and social impacts of new policies or technologies *a priori* without empirical knowledge?
Understanding cross-scale interactions	Are there tractable methods available for practitioners to understand the complex interactions within a system of systems across multiple spatial and temporal scales?
General vs. specified resilience	Can systems be designed for "inherent" resilience to disruptions in general, rather than to specified threats?
Justification of need for systems approach	How can issues that require systems thinking be identified and communicated, with an appropriate business case?
Establishment of accepted practice	How can we establish commonly accepted, credible methods, practices, and data, with compelling examples?

Breakout Team 2	Systems (aggregation, linkages, system of systems, sustainability-resilience synergy and interdependencies)
Problem or Issue:	What methods are useful for characterizing the linkages among mechanistic processes designed by humans and organic processes that have evolved in nature?
Root Cause:	Economic development has led to undesired ecological impacts, leading to greater awareness of interdependence between human and natural systems.
Recommendation:	Improve quantification of resource flows, emissions, and other interactions between human and natural systems.

Action Plan: *Possible steps towards the goal*	**Roles**
1. Identify ecological constraints, such as scarce minerals, land availability, that influence construction and manufacturing decisions	**Industry** (see following)
2. Develop full understanding of resource depletion and other ecological impacts of human activities	**Government**
3. Identify ecological conditions, such as biodiversity, soli quality, nutrient cycling, that are disrupted by human activities	**Academia**
4. Characterize beneficial ecosystem services that enhance sustainability of construction and manufacturing, e.g., stormwater management	**NGO**
5. Develop early warning indicators of change, such as indicator species.	**Software/Hardware**
6. Develop indicators of resilience to unexpected shocks, e.g., diversity, buffering	

Breakout Team 2	Systems (aggregation, linkages, system of systems, sustainability-resilience synergy and interdependencies)
Problem or Issue:	How can decision makers assess the potential ecological, economic, and social impacts of new policies or technologies *a priori* without empirical knowledge?
Root Cause:	In an age of rapid innovation and globalization, systems are becoming more complex, and their emergent properties are poorly understood.
Recommendation:	Develop possible future scenarios, and utilize advanced measurement science tools and techniques to monitor and interpret observable outcomes.

Action Plan: *Possible steps towards the goal*	**Roles**
1. Engage stakeholders in developing scenarios to understand envelope of possible futures 2. Characterize relevant baseline system conditions and historical changes 3. Enable extensive data collection, validation, and interpretation, using "big data analytics" 4. Inventory available system modeling tools and identify appropriate applications 5. Utilize multi-criteria decision-making tools to establish collective stakeholder priorities 6. Adopt an adaptive management approach to respond to changing conditions and unexpected outcomes 7. Encourage development of a common ontology for indicators to characterize sustainable and resilient systems	**Industry** (see following) **Government** **Academia** **NGO** **Software/Hardware**

Breakout Team 2	Systems (aggregation, linkages, system of systems, sustainability-resilience synergy and interdependencies)
Problem or Issue:	Are there tractable methods for practitioners to understand the complex interactions within a system of systems across multiple spatial and temporal scales?
Root Cause:	Complex, dynamic, non-linear systems are heavily influenced by cross-scale linkages, from micro to macro and vice versa (e.g., climate change drives local flooding, isolated incidents can cascade into large-scale supply disruptions)
Recommendation:	

Action Plan: *Possible steps towards the goal*	**Roles**
1. Develop guidance for establishing system boundaries for analyzing broader implications of manufacturing or construction design decisions (beyond conventional "life cycle") 2. Expand concepts of energy, water, and material balance beyond individual structures and processes to a regional or even global scale 3. Encourage research on how to perform aggregated, high-level system-level analysis without losing important fine-grain details 4. Utilize analytic methods to understand the sensitivity of system sustainability or resilience indicators to key variables at higher or lower scales of resolution. 5. Develop meta-data standards to assure compatibility and interoperability	**Industry** Provide needed level of transparency (e.g., carbon disclosure), Identify important decision criteria and data needs, and validate new techniques **Government** Federal: Provide research priorities and funding State & local: Test-beds and outcome priorities **Academia** Innovation, research, education, advocacy, partnerships with industry **NGO** Consensus building, education, advocacy, standards, partnerships with industry & government **Software/Hardware** Measurement tools, technologies, models, methods, integration to respond to above needs

Breakout Team 2. Systems

Name/Affiliation	Email/Phone
Joseph Fiksel*	Fiksel.2@osu.edu 614-226-5678
John Carberry*	johncarberry01@comcast.net 302-738-4063
Vilas Mujumdar	V_mujumdar41@yahoo.com 703-938-2117
Chris Renschler	rensch@buffalo.edu 716-645-0480
Bill Anderson	wanderson@tisp.org 202-302-9170
Matthew Dahlhausen	Matthew.dahlhausen@gmail.com 216-618-0753
Eric Coffman	Eric.coffman@montgomerycountymd.gov 240-777-5595
Ryan Colker (comments via e-mail)	rcolker@nibs.org 202-289-7800

