Design principles for sustainable materials & manufacturing processes, I

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UC Berkeley
02/13/12

Outline

• Topics:
  – first … dimensions of impact!
  – operation and control of manufacturing processes
  – optimizing energy use
  – supply chain management
  – OECD framework

Readings

• “Greening the Industrial Facility,” TE Graedel and JA Howard-Grenville, Springer, 2005
Manufacturing Sustainability Footprint

Dimensions of impact and influence

The typology of eco-innovation*

Environment vs Economic Benefit**


Dimensions of impact and influence

- Institutions
- Organisations
- Marketing methods
- Processes
- Products

Eco-innovation targets

Higher potential environmental benefits but more difficult to coordinate

Primarily non-technological change

Primarily technological change

Modification
Re-design
Alternatives
Creation

Eco-innovation mechanisms

Use vs manufacturing

Environment vs Economic Benefit

Spatial vs temporal


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Dimensions of impact and influence

Spatial vs temporal

- Supply Chain Design: Proximity to Alternate Energy
- Logistics Design: Transportation Mode
- Logistics Adjustments: Adjust Supplier Location
- Final Adjustments: Pallet Size

- Facility Design: Structural Materials
- Construction Design: Choice of Equipment
- Facility Adjustments: Lighting Controls
- Facility Retrofitting: Energy Source (ex. water)

- Machine Design: Tool Material Choice
- Machine-Mfg Design: Choice of Tooling
- Machine Mfg Adjustments: Adjust Consumables
- Machine Post Process: Capture/Sub/Emittions

- Product Design: Material Choice
- Product-Mfg Design: Choice of Tooling
- Process Adjustments: Adjust Consumables
- Product Post Process: Capture/Sub/Emittions


Dimensions of impact and influence

Eco-Care Matrix (ECM)

Section A: „Green Solutions“
Section B: Advantage in productivity, but disadvantage in environmental impact (Eco Design)
Section C: Advantage in Environmental Impact, but Disadvantage in Productivity (Design-to-Cost)

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One more! BASF SEEbalance

Dimensions of impact and influence – one more!


Lecture 8
The product life-cycle


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How do things get made?

- Macro planning
- Micro planning
- Precedence
- Availability
- Balance
- Yield
- BOM
- Tasks

Detailed decisions

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Lecture 8
Material problems for starters…

Rule of Thumb:
You want to take the shortest path for material recycling

Sustainable design

Design guides usually:
- Propose a methodology
- Offer examples/do’s/don’ts
- Ask questions

Example – Designer’s Field Guide

What is it trying to accomplish?
How is it brought to life?
How is it used?
Where does it end up?

Lists and more lists … DfX

- Design for Short Time to market
- Design for reliability
- Design For Test
- Design for safety
- Design for quality
- Design Against Corrosion Damage
- Design for Minimum Risk
- Design to cost
- Design to standards
- Design for assembly
- Design for manufacturability
- Design for logistics
- Design for Electronic Assemblies
- Design for Low-Quantity Production
- Design for user-Friendliness
- Design for Ergonomics
- Design for Aesthetics
- Design for Serviceability
- Design for Maintainability
- Design for Environment
- Design for Sustainability
- Design for Reuse
- Design for Remanufacturing
- Design for Recycling
- Design for Disassembly

Usually centered on the stage of life – design, production, distribution, use, disposal, re-use.

Opportunities for improvement

1. Improve manufacturing process
   - Technology
   - Improve energy efficiency
   - Reduce embedded energy
   - Use clean energy sources

2. Improve material efficiency
   - Material
   - Use lower impact materials

3. Cost issue

Ref: Chris Yingchun Yuan, LMAS Presentation, 2009
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Effects at different scales

Enterprise
Facility
Line/system
Machine
Tooling/setup
Process

And across the supply chain...

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
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

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

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

Supply Chain Impacts

(Depends on the product/process!)

