Green Issues in Manufacturing

- Greening processes, systems and products

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Outline

- LMAS research information
- Background, motivation, drivers
- What is “sustainable” (or “green”)?
- What are the opportunities/challenges?
- What about manufacturing processes, systems and machine tools?
- Some examples
- Summary

LMAS ("Who we are")

lmas.berkeley.edu

Blog: http://green-manufacturing.blogspot.com/

Research in the LMAS is concerned with the analysis and improvement of manufacturing processes, systems and enterprises and the development of tools to analyze their sustainability.

Research is focused on:

- *metrics and analytical tools* for assessing the impact of processes, systems and enterprises
- *modeling* sustainable, environmentally-conscious manufacturing processes and systems
- *green supply chains*
- manufacturing *technology for reduced impact*
- manufacturing *technology for* producing *advanced energy* sources or storage
- *cleantech*
- *sustainable products and systems*

Specific projects include:

- design for sustainability
- green machine tools
- sustainable packaging
- impact and life cycle assessment tools for manufacturing (including embedded energy, materials, water, consumables)
- metrics for assessing green technology ROI (e.g. GHG ROI, Energy payback time, etc.)
- risk assessment for energy and resource use
- enterprise carbon accounting

LMAS Research

Applications

US Air Force
Mfg Energy Optimization

Mori Seiki
Green Machine Tools

IMPACT
Semi/DFM

Cleanability
NSF/Daimler

Energy suppliers
SolFocus
Diamler/AFCC

LBNL/HELIOS
Alt energy

Mfg technologies
Micromachining
CMP
Sensors

US Air Force
Mfg Energy Opimization

Sustainability Consortium
Product Labeling

SPS
Sustainable
Packaging

Energy suppliers
SolFocus
Diamler/AFCC

Mfg Industry
AMAT
Mori Seiki, Daimler
SPC

Analytical/assessment
Metrics
LCA, EnVs
Footprint

Samsung
DfM/MfD

Mori Seiki
Green Machine Tools

Cleanability
NSF/Daimler

IMPACT
Semi/DFM

SINAM
Nano-X

LBNL/HELIOS
Alt energy

Mfg "systems"
Scaleup
Planning/org
optimization

Education

Partners
CGDM/ERG
BERC
CFI
CET/MOT
LUCE

SPS
Sustainable
Packaging

NGO's/Gov't
MIRAI
ETEC
AMT
LBNL

Mfg Industry
AMAT
Mori Seiki, Daimler
SPC

Clean tech
cleanability
CMP consumable
Green machine tools

Partners
CET/MOT
LUCE
CFI

Business drivers
"green tech"
Business models

Tools

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Why does industry care?

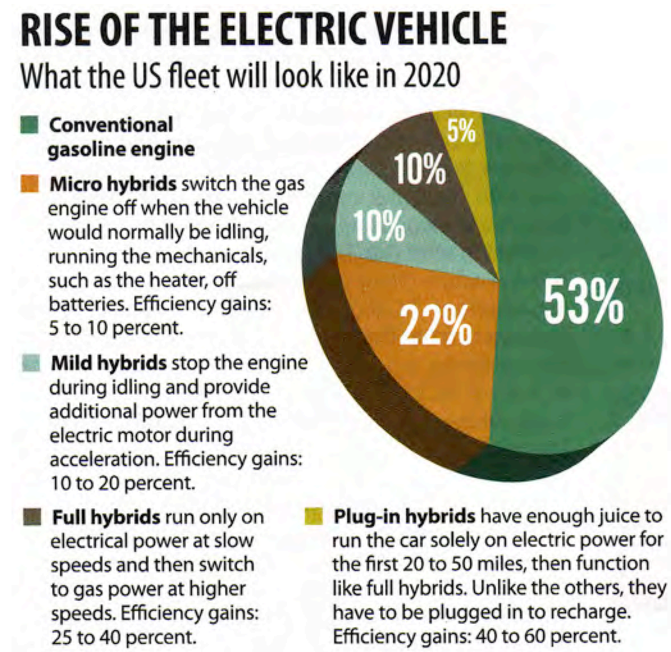
- Pressure from Government
  - Regulations
  - Penalties
  - Tax benefits
- Interest in Efficiency/Reduced CoO
- Scarcity of Resources/Risk
- Continuous Improvement
- Pressure from Society/Consumers/Customers
- Pressure from Competitors
- Maintain Market Leadership
- Supply Chain Effects (what's happening outside of your facility?)

Major Opportunities

- *All future* energy, transport, medical/health, life style, dwelling, defense and food/water supply *systems based on increasingly precise elements and components*
- Manufacturing for an energy and *environmentally aware consumer* (*autos*, consumer products, buildings, etc.)
- Manufacturing *alternate energy supply systems*
- Machine tools *using less energy, materials, and space*
- *Efficient* factory *operation*
- Comply with *government regulations*

These can all be competitive advantages if addressed by the machine and tool manufacturers and industry

Let’s look at autos - What kind of car are we building?



“There isn’t going to be any part of the vehicle that will remain untouched by the search for better mileage.” Paul Lacy, IHS Global Insight

Source: P. Grier and M. Clayton, “Cars - The shape of a new industry,” Christian Science Monitor, June 28, 2009.

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What manufacturing technology will it rely on?

- More plastic - dies and molds production
- More “hybrid” technology (mixing process requirements)
- Higher precision components (fuel efficiency and performance)
- Wider range of materials to machine
- Design/build for reuse, recycling, reman.
- Larger production volumes (?)
- Sustainable production
- More complex supply chains/distribution
- Sustainable supply chain
- Low “life-cycle costs” of operation

New materials - New energy sources - New processes - New business models

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Example: Energy and GHG

Greenhouse gas conversion factors

France	83
Sweden	87
Canada	220
Austria	250
Belgium	335
European Union	353
Finland	399
Spain	408
Japan	483
Portugal	525
United Kingdom	580
Luxembourg	590
Germany	601
USA	613
Netherlands	652
Italy	667
Ireland	784
Greece	864
Denmark	881

Lowest (so far)

5.8x wrt France

7.4x wrt France

China 788

India 944

Carbon intensity of electricity production (gCO_2 per kWh of electricity (or 0.001 MTon/MWh)

A new car's "embodied energy" is approximately 76,000 kWh; depending on where it is manufactured:

France = 6.30 MTons CO_2*
Japan = 36.70 MTons CO_2
USA = 46.60 MTons CO_2
India = 71.76 Mtons CO_2

Same car…same process steps… big difference!

(* 76 MWH x .083 MTon/MWh = 6.30 MTon)

What about within the US?

Source: MacKay, D., *Sustainable Energy - without the hot air*, UIT, Cambridge, 2009, pp. 335
Embodied energy data: Treloar, G., et al, "Hybrid life-cycle inventory for road construction and use," *J. Const. Engrg. and Mgmt.*, 130, 1, 2004, 43-49. (Values vary depending on recycling, etc.)
China/India: http://www.ghgprotocol.org/calculation-tools/all-tools; accessed 7/9/09

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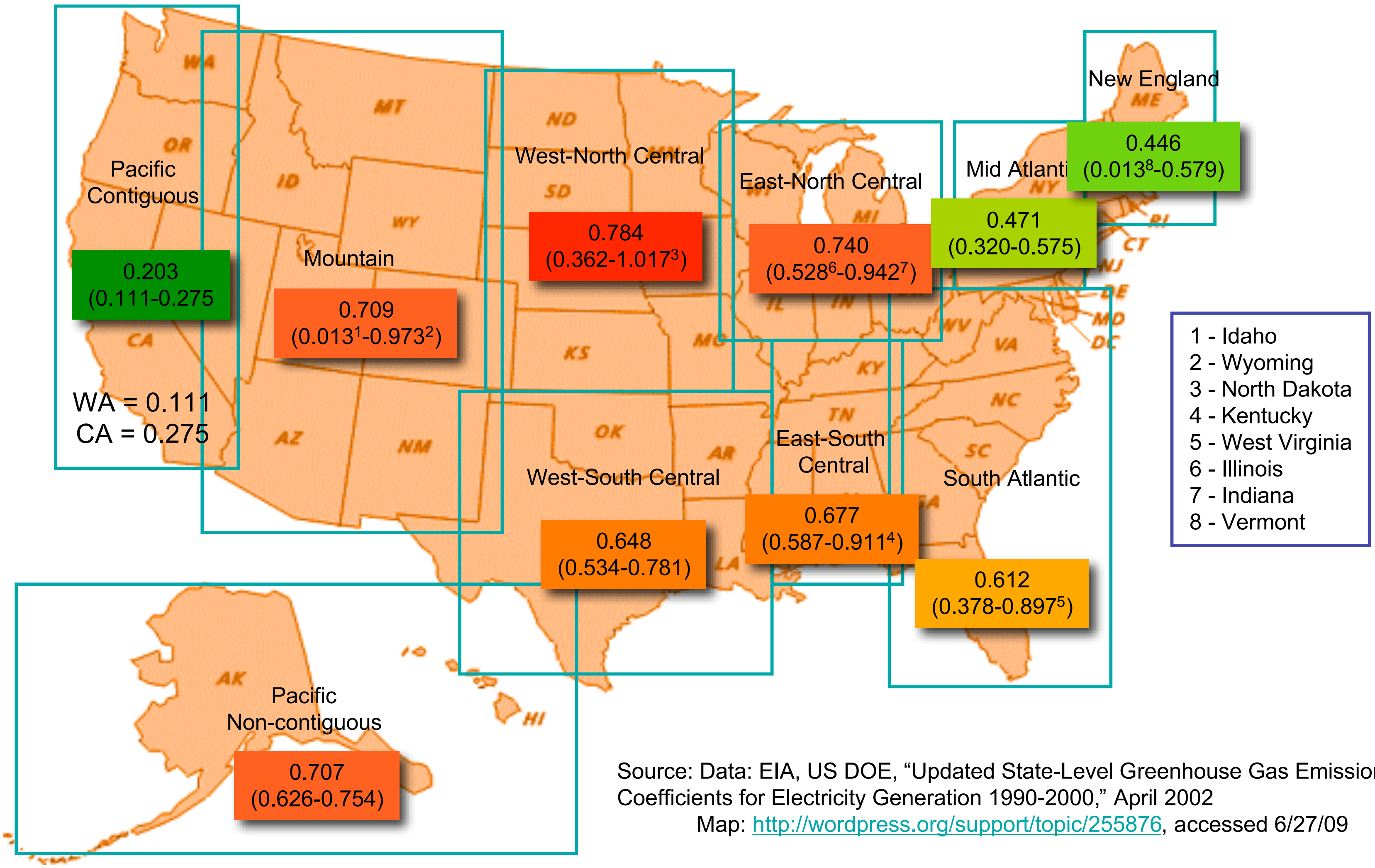
1998-2000 Average State Level CO_2 Emissions Coefficients for Electric Power, metric tons/MWH

(US Average 0.606)



Source: Data: EIA, US DOE, "Updated State-Level Greenhouse Gas Emission Coefficients for Electricity Generation 1990-2000," April 2002

Map: http://wordpress.org/support/topic/255876, accessed 6/27/09

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Let's build our car in…

(Same car and "embodied energy" of approximately 76,000 kWh)

If it is manufactured:

France = 6.30 MTons CO_2
Japan = 36.7 MTons CO_2
US ave = 46.6 MTons CO_2

What if this was a precision machine tool instead of a car?

Washington (0.111)	= 8.44 MTons CO_2
California (0.275)	= 20.90 MTons CO_2
North Dakota (1.017)	= 77.30 MTons CO_2
Kentucky (0.911)	= 69.00 MTons CO_2
Vermont (0.013)	= 0.99 MTons CO_2 (!!??)

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What does sustainable mean?

Green manufacturing is a first step towards sustainability

"Sustainable manufacturing is defined as the creation of manufacturing products that use materials and processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound."

Adapted from the Department of Commerce Definition

Brundtland Commission, i.e. World Commission on Environment and Development (WCED), 1983

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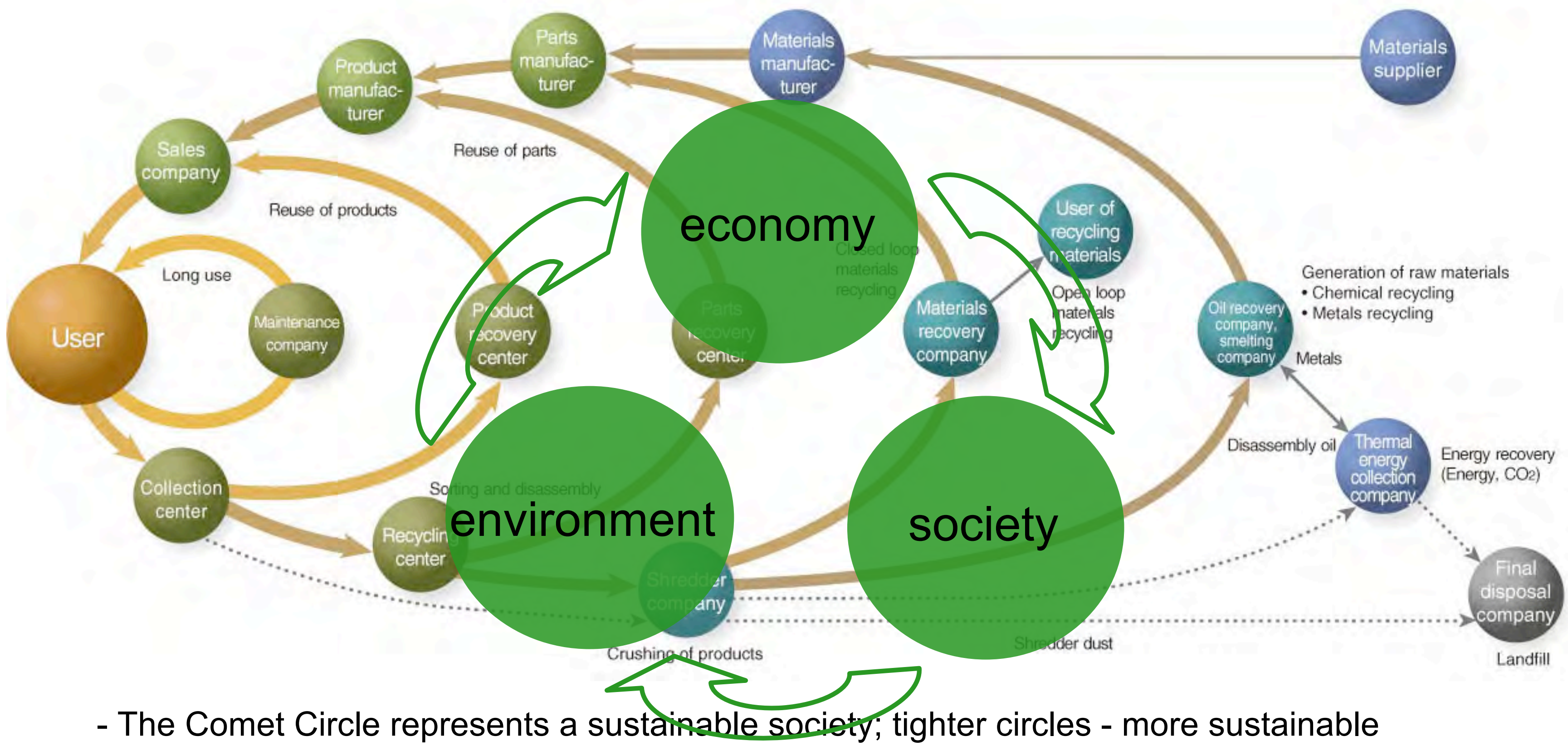
Ricoh "comet circle"

- an excellent visualization of the green supply chain



- The Comet Circle represents a sustainable society; tighter circles - more sustainable
- Circles indicate partners we work together with to achieve a sustainable society.
- The upper and lower routes represent the upstream and downstream supply chain
- Resources taken from the natural environment at the upper right are processed into products
- The end-of-life products move from left to right along the lower route.