* co-moderators

3. Planning, design and supply chain (lifecycle analyses and treatments, and material and energy efficiency)

Problem Title	Problem Description
How to apply systems thinking during planning and design of systems that considers interdependencies & trade-offs between economic, environmental and societal impacts?	Sustainability-oriented interventions often involve trade-offs between various activities along the value chain. Without a systems-oriented approach, the impact of these interdependencies are difficult to evaluate.
How to develop predictive models that can realistically estimate future cross-company and cross-supply chain economic, environmental or societal impacts?	Sustainability improvements often take a long-term to materialize and benefits are likely to accrue across the supply chain. However, existing frameworks do not lend themselves to accurately determine cross-company benefits, economic or otherwise. Can predictive models be developed to realistically predict the influence of such improvement efforts? Can models be developed to predict impacts of emergent and future conditions; to evaluate and design adaptive alternatives?
How to ensure designed systems have the resilience to withstand disruptive events and operational turbulence?	Global supply chains are increasingly exposed to uncertain events and disruptions. The sustainability performance of supply chains is catastrophically affected when such unpredictable events occur. Quantitatively models for evaluating interdependent risks between supply chain partners and methods to analyze their propagation through the supply chains are lacking.
How to develop a common nomenclature and terminology related to sustainability that can be across the supply chain?	Sustainability is a relatively new concept and common language for talking about it does not yet exist. The definition of sustainability itself varies from person to person, making it difficult to address the aspects of the issue and develop effective ways to measure it. Establishing consistent, standard terminology for talking about sustainability will help to align researchers and manufacturers communicating about common issues and designing products that address those needs.

3. Planning, design and supply chain (lifecycle analyses and treatments, and material and energy efficiency)

Problem Title	Problem Description
How to increase data sharing and interoperability between relevant stakeholders across the supply chain?	In this electronic age, companies amass considerable data related to their products, processes and systems. However, this data is not used effectively to produce actionable information; in situations where such information is available, it is not shared across the supply chain to increase benefits to all stakeholders.
How to design products, processes and systems to increase remanufacturing, recycling and end-of-life management?	To enable closed-loop material flow across multiple life-cycles of products, they must be designed and manufactured to enable better remanufacturing, recycling and end-of-life management.
How to routinely optimize reverse logistics operations given uncertainty in quality and quantity of end-of-life products?	The uncertainties in the quality and quantity of product flow in reverse supply chains makes it difficult for companies to engage in these activities profitably. What strategies can be implemented to encourage OEMs to engage in reverse logistics operations?
How to ensure material and energy efficiency become integral steps during the planning and design of products, processes and systems/supply chains?	Assessment categories currently being used in standard LCA analyses don't allow for a comprehensive analysis of material and energy efficiency. What tools can be used and how can LCA be complemented?

Breakout Team 3	Planning, design and supply chain (lifecycle analyses and treatments, and material and energy efficiency)
Problem or Issue: Design for EOL – Remanufacturing, recycling	
Root Cause: Lack of design methodologies, incentives, tools	
Recommendation: Metrics, methods, measurements	

Action Plan: *Possible steps towards the goal*	**Roles**
• Lead/support development of design tools and methodologies for design for EOL with metrics and targets • Support development of sector based metrics for design for EOL • Benchmark data (design and implementations) sharing • Lessons learned from EOL products	**Industry** Participate in development, provide data, validation **Government** Lead development, provide incentives, fund research **Academia** Development, research **NGO** support **Software/Hardware** Integrative software, validation equipment

Breakout Team 3	Planning, design and supply chain (lifecycle analyses and treatments, and material and energy efficiency)
Problem or Issue: Reverse logistics/ Reverse supply chains	How to increase data sharing and interoperability between relevant stakeholders across the supply chain?
Root Cause: Lack of Integrated approaches, incentives, tools	
Recommendation: Metrics, methods, measurements	

Action Plan: *Possible steps towards the goal*	**Roles**
• Developments of frameworks for reverse logistics and metrics for measuring effectiveness • Support development of standard data exchange	**Industry** Participate in development, provide data, validation **Government** Lead development, provide incentives, fund research **Academia** Development, research **NGO** support **Software/Hardware** Integrative software, validation equipment