- Materials
- Energy
- Water
- GHG

“upstream” impact

Big variation depending on mfg supply chain(s)

Reductions if recycling/reuse
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 Reduction Tools and Strategies

Big Losses That Lower Equipment Efficiency

Increased equipment operating efficiency reduces energy waste. When machines are optimally tuned to accomplish the desired work, energy inputs are most efficient. Total productive maintenance’s (TPM) emphasis on equipment efficiency can lead to reduced costs, increased productivity, and fewer defects.

TPM focuses on the six big losses that lead to equipment inefficiency:

- Breakdowns
- Setup and adjustment loss
- Idling and minor stoppages
- Reduced speed
- Defects and rework
- Start and yield loss

Source: http://www.epa.gov/lean/energy/toolkit/v4.htm
Energy use in manufacturing

Energy reduction strategies

Mode
- Operation (with process)
- Operation (w/o process)
- Embedded (no operation)

Power/unit product? or Power/unit time?

Mode
- Operation (with process)
- Operation (w/o process)
- Embedded (no operation)

Highest MRR
- Shortest t

Highest MRR or Optimize process
- Tooling, path, f, v

Optimize process
- Reduce tare?

Reduce embedded energy: material, fabrication, transport and installation, maintenance, removal and recycle/repair
Components of electricity consumption

in automotive parts machining systems

- Oil cooler 0%
- Hydraulic pump 12%
- Shower coolant pump 18%
- Washing station coolant pump 0%
- Through spindle coolant water pump 20%
- Through spindle coolant pump 6%
- Coolant pump 9%
- Mist collector 0%
- Coolant cooler 7%
- Coolant cooler water pump 4%
- Control box 9%
- NC 7%
- Servo/spindle 11%

60% of electricity consumption is coolant-related.

Source: M. Mori, EERE Presentation, CIRP, Pisa, 2010
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Automatic power off

- Backlight of in-machine lighting and display hibernates when machine is idle
- Power of spindle, servo motor, cutting oil, and chip conveyor shuts off, when machine is idle
- Power state resumes on keyboard input

Source: M. Mori, EERE Presentation, CIRP, Pisa, 2010
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Use matrix for manufacturing

What if we looked at manufacturing in the same manner...that is a “use matrix of manufacturing classes”?

<table>
<thead>
<tr>
<th></th>
<th>High load factor</th>
<th>Modest load factor</th>
<th>Low load factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary power-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>consuming</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary power-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>consuming</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non power-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>consuming</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

High impact ↔ Low impact

Energy intensive

Material intensive

How would this look for manufacturing?

Ashby- matrix for energy/impact

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</thead>
<tbody>
<tr>
<td>Primary power-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>consuming</td>
<td>Family car</td>
<td>Television</td>
<td>Coffee maker</td>
</tr>
<tr>
<td></td>
<td>Train set</td>
<td>Freezer</td>
<td>Vacuum cleaner</td>
</tr>
<tr>
<td></td>
<td>Aircraft</td>
<td></td>
<td>Washing machine</td>
</tr>
<tr>
<td>Secondary power-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>consuming</td>
<td>Housing (best,</td>
<td>Car-park (light)</td>
<td>Household dishes</td>
</tr>
<tr>
<td></td>
<td>light)</td>
<td></td>
<td>Clothing (washing)</td>
</tr>
<tr>
<td>Non power-</td>
<td>Bridges</td>
<td>Furniture</td>
<td>Canoe</td>
</tr>
<tr>
<td>consuming</td>
<td>Roads</td>
<td>Bicycle</td>
<td>Tent</td>
</tr>
</tbody>
</table>