Source: Ricoh, 1994; http://www.ricoh.com/environment/management/concept.html; accessed 6/29/09

Source: D. Dornfeld, *Path of Precision - Machine Tools and the Products they Make*, Mori Seiki, 2008.

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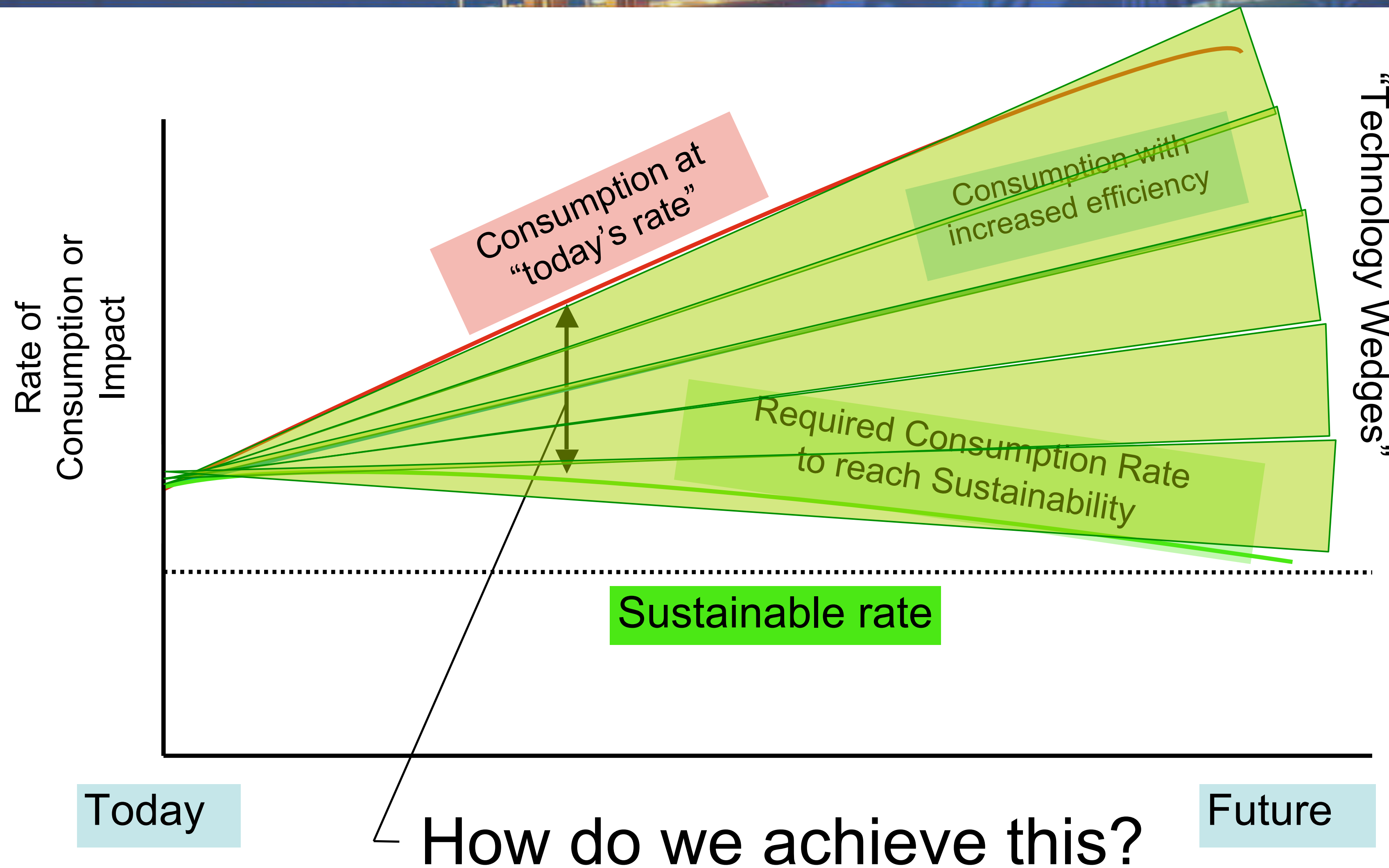
Sustainability frame of reference



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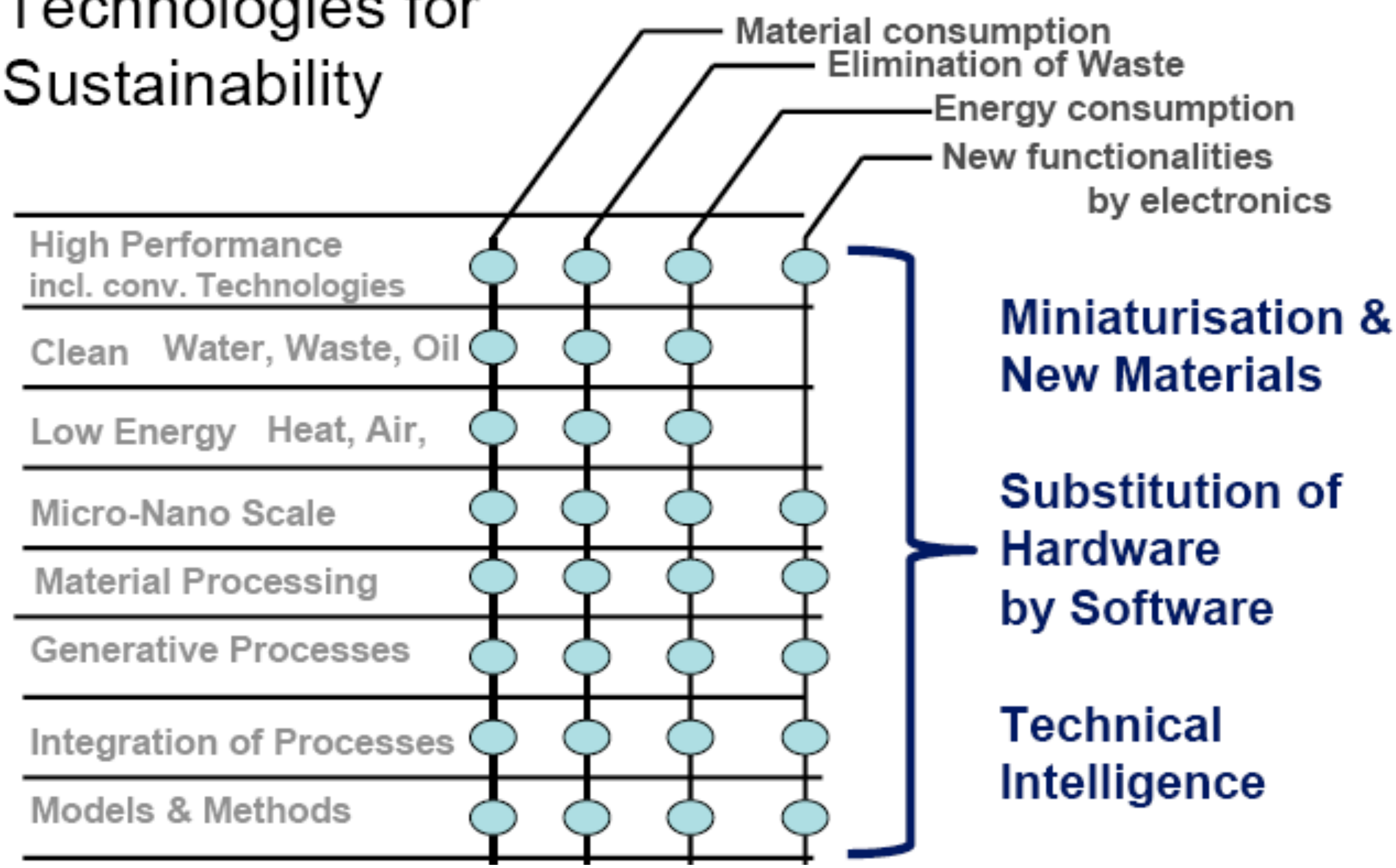
Wedge Technologies

Technologies for Sustainability



Source: E. Westkamper, “Sustainable Manufacturing” presentation at ManuFuture, 2007

How do we define sustainability?

- Global warming gases emission (CO_2, methane CH_4, N_2O, CFC's)
  - per capita
  - per GDP
  - per area/nation
- Recyclability
- Reuse of materials
- Energy consumption
- Pollution (air, water, land)
- Ecological footprint - "fair share"
- Exergy (available energy) or other thermodynamic measures

Measuring progress - return on investment (ROI) or similar concepts of:

- greenhouse gas return on investment (GROI)
- energy payback time
- water (or materials, consumables) payback time
- carbon footprint
- efficiency improvement (for example, wrt exergy)

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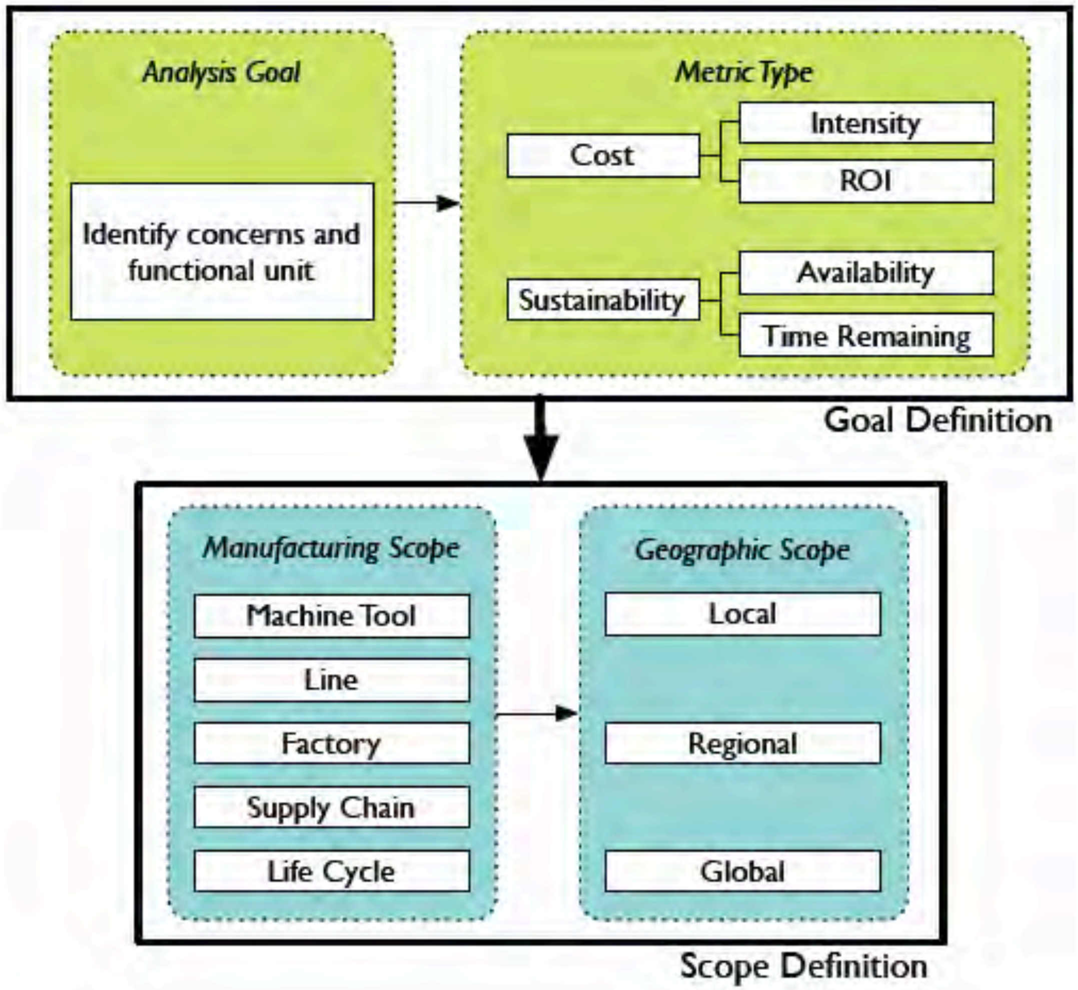
Metrics - measuring where we are and where we are going



Source: C. Reich-Weiser, Decision-Making to Reduce Manufacturing Greenhouse Gas Emissions, PhD Thesis, UC-Berkeley, 2010