Breakout Team 3	**Planning, design and supply chain (lifecycle analyses and treatments, and material and energy efficiency)**
Problem or Issue:	**Sustainability impacts ~~improvements often~~ occur at different points during the life of the product or structure and may take a long-term to materialize ~~and~~ as benefits are likely to accrue across the supply chain. However, existing frameworks do not lend themselves to accurately determine time dependent cross-company benefits (environmental, economic or societal). Can predictive models be developed to realistically predict the influence of such improvement efforts? Can models be developed to predict impacts of emergent and future conditions; to evaluate and design adaptive alternatives?**
Root Cause:	**Analysis approaches tend to take a unit process view and overall impacts are treated on an additive basis rather than a time series, integrated system view.**
Recommendation:	**1) Not only collect LCI/LCA data for materials and products in a national database but also typical use statistics such as recovery and reuse rates, typical product lifespans, and incremental impacts to assembly or building operational cycles.** **2) Research should be conducted on developing a system of prioritization matrices that quantify the trade offs of various impacts over time and "present-values" those impacts into a comparable form. Note: this may seem to be impossible but only if it is looked at in absolute terms rather than a tool that could be used to assess a variety of scenarios.** **3) Develop a tool to utilize these matrices in relation to product and building design decisions across the cradle-to-cradle lifecycle of the product or building as a contribution to the initial decision making process.**
Action Plan: *Possible steps towards the goal*	**Roles**
	Industry
	Industry should be prepared to collect and share necessary data (reuse and recovery rates, operational impacts and typical lifespans) just as EPD data is shared.
	Government
	Serve as a catalyst to this process through further definition of the issues involved, sponsoring research projects and promoting the concept. Government should maintain and manage the database. Perhaps the tool development should be driven through an organization such as NIST so that the base level of the tool is cross-disciplinary, cross-industry and extensible,.
	Academia
	Engage in meaningful, creative research
	NGO
	Industry trade organizations need o take the lead in collection of industry wide data and support the effort.
	Software/Hardware
	Tool has to be credible but not overly complex in order to encourage its utilization.

Breakout Team 3	Planning, design and supply chain (lifecycle analyses and treatments, and material and energy efficiency)
Problem or Issue:	How to apply systems thinking during planning and design of systems that considers interdependencies & trade-offs between economic, environmental and societal impacts?
Root Cause:	Lack of information about the total life cycle issues of, materials, processes, and products, data ownership, lack of understanding of process capabilities in terms of energy, material, and water Perception that sustainability cost more
Recommendation:	Develop Design for sustainable supply chain for risk-based better multi-criteria decision making. Develop data standards, analytical tools that can readily consume data,

Action Plan: *Possible steps towards the goal*	**Roles**
Develop industry challenge problems for benchmarking and understanding of process capabilities in terms of energy, material, and water Seamless information flow across supply network for all lifecycle phases through data standards Promote code for America makes (crowd sourcing) for developing analytical tools for risk-based better multi-criteria decision making Promote better life cycle thinking of cradle to cradle process and explain it in terms of value system than first cost. Robust and adaptable models of life cycle analysis and synthesis for spatial and temporal uncertainties	**Industry** Challenge problems, change perspective on sustainability as competitiveness **Government** Promote and enable standards, better informed policy instruments, consumer awareness, promote high risk research for long term benefits **Academia** Education and training, work with industry to develop science for sustainable construction and manufacturing, develop curriculum that reflects industry and society needs and requirements **NGO** Industry and technology roadmap, help develop better policy instruments, better balance of public and private good. And partnership **Software/Hardware** Open architecture platforms for s/w and h/w to enable life cycle information flow, Information models, implementation of data standards and development tools

Breakout Team 3	Planning, design and supply chain (lifecycle analyses and treatments, and material and energy efficiency)
Problem or Issue:	**Resilience** - How to ensure designed systems have the resilience to withstand disruptive events and operational turbulence?
Root Cause:	Lack of: 1) Performance criteria at a component level 2) Performance data of components against the climate change spectrum 3) Sensitivity of matrices in life cycle cost analysis and risk assessment modeling
Recommendation:	NIST should define performance criteria against the climate change spectrum at the component and building levels. This will allow decision makers to use the appropriate indicators for better decisions.

Action Plan: *Possible steps towards the goal*	**Roles**
1. Develop and publish component-level performance criteria. 2. Evaluate and compare US regional codes to develop climate change spectrum. 3. See "Roles" section for further actions.	**Industry** 1) Provide all the basis of design at a molecular level to NIST so they can test and define criteria. 2) Provide system integration modeling so NIST can complete testing. **Government** Use and enforce criteria through acquisition regulation. **Academia** Provide criteria to students, the future implementers and building owners. **NGO** Use criteria to propose changes to policy and regulation. **Software/Hardware** Tools utilizing NIST performance criteria to allow for users to predict for better decision making.