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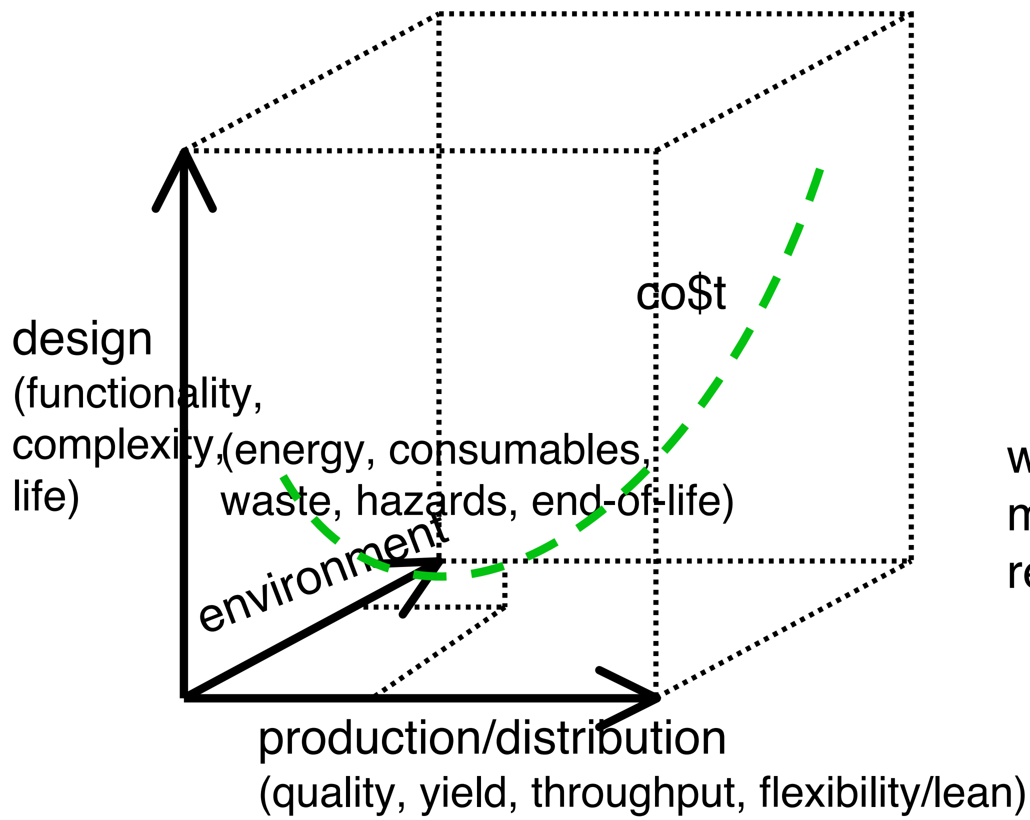
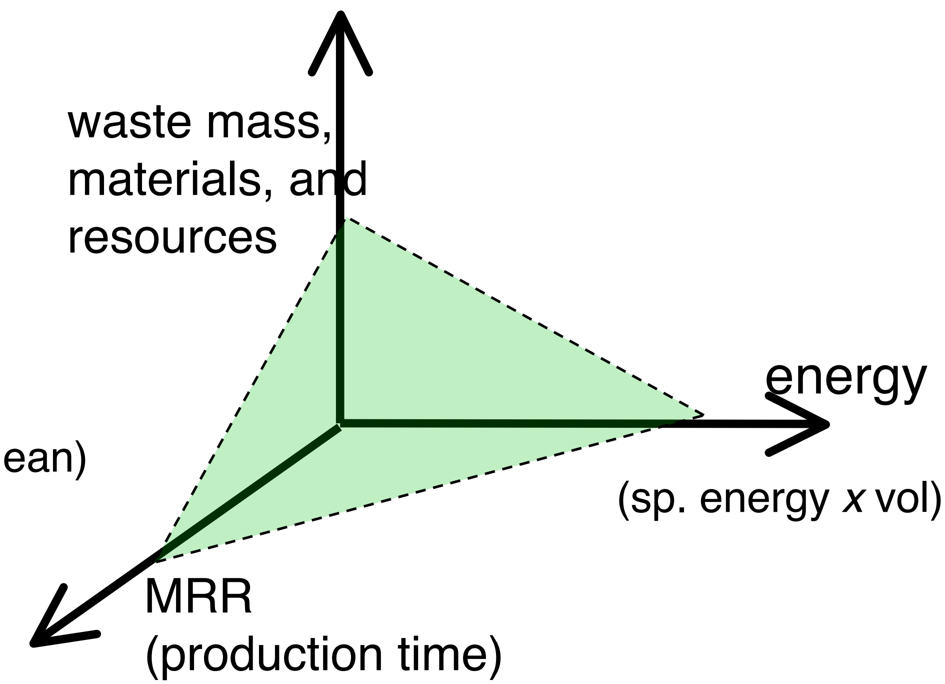
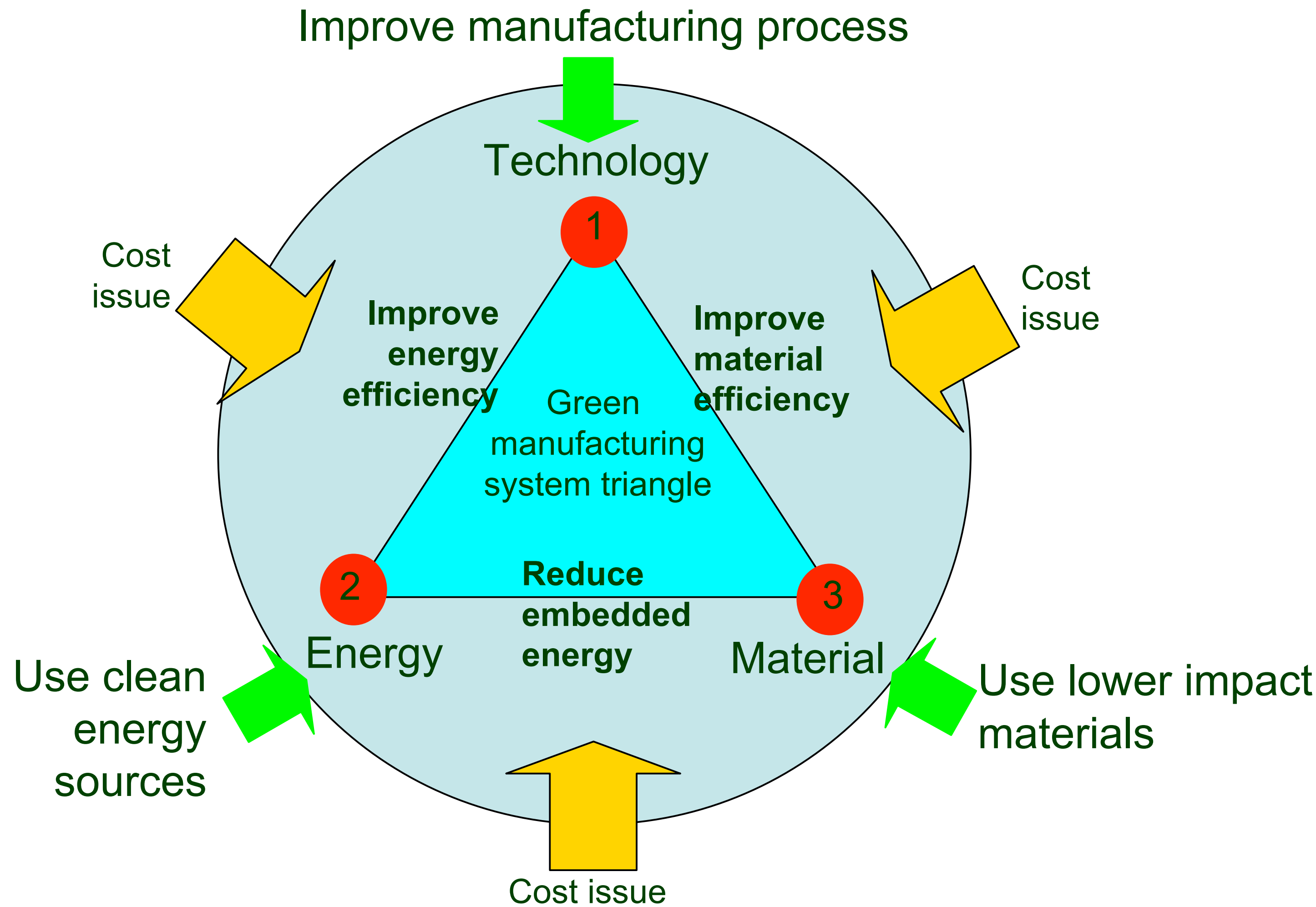
Dimensions of design, manufacturing and environment





Opportunities for improvement



Ref: Chris Yingchun Yuan, LMAS Presentation, 2009

Look how far we've come

Key to each transition

Paradigm	Craft Production	Mass Production	Flexible Production	Mass Customization and Personalization	Sustainable Production

Automation
"F. W. Taylor"

Break complex tasks into elements; control

Move non-essential elements outside productive time

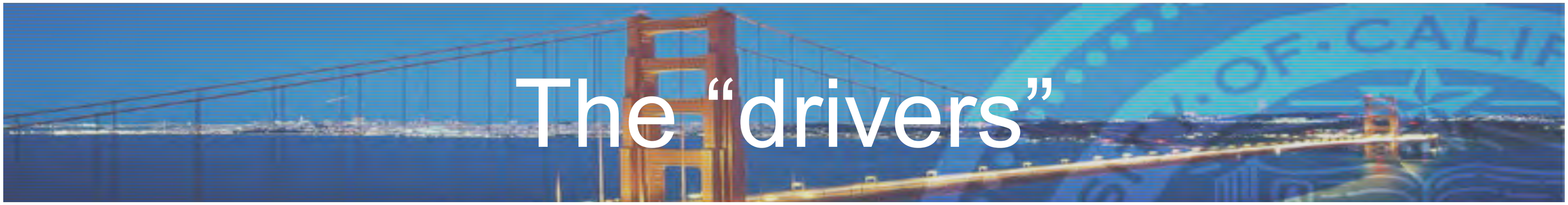
Computer Aided Manufacturing (CAM)
"M. E. Merchant"

Minimize working capital

Lean Manufacturing
"Toyoda, et al"

Include whole life cycle cost of environmental impact, externalities

After: F. Jovane, et al, "Present and Future of Flexible Automation: Towards New Paradigms," CIRP Annals, 52, 2, 2003, 543.



The "drivers"

- Customer
- Competitor
- Society
- Gov't/Regs
- ⋮

Manufacturing
- plant/HVAC
- cafeteria, HR, mgmt
- packaging
- shipping
- other waste
- ⋮

Processes & Systems
- energy
- water
- materials
- consumables
- compressed air
- other waste
- ⋮

Machinery & Tooling
- design
- setup
- operation
- maintenance
- other waste
- ⋮

Repeat

Across the supply chain

Effects at different scales

www.caranddriver.com/features/7207/virtual-tour-of-vws-transparent-factory.html
www.remmele.com/flash/contractManu/pca.html

Supply chain considerations

TRANSPORTATION

Economic
- Accessibility
- Availability
- Lead Times
- Risk

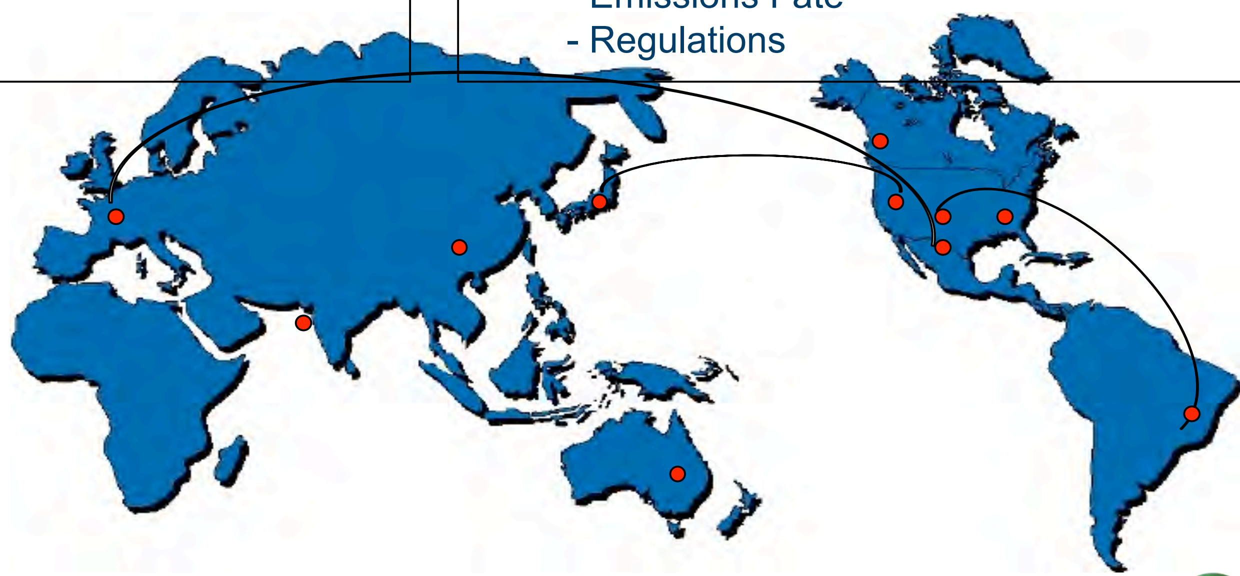
Environmental
- Emissions
- Resource Use
- Distance

SUPPLIER - Location

Economic
- Part Quality
- Resource Availability
- Lead Times & Inventory
- Risk

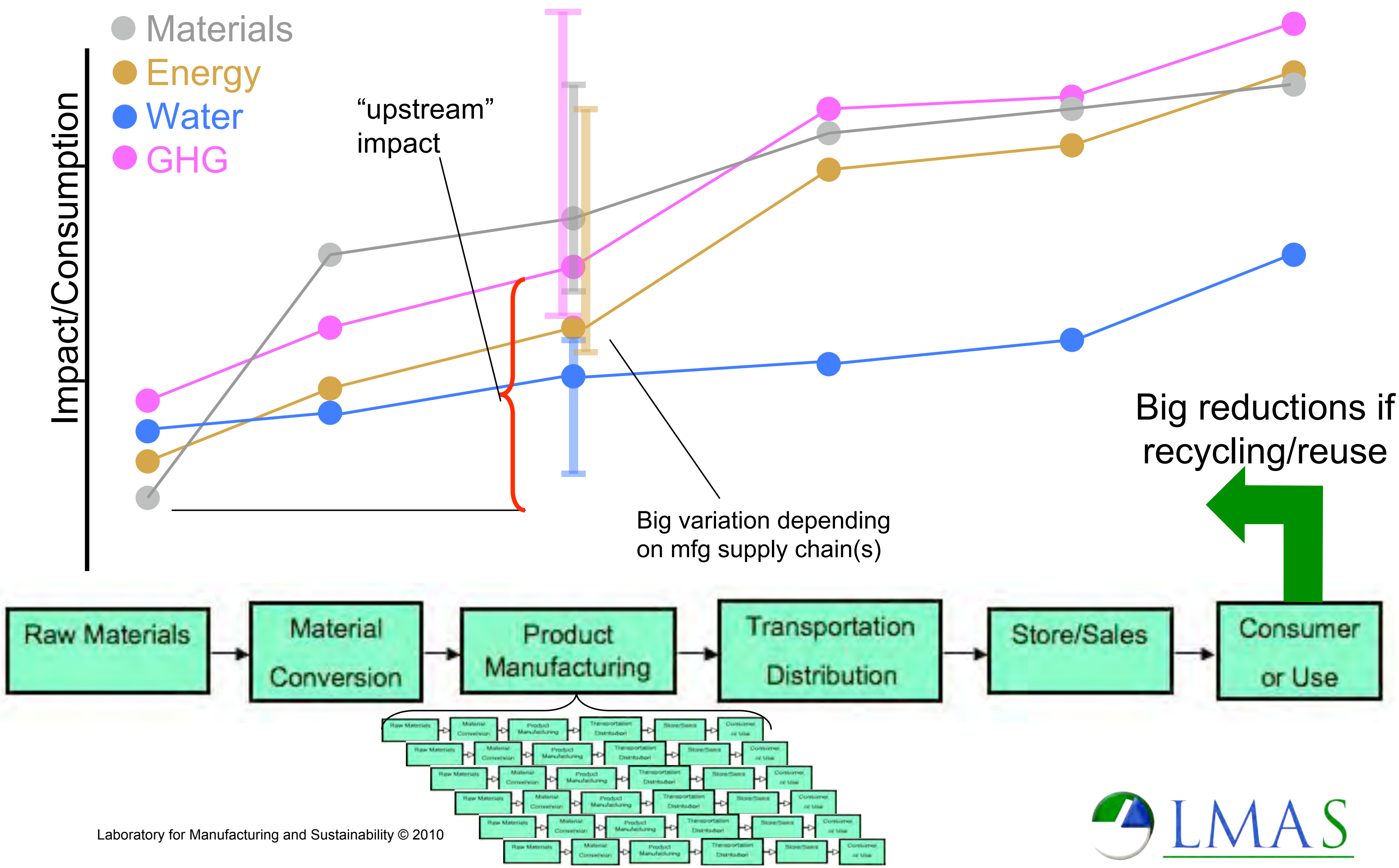
Environmental
- Electricity Mix
- Resource Availability
- Electricity Demand
- Emissions Fate
- Regulations

Social
- Quality of Life
- Pay Rates
- Working Conditions
- Health Care



Supply Chain Impacts

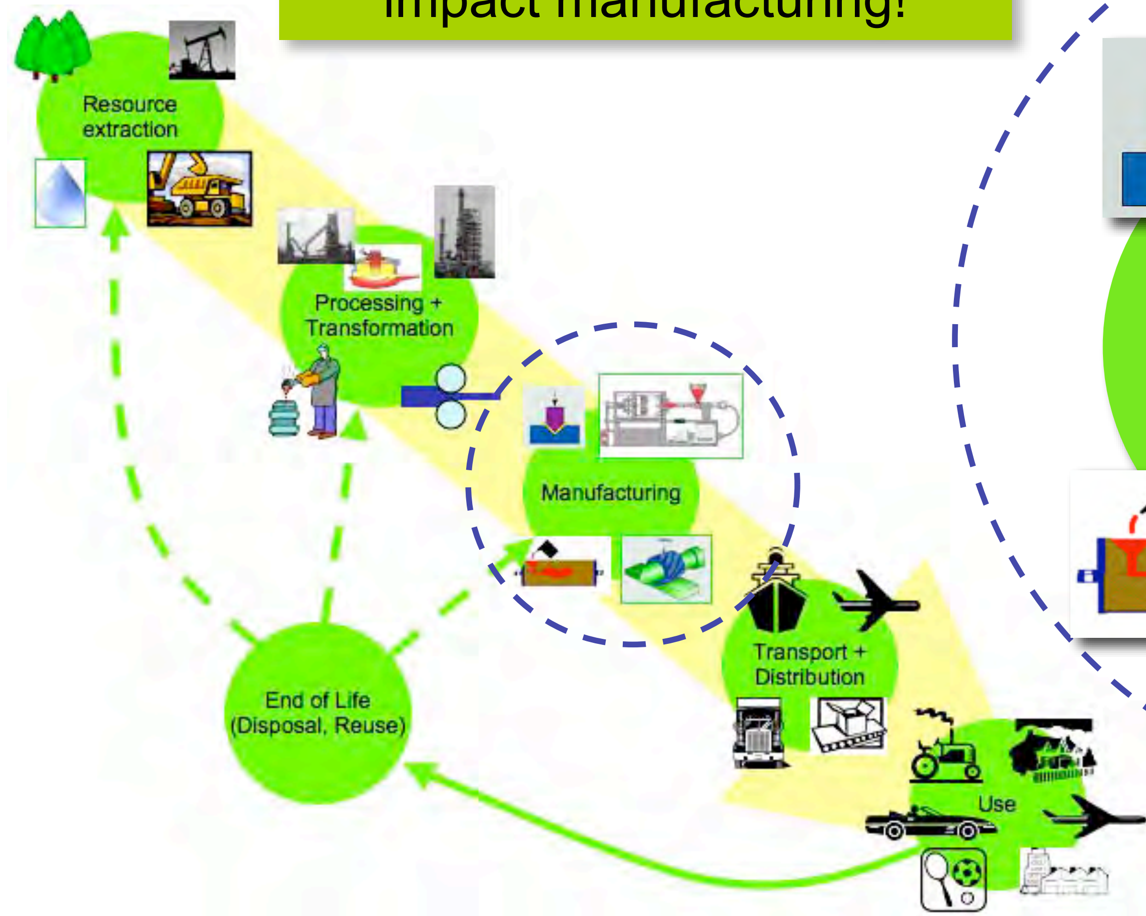
(Depends on the product/process!)

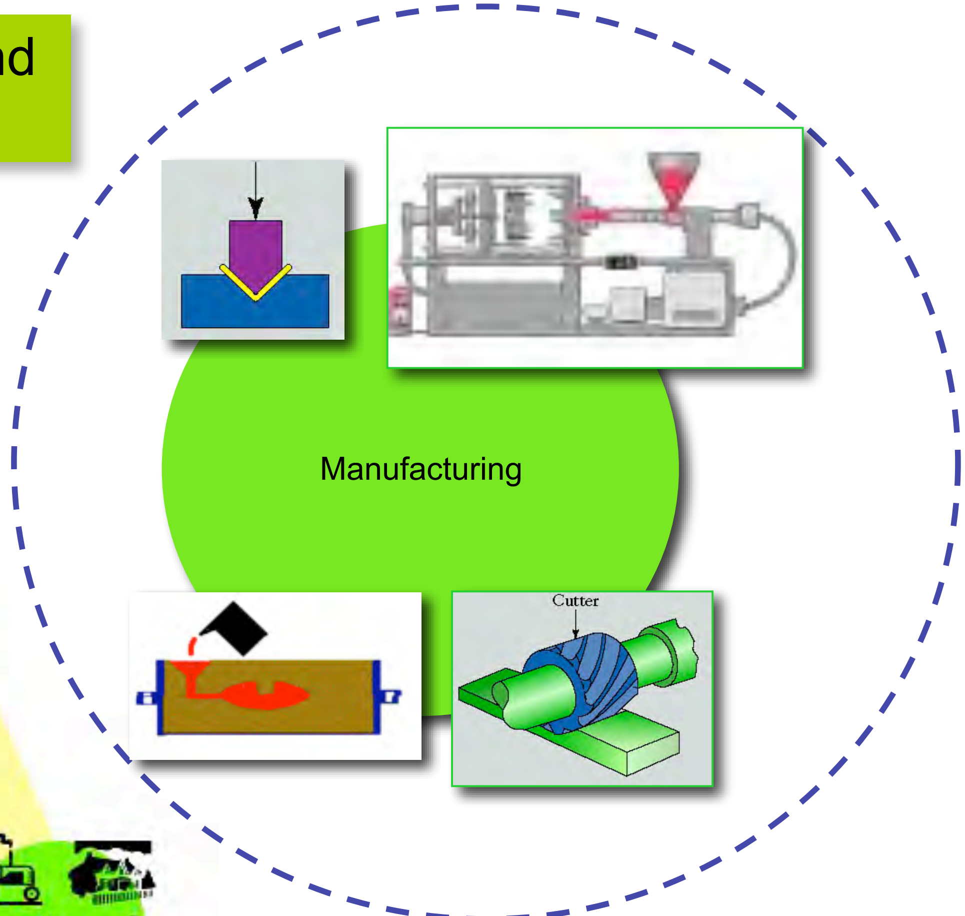


Product "life-cycle"

- focus on manufacturing -

All phases are important and impact manufacturing!



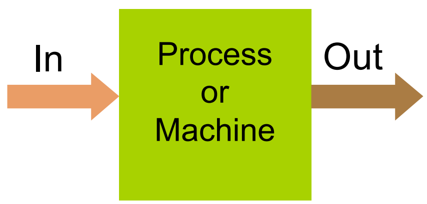


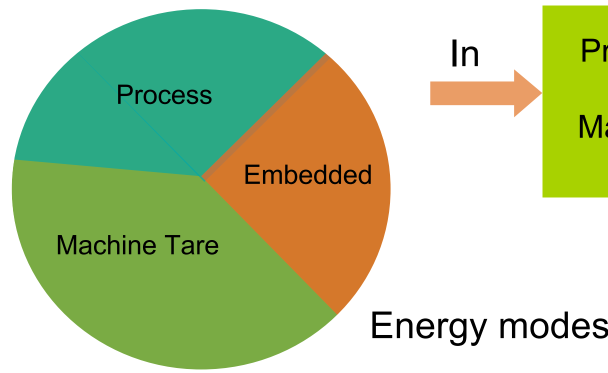
Strategies for greening manufacturing

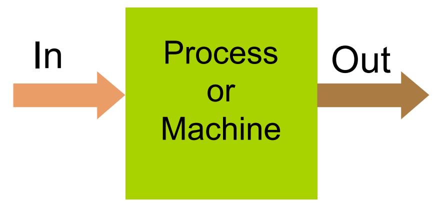
- Create products/systems that *use less material and energy*
- Substitute input materials: non-toxic for toxic, renewable for non-renewable
- Reduce unwanted outputs: cleaner production, industrial symbiosis
- Convert outputs to inputs: recycling and all its variants (zero waste)
- *Changed structures of* ownership and *production*: product service systems and supply chain structure

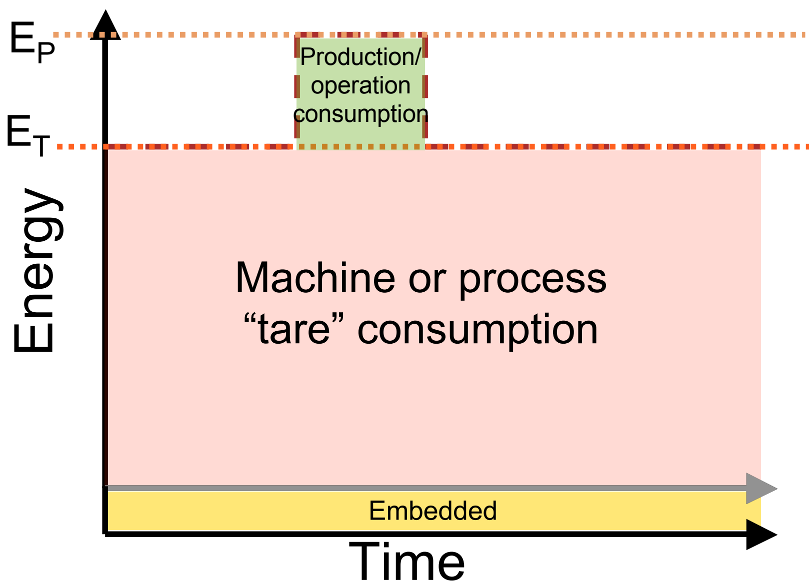
Source: after J. Allwood, Cambridge University

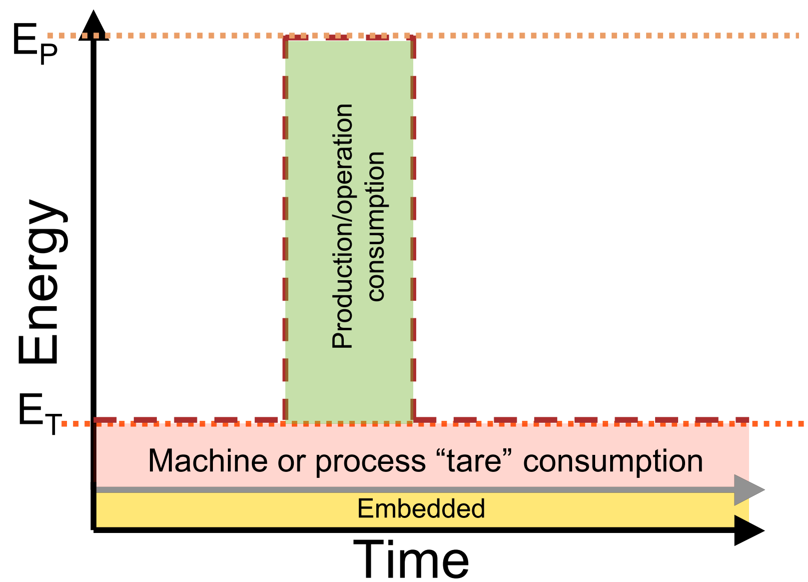
Energy use in manufacturing



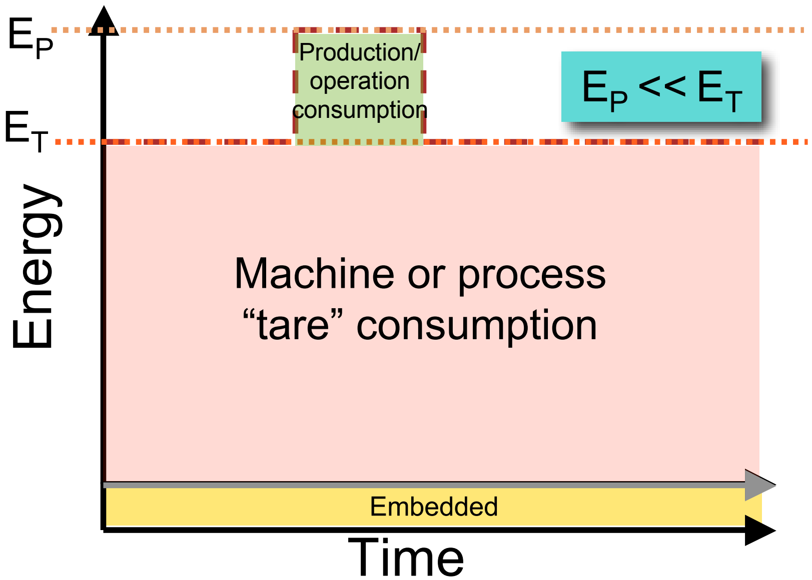




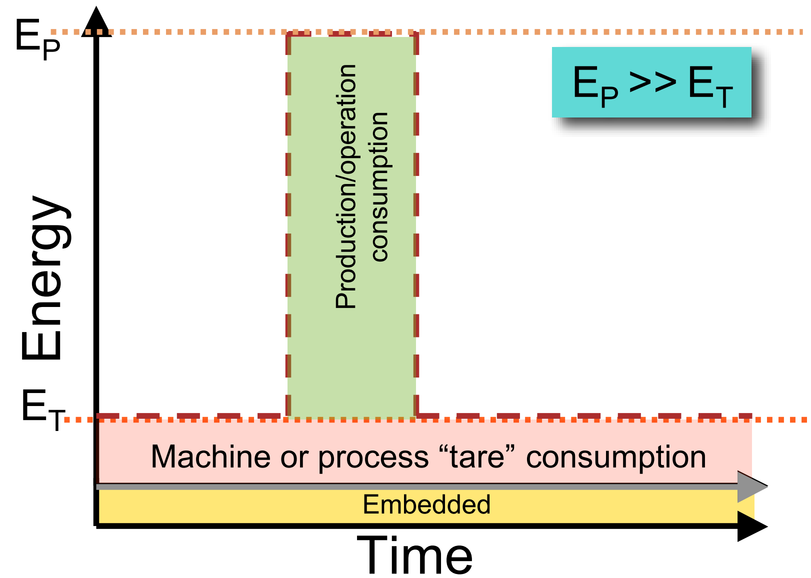




Energy reduction strategies



Power/unit product? or Power/unit time?