Breakout Team 3, question 8, Joe Cresko and Kathi Futornick	Planning, design and supply chain (lifecycle analyses and treatments, and material and energy efficiency)
Problem or Issue: restating: "Data sharing and interoperability between relevant stakeholders across the supply chain is insufficient to enable improvements in EE and ME"	How to increase data sharing and interoperability between relevant stakeholders across the supply chain?
Root Cause:	Benefits through a supply chain are unknown and/or diffuse (principal agent type problem). Supply chains are highly variable, and estimating as well as allocating benefits is complicated.
Recommendation:	Build off of existing, appropriate tools/models, and ultimately standardize underlying data and tool architectures.

Action Plan: *Possible steps towards the goal*	**Roles**
1. Define materials efficiency and energy efficiency in this context. **2**. Identify existing, appropriate tools/models – possibly include embodied energy; materials flows through the economy; cross-sector energy impacts; energy use of (specific) products through their lifecycle; **3**. Build upon those tools/models (one example framework could be embodied energy and cross-sectoral energy impacts tools being develop by DOE; another could be BEES tool at NIST). **4**. Materials certification – currently, certifications are required for products marketed to EU; underlying data analysis should be standardized/verified and then could be utilized **5**. Include in the existing tools/models, or develop additional model frameworks to include other materials-associated "externalities" that directly or indirectly impact costs such as environmental, labor, regulatory, risks.	**Industry** Examples: engage in standards development, and implementation **Government** Examples: NIST work with standards groups (ISO, ANSI, etc.); DOE work with industry on voluntary programs; USG to collaborate on tools/models/databases **Academia** Examples: engage in standards development, and work with local regulatory agencies. Take leadership role in defining sustainability, materials efficiency, etc., and develop training/tools/etc. useful to industry and society. **NGO**

Problem or Issue:	How to develop a common nomenclature and terminology related to sustainability that can be used across the supply chain?
Root Cause:	No consistent definition for sustainability
Recommendation: Define common grounds for sustainability in both construction and manufacturing industries based on their needs to sustain business and operations while reducing impact on critical environmental areas. Quantify uncertainties in statements and criteria. Account for subjectivity such as social aspects.	Define needs and impacts (tangible, intangible)

Action Plan: *Possible steps towards the goal*

Defined Needs to sustain business and impact on the env.:

Resources

1. energy, fossil fuels
2. water
3. raw materials

Tangible impacts

Environmental <impact

1. climate (carbon emissions and ozone)
2. land
3. water
4. pollution

Economic impact

1. profits
2. Investment
3. Risk
4. Life cycle costs

Intangible impacts

1. social justice
2. health and well being

Roles

Roles	
Industry	Prrovide sets of criteria relevant to their operations and ensure practicabilty.
Government	Definine priorities and fund accordingly.
Academia	Develop scientific framework to minimize subjectivity and deal with uncertainty.
NGO	Supporting role.
Software/Hardware	

Breakout Team 3	Planning, design and supply chain (lifecycle analyses and treatments, and material and energy efficiency)
Problem or Issue:	How to develop predictive models that can realistically estimate future cross-company and cross-supply chain economic, environmental or societal impacts?
Root Cause:	
Recommendation:	
Action Plan: *Possible steps towards the goal*	**Roles**
	Industry
	Government
	Academia
	NGO
	Software/Hardware

Breakout Team 3	Planning, design and supply chain (lifecycle analyses and treatments, and material and energy efficiency)
Problem or Issue:	How to ensure designed systems have the resilience to withstand disruptive events and operational turbulence?
Root Cause:	
Recommendation:	
Action Plan: *Possible steps towards the goal*	**Roles**
	Industry
	Government
	Academia
	NGO
	Software/Hardware

Breakout Team 3. Planning, design and supply chain

Name/Affiliation	Email/Phone

Measurement Science for Sustainable Construction and Manufacturing

Concluding Remarks and Adjournment

June 13, 2014

Summary

Thanks for coming

- Workshop: Measurement Science for Sustainable Construction and Manufacturing
  - Background, context, challenges, problems and needs
  - Knowledge gaps and research needs
- By the numbers
  - 80 participants
  - 38 papers
  - 25 speakers and panelists

Workshop Outcomes

- Problem lists
- Problem descriptions
- Breakout reports
- Proceedings

- Opportunity
  - Send comments
  - Send papers


Draft (to be revised after the workshop)

Note to authors: in case of changes, please send me a marked up copy (not a new paper) and I will make sure than your changes are properly implemented.

MEASUREMENT SCIENCE FOR SUSTAINABLE CONSTRUCTION AND MANUFACTURING

Position papers by participants and selected others

A Workshop Held at
ASCE Headquarters
Bechtel Conference Center
1801 Alexander Bell Drive
Reston, VA 20191,
June 12 and 13, 2014

Edited by: TBD

June 7, 2014

Next Steps

Thanks for coming

- Publication of proceedings – public domain

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