Mode	$E_P << E_T$	$E_P \sim E_T$	$E_P >> E_T$
Operation (with process)	Highest MRR Shortest t_c	Highest MRR or Optimize process	Optimize process (tooling, path, f, v)
Operation (w/o process)	Idle/sleep or Reduce tare	Idle/sleep or Reduce tare	Reduce tare?
Embedded (no operation)	Reduce embedded energy: material, fabrication, transport and installation, maintenance, removal and recycle/reman		

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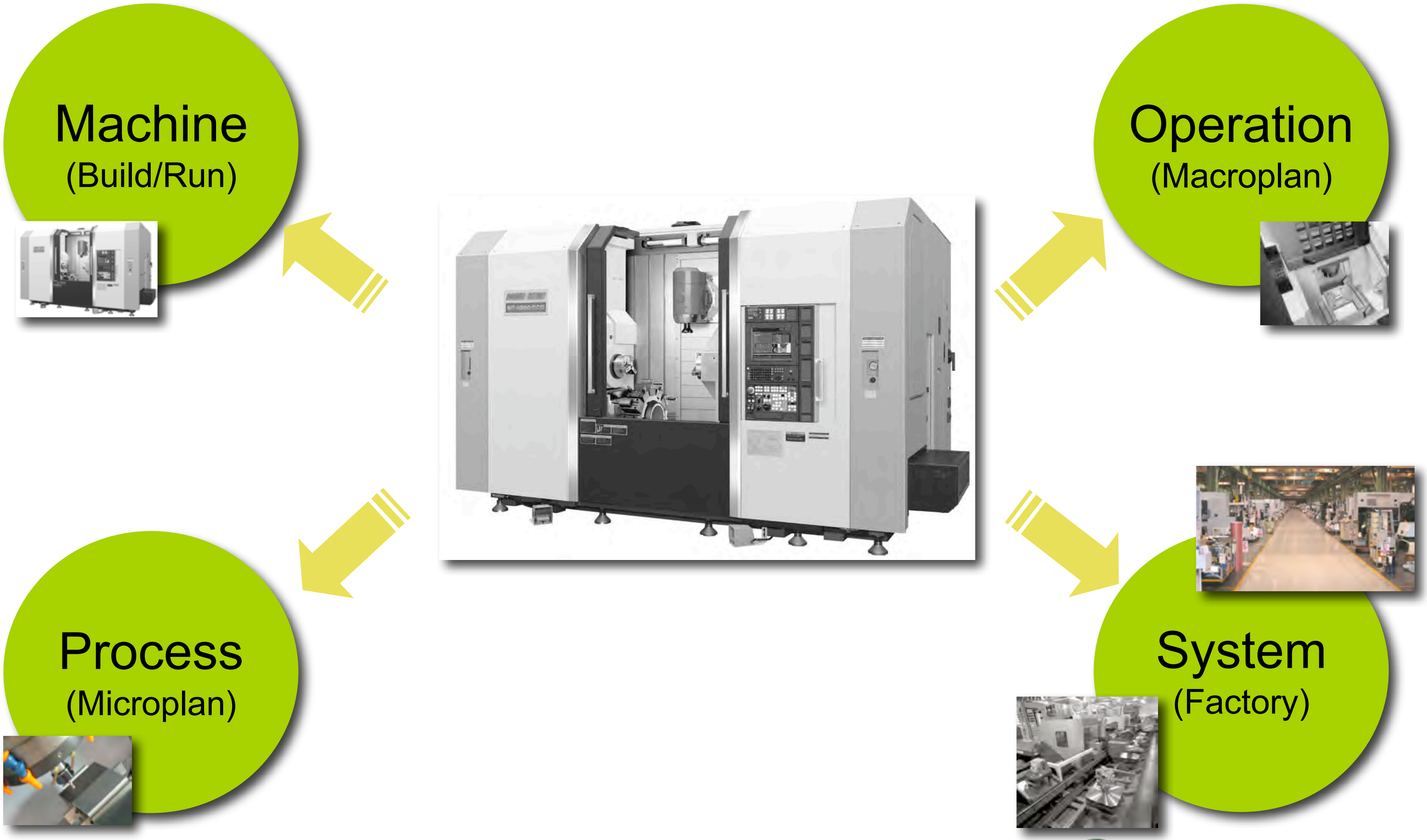
Greening…effects at different scales



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Greening…machine tool level

Machine
(Build/Run)

- Minimum embedded energy, materials, resources per unit of performance (positioning accuracy, speed, thermal stability, etc. in machine tool frame and components)
- Minimum operating energy (hydraulics, spindles, tables/axes, idle, *energy recovery*)
- Alternate energy sources for operation (fuel cell, etc.) and energy storage/recovery capability; variable motors energy req'ts
- Minimized environmental requirements
- Machine work envelope/machine footprint minimization
- Design using sustainability metrics (GHGROI, etc.)
- Design for re-use/re-manufacturing/component upgrade
- Low maintenance
- ?

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Green machine tool?

MAG SPECHT® 500/630 HMC

"Green-design eliminates warm-up time, sleeps when idle, minimizes coolant and air-extraction, cuts dry, wet or with MQL, conserves space at just 1.8 m wide."

Source: http://www.mag-ias.com/home/news/current-news/news-article/article/283/195.html?cHash=855918060f, accessed 10/21/09.

Greening…process level

Process
(Microplan)

- Feeds/speed for minimum energy machining
- High speed machining
- Rough/finish plan for minimum energy, consumables, finishing, etc.
- Spindle/tooling/*tool* design
- Optimized tool path for high productivity and minimum energy
- Minimized environmental requirements
- ?

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Greening…system/factory level

System
(Factory)

- Energy “load balancing” over line/system
- Energy “load balancing” over plant
- Resource/consumable optimization
- Factory/line alternate energy supply and network/grid
- Minimized environmental impact over line/system and plant
- ?

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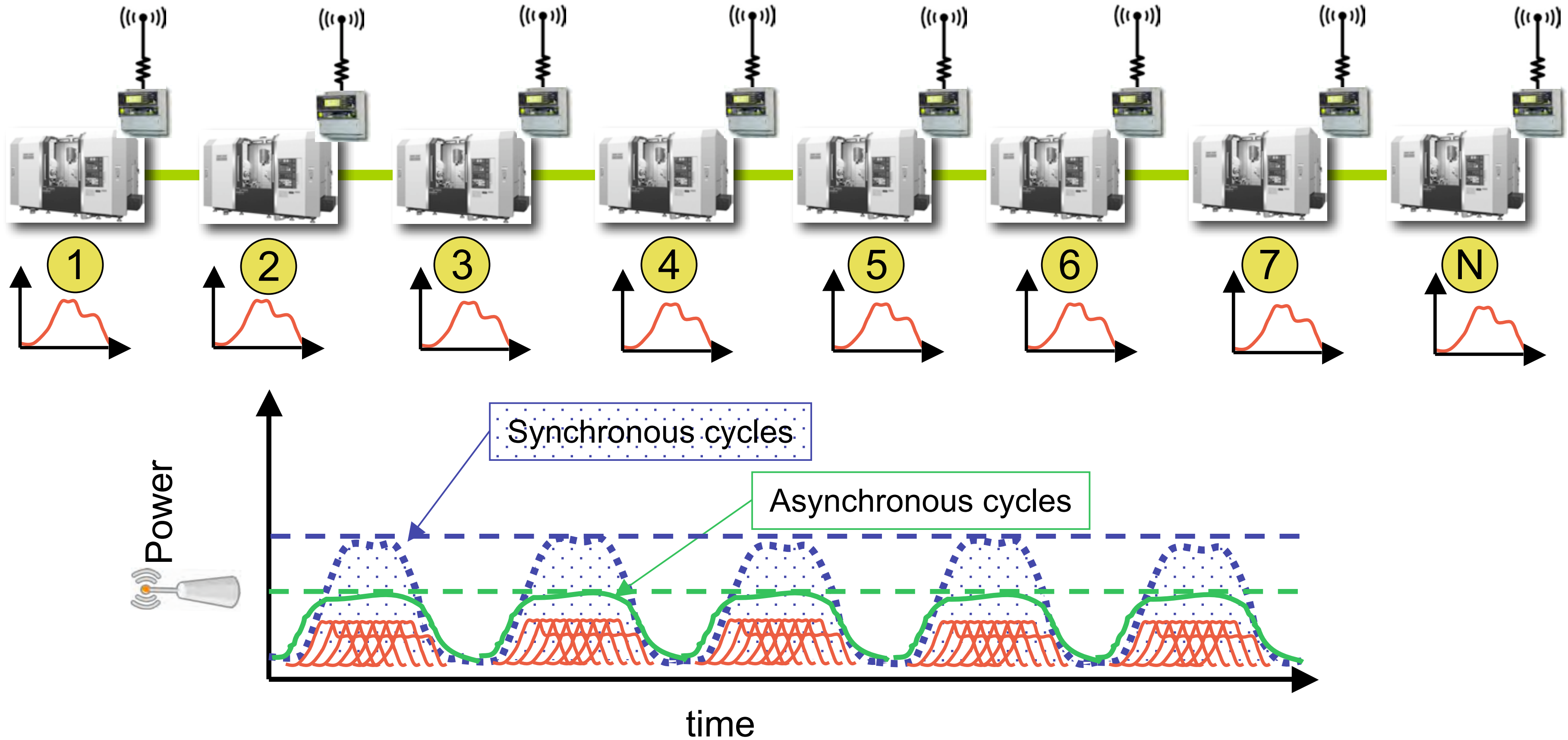
Greening…system performance tracking/optimization



- Energy “load balancing” over line/system
- Energy “load balancing” over plant
- Resource/consumable optimization

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Greening…multi-process machine?




drill + turn + vertical mill + horizontal mill

drill + turn + mill

Is one better than the other from an energy point of view?

- One machine with extended capability to replace several individual machines; for example, milling + drilling + turning → "mill-turn"

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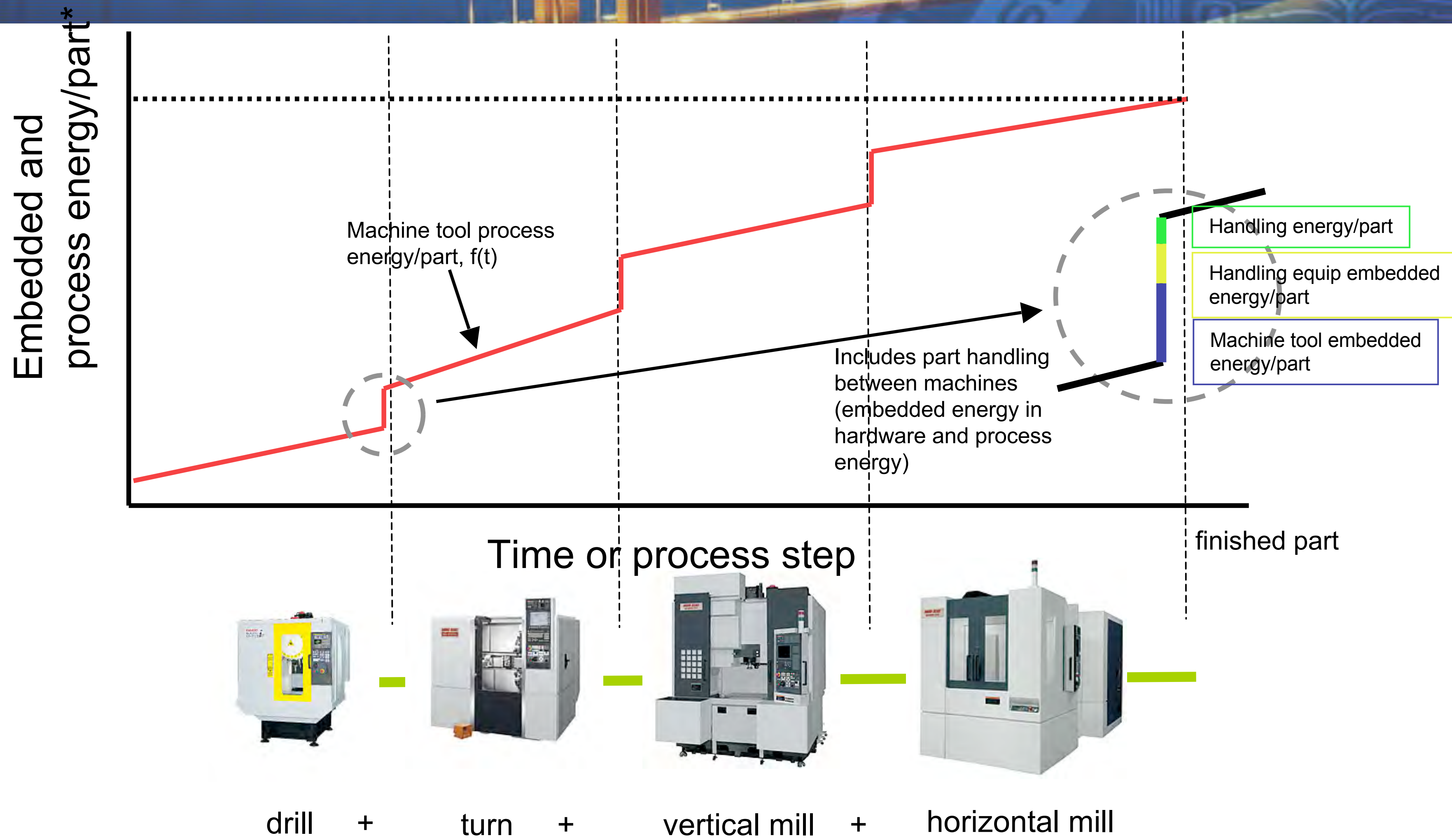
Energy footprint - individual machines



* Energy in materials and construction/transport and setup/operation + energy for operating for specific part, including floor space and factory HVAC, etc.

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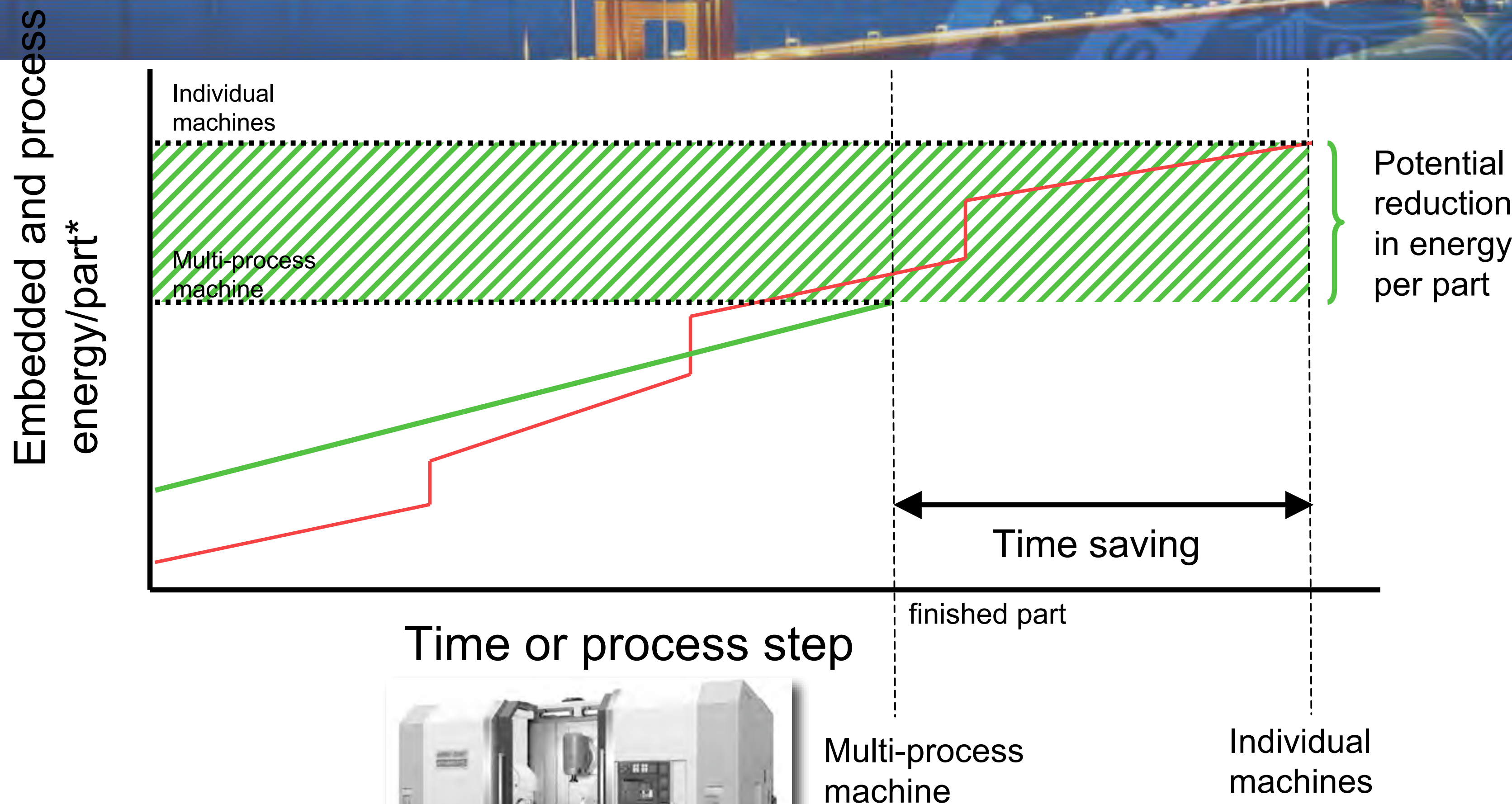
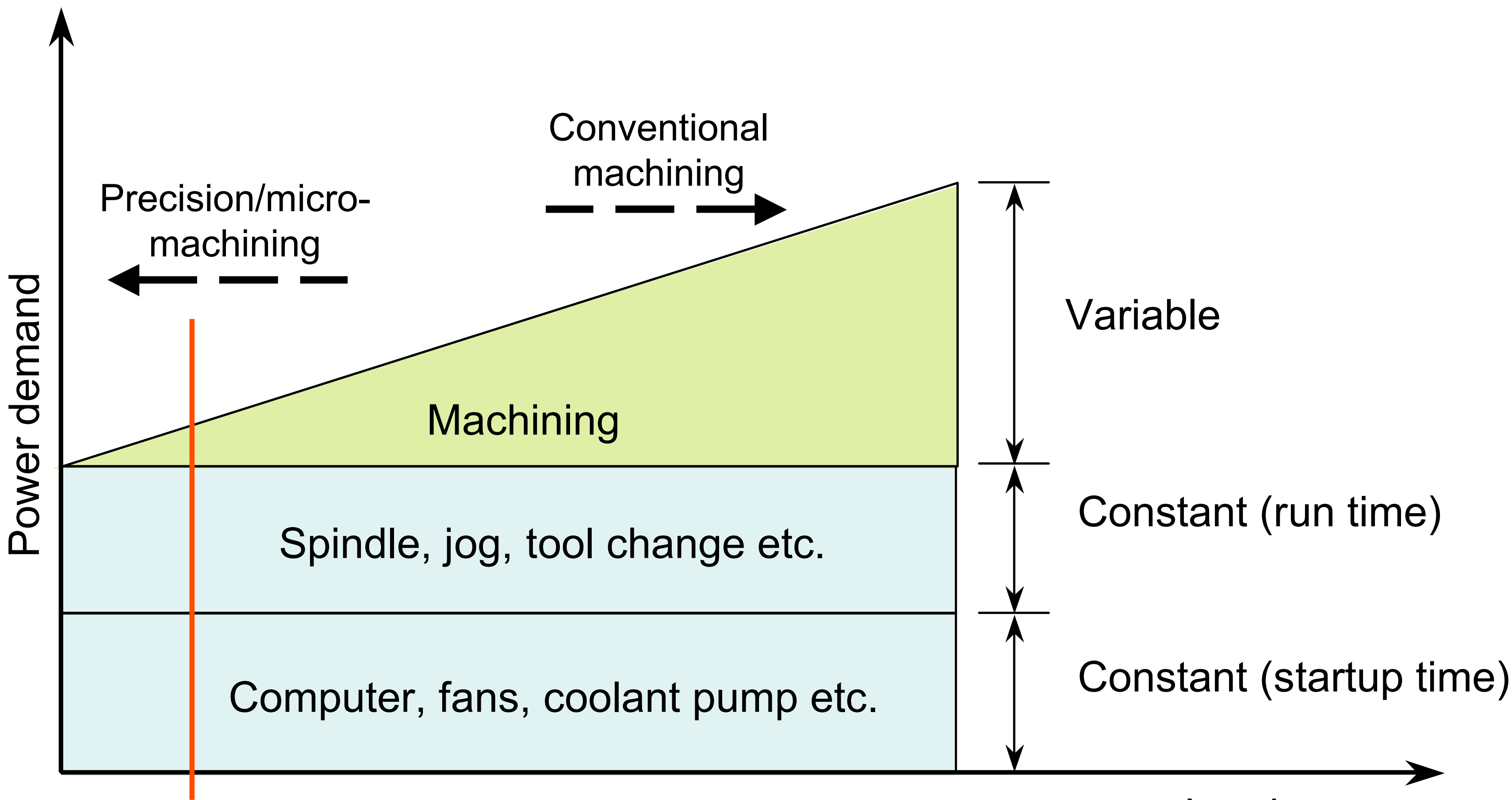
Energy- multi-process vs individual machines



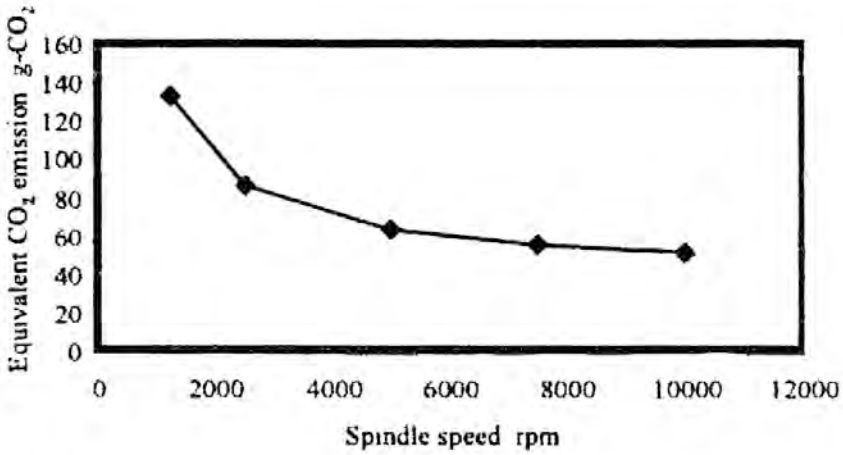
* Energy in materials and construction/transport and setup/operation + energy for operating for specific part, including floor space and factory HVAC, etc.

Power demand vs cutting load



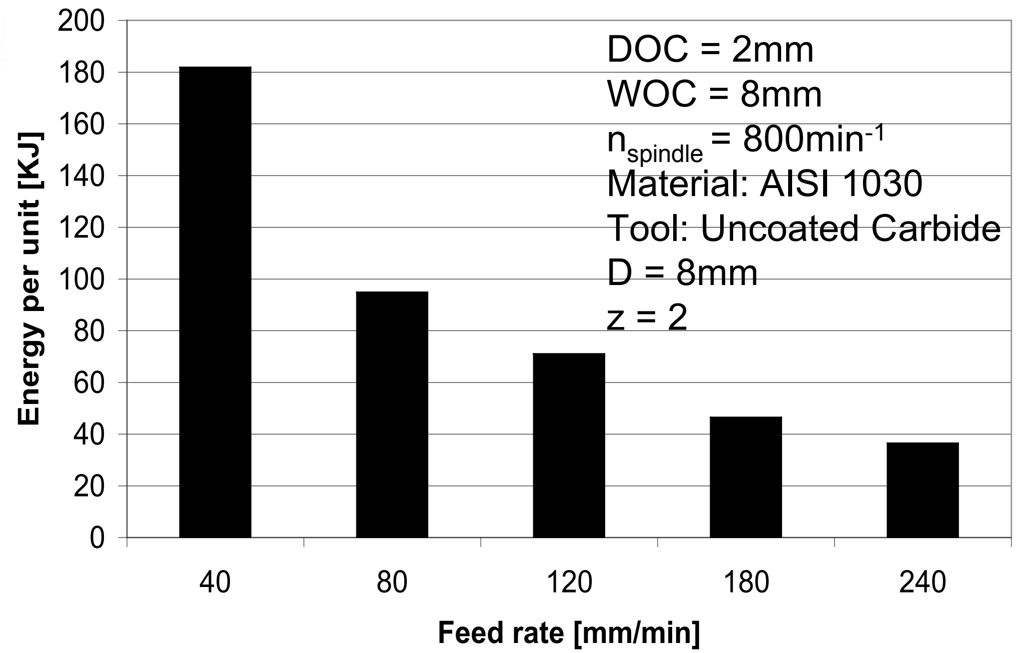
For small loads (low chip load) most power consumed by "non-cutting"

Higher speed saves energy/CO_2 *



Ref: Narita, H., et al, "Development of Prediction System for Environmental Burden for Machine Tool Operation (1st Report, Proposal of Calculation Method for Environmental Burden)," *JSME International*, Vol. 49, No. 4, 2006, pp. 1188-1195.

* On a per part basis!



Source: Stefan Tönissen, "Power Demand of Precision Machine Tools", MS Report, UC-Berkeley, 2009

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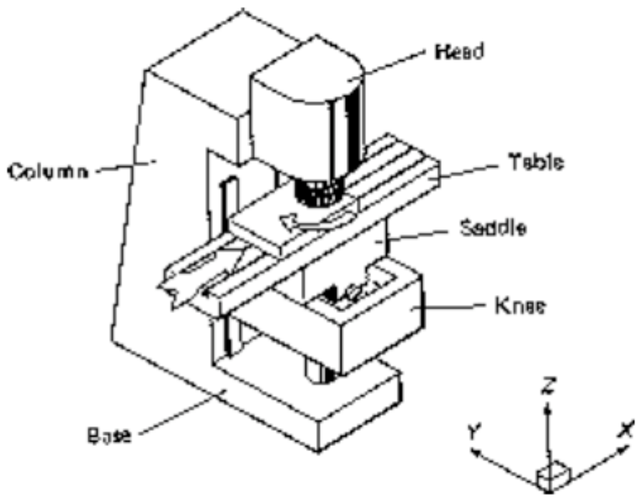
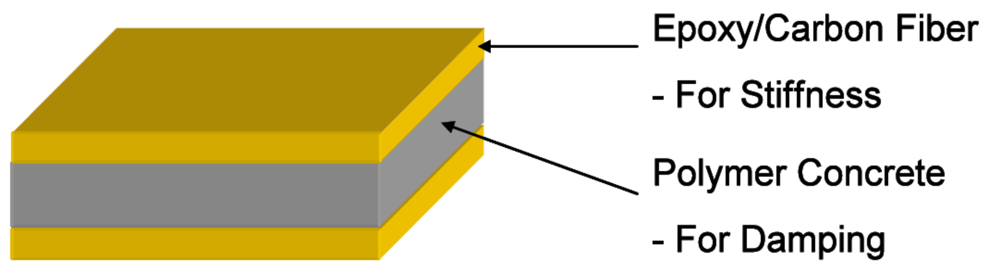
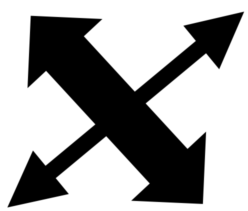
Reducing the mass
- machine tool design affects energy consumption



Composite construction saddle and table





Relative energy use for motion
with “stacked” axes

Component mass influences tool path, machining time and energy consumption

Source: J. Chien and S. Choi, “Design of Polymer Machine Tool for Reduced Energy Use, MEC223 Project, 2009

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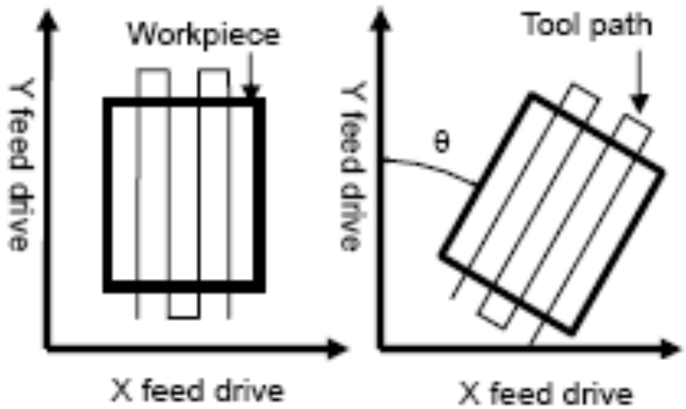
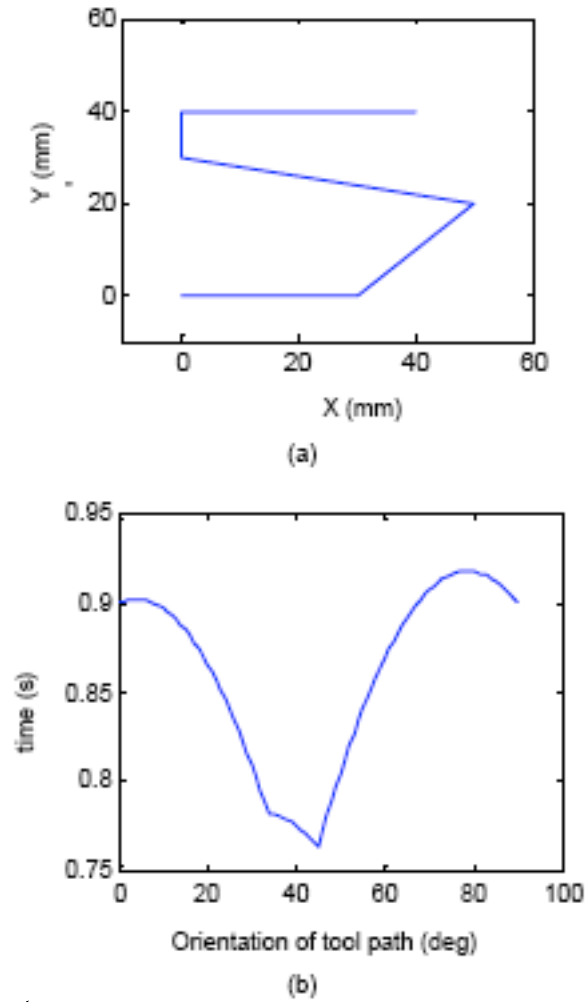
Work orientation effects



Work/table configuration



Tool path and machining time for tool path

Orientation influences tool path, machining time and energy consumption

Source: Rangarajan, A., and Dornfeld, D., "Efficient Tool Paths and Part Orientation for Face Milling," *CIRP Annals*, 53, 1, 2004.

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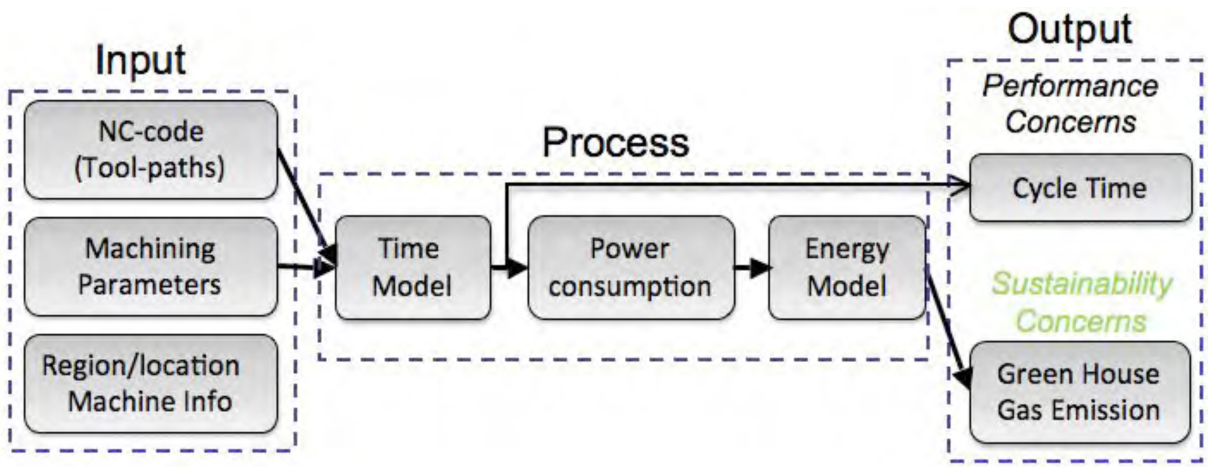
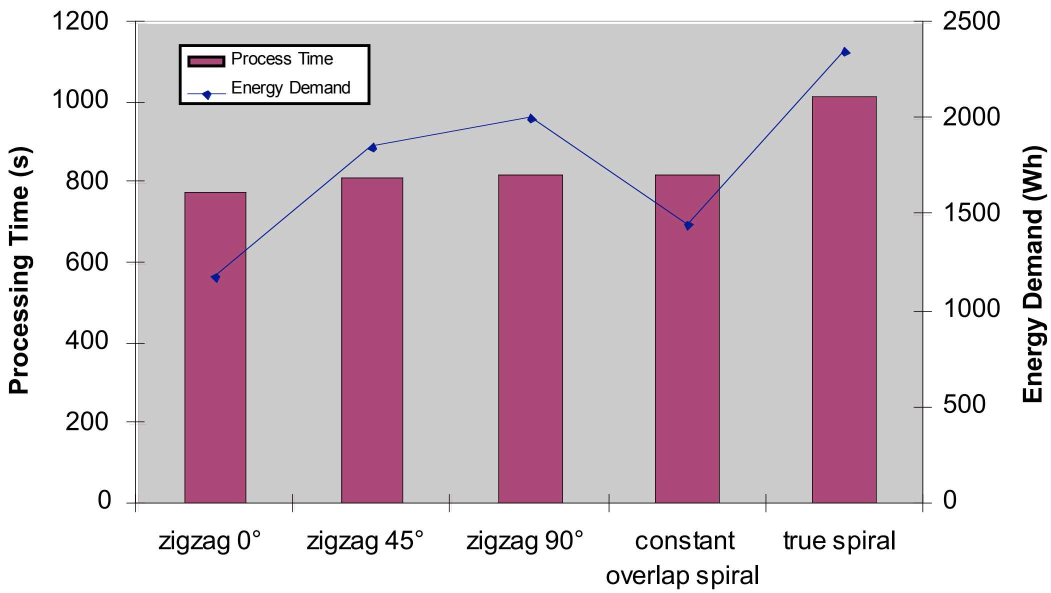
Tool path effects





Tool path, for a machine and process influences machining time, energy consumption and impact (GHG)

Pocket milling example with differing tool paths

Source: S. Choi, et al., "Evaluation of Toolpath w.r.t. Precision and Environment," ME290C Project, UC-Berkeley, Fall 2009.

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KERS* in machine tools

*Kinetic Energy Recovery Systems

- Tool change offers potential to recover energy from spindle.
- Energy recovery during air cutting may mean the most efficient tool path is not necessarily the most rapid.
- Energy recovery “in cut” also possible
- Energy recovery from the table should be disregarded
- Numerous strategies for energy recovery:
  - Supercapacitors
  - Motor-generators
  - Coast-cutting (!)

Source: A. Jarvis, “KERS in Machine Tools,” MS Report, UC-Berkeley, 2009

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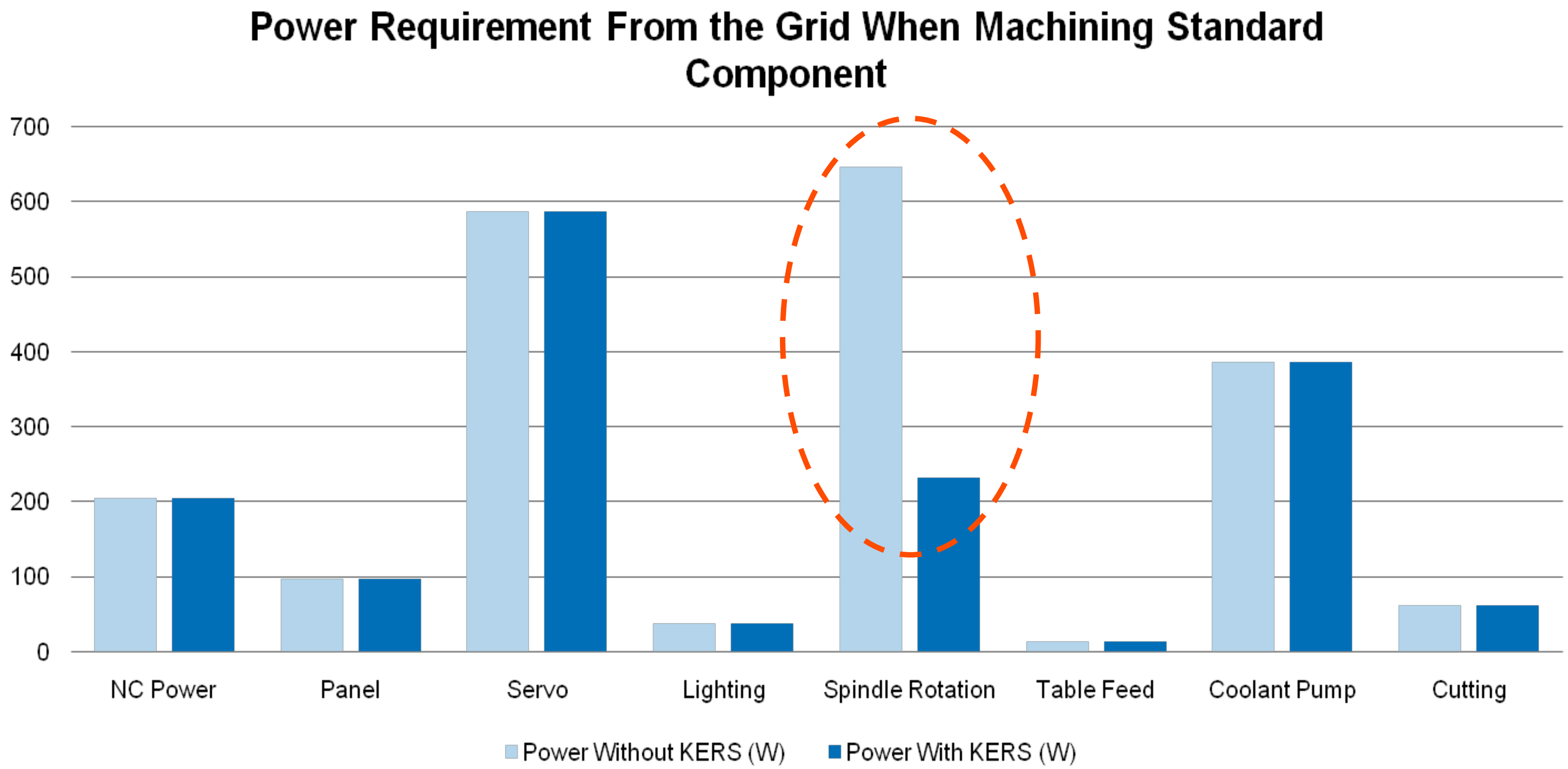
KERS example

- Overall power saving of 20.41% (413W)
- Energy saving of 49.6kJ per part



Source: A. Jarvis, "KERS in Machine Tools," MS Report, UC-Berkeley, 2009

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Enabling Energy Monitoring

Challenge: integrate energy data with the operational data from the machine

system insights

How much machine is consuming along with *what it is doing*

Energy Data

Operational Data

MTConnect

Integrate operational and energy data using MTConnect interoperability standard

Enable decision making based on combined data

Source: System Insights, 2009

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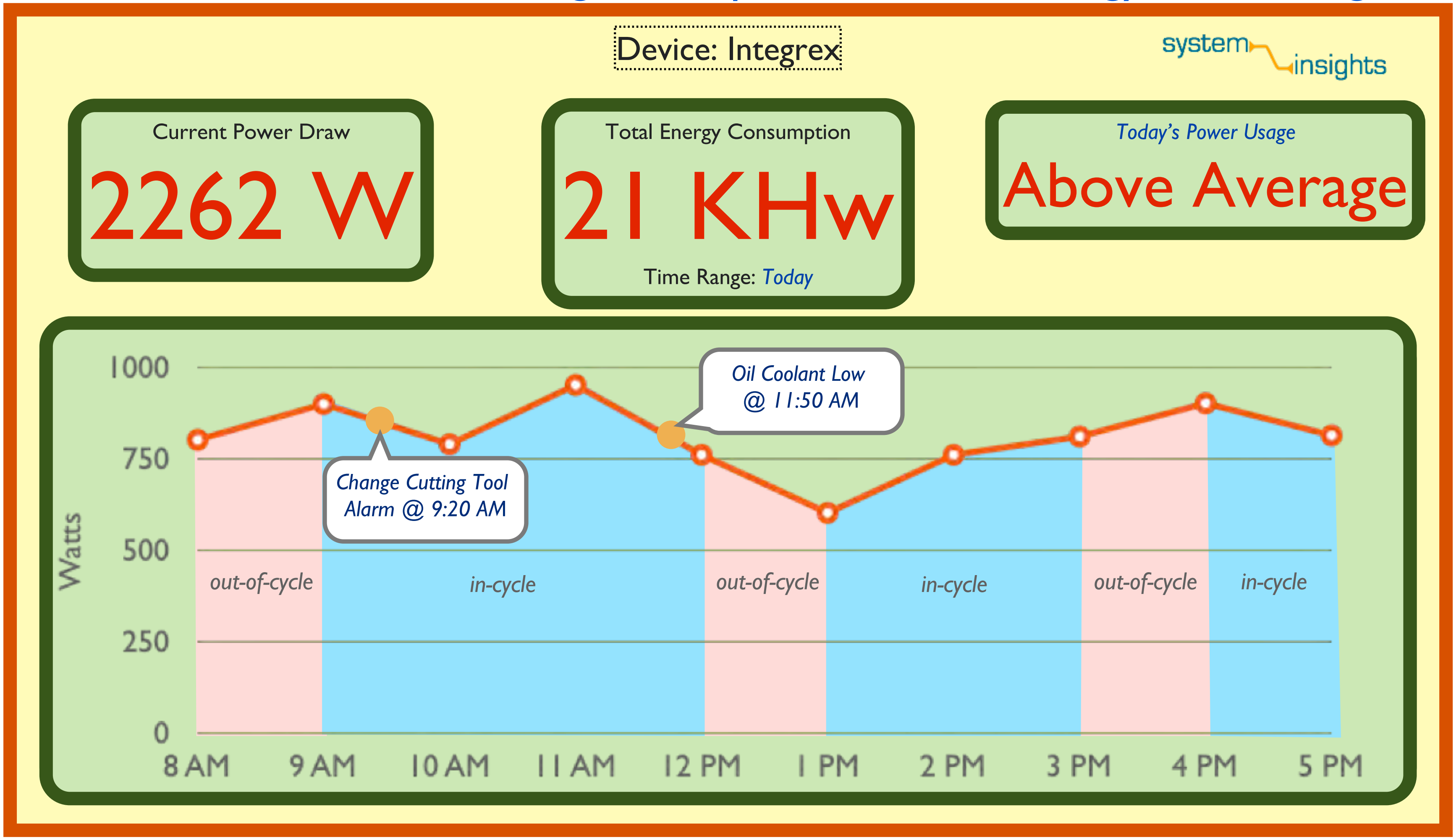
Example: Energy Dashboards

Build dashboards for integrated operational and energy monitoring



Source: System Insights, 2009

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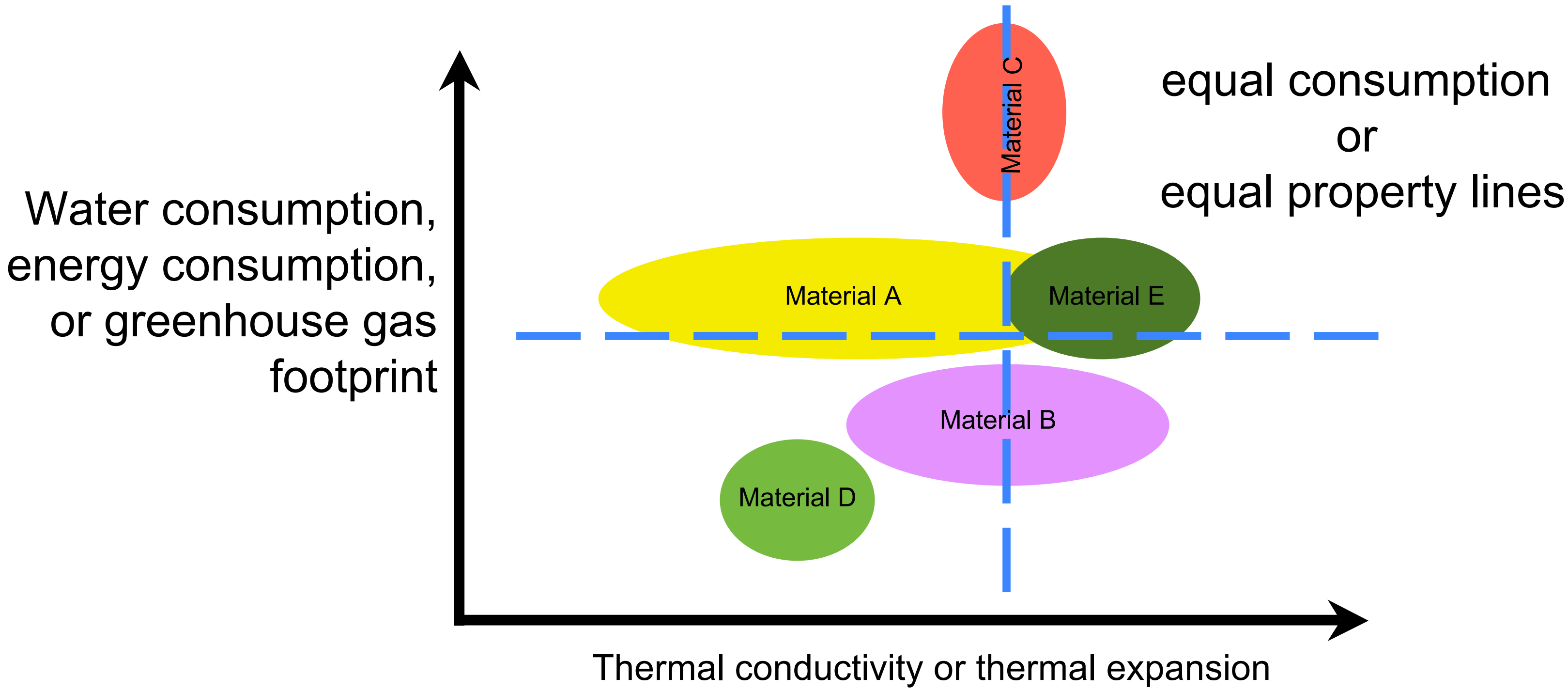
Green Machine Design - Linking Design to Sustainability

How about mass, stiffness, thermal conductivity or thermal expansion/unit of primary water consumption, or primary energy consumption?



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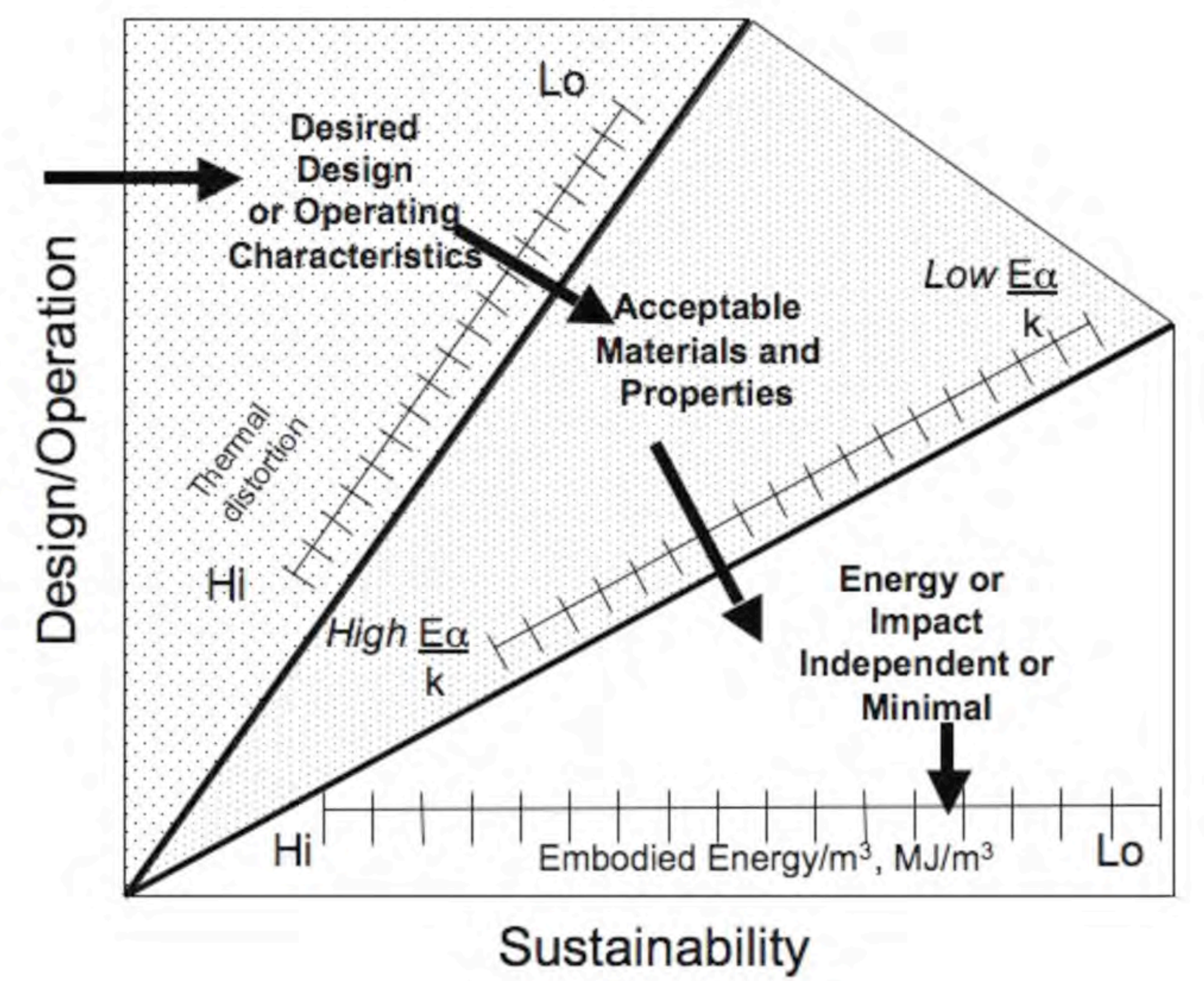
Green Design: Thermal Stability



Source: Dornfeld, D. and Lee, D., *Precision Manufacturing*, Springer, Chapter 12, 2008.

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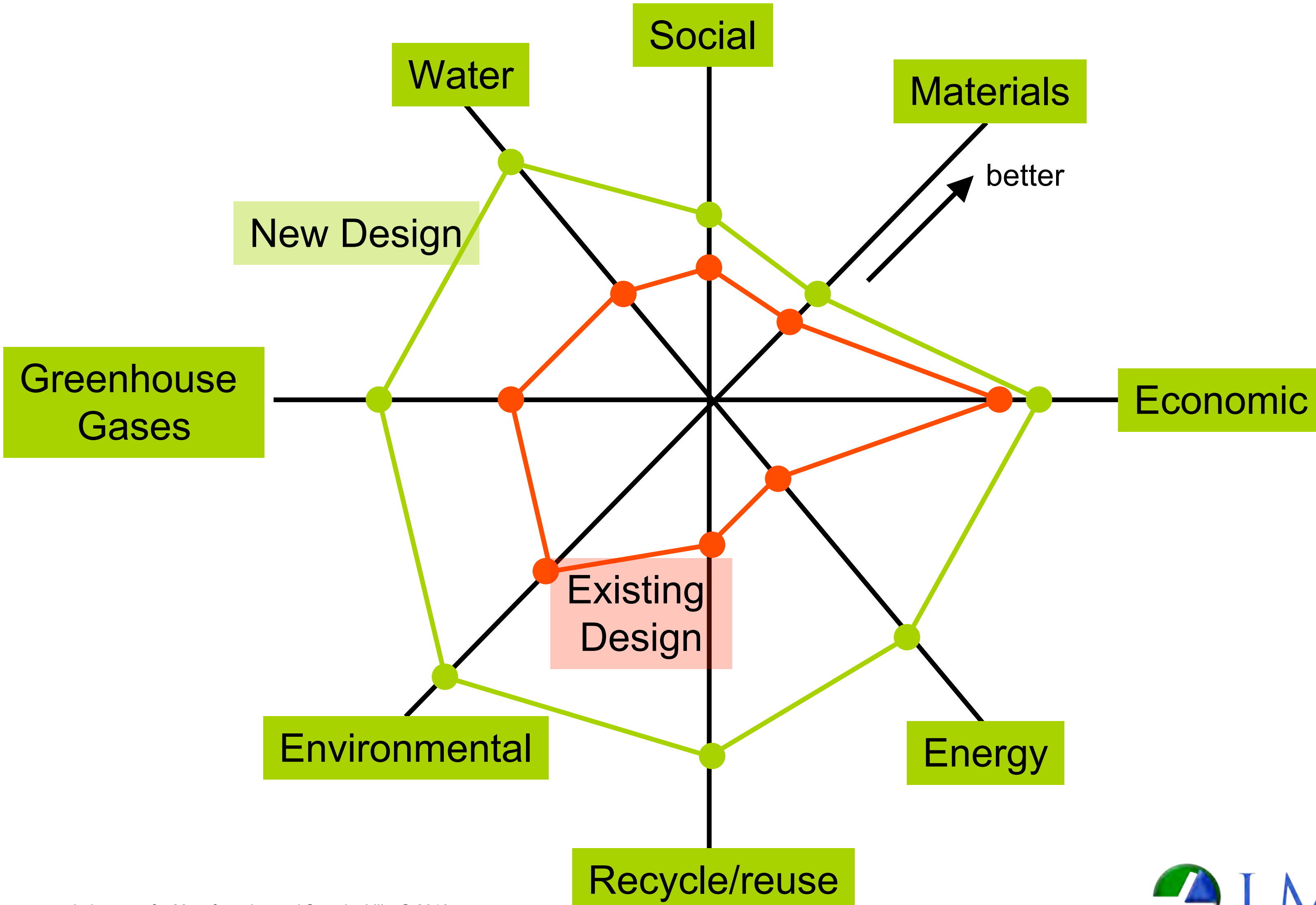
Manufacturing Sustainability Footprint



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Conclusions

- Energy, green manufacturing and related issues are a big opportunity for industry/manufacturing
  - new products/services/market leadership
  - better overall performance/lower CoO
  - more competitive, reduce risk
  - take advantage of growing regulatory environment
- This requires careful analysis and development of metrics and analytical tools
- Including energy and green manufacturing aspects can be part of a successful sustainable business strategy
- The problem is too large for individual companies to solve - must be a cooperative effort among industry, associations, researchers, government

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Thanks for your attention!

Follow-on questions, comments, suggestions?

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