High impact ↔ Low impact

Energy intensive

Material intensive
### Draft use matrix for manufacturing

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<th>Low load factor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary power-consuming</strong></td>
<td>Process energy: furnaces, rolling mills (electric motors), smelting, refining ore, semiconductor mfg</td>
<td>Process energy: machine tools, inj. mold presses, server farm (electric motors), welding</td>
<td>Process energy: converting machinery, conveyors, ASR (electric motors), food processing</td>
</tr>
<tr>
<td><strong>Secondary power-consuming</strong></td>
<td>Hi tech factory heat + a/c, light, compressed air, de-i water, etc., traditional farming</td>
<td>Service center (server) with HVAC, sewing</td>
<td>Warehouse, office, service center (non server), non-organic farming, recycling ctrs.</td>
</tr>
<tr>
<td><strong>Non power-consuming</strong></td>
<td>Buildings, foundations (incl. machine tool), logging</td>
<td>Furniture, workstations, tooling (drills, mills), hand crafts</td>
<td>Landscaping, composting</td>
</tr>
</tbody>
</table>

**Energy intensive**

**Material intensive**

**High load factor**

**Modest load factor**

**Low load factor**

### Back to the matrix

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<td><strong>Non power-consuming</strong></td>
<td>Buildings, foundations</td>
<td>Furniture, workstations</td>
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</tr>
</tbody>
</table>

**High load factor**

**Modest load factor**

**Low load factor**

**Energy intensive**

**Material intensive**

**High impact**

**Low impact**

**Consider:** material production

manufacture

use

disposal
Example: 1500 ton Verson

CAPACITY..............................: 1500 TONS
(CENTER CYL 900 TONS @ 2,500 PSI)
2 x OUTER CYLS 600 TONS @ 2,500 PSI)
BED (RL/FB).........................: 144” x 96”
STROKE:................................: 48”
ADJUSTMENT:................................:
SHUT HEIGHT.........................: 32”
KNOCKOUT CAP.......................: 100 TONS @ 2,500 PSI
KNOCKOUT STROKE.................: 36”
KNOCKOUT EJECTION SPEED...........: 318 IPM
PRESSING SPEED......................: 62.5 IPM
FAST ADVANCE SPEED..................: 632 IPM
FAST RETURN SPEED...................: 550 IPM
CUSHIONS CAP.................: 200 TON
CUSHIONS STROKE..................: 24”

EQUIPPED WITH:
200 HP MOTOR & CONTROLS
4 POINT EJECTOR SYSTEM

Press design

What do we design for?
- tonnage (pressure/power)
- stiffness
- speed/strokes per minute
- ease of load/unload
- die changing/handling/setup

And, don’t forget other efficiencies/savings:
• Breakdowns
• Setup and adjustment loss
• Idling and minor stoppages
• Reduced speed
• Defects and rework
• Start and yield loss
But it moves ... a lot!

<table>
<thead>
<tr>
<th>Function</th>
<th>Maximize*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum energy content for given tensile stiffness</td>
<td>$E / H_p \rho$</td>
</tr>
<tr>
<td>Minimum CO$_2$ emissions for given tensile strength</td>
<td>$\sigma_y / [CO_2] \rho$</td>
</tr>
<tr>
<td>Minimum energy for given bending stiffness (beam)</td>
<td>$E^{1/2} / H_p \rho$</td>
</tr>
<tr>
<td>Minimum energy for given bending stiffness (panel)</td>
<td>$E^{1/3} / H_p \rho$</td>
</tr>
<tr>
<td>Minimum CO$_2$ for given bending strength (beam)</td>
<td>$\sigma_f^{2/3} / [CO_2] \rho$</td>
</tr>
<tr>
<td>Minimum CO$_2$ for given bending strength (panel)</td>
<td>$\sigma_f^{1/2} / [CO_2] \rho$</td>
</tr>
<tr>
<td>Minimum eco-indicator points for given thermal conduction</td>
<td>$\lambda / I_\theta \rho$</td>
</tr>
</tbody>
</table>

* $H_p$ = production energy content per kg; $[CO_2]$ = CO$_2$ production per kg; $I_\theta$ = eco-indicator per kg; $E$ = Young’s modulus; $\sigma_y$ = tensile strength; $\rho$ = density.

so material density matters also...

Tradeoffs

What is best for the press?
Production Planning

Goals & Approach

- Assess resource consumption for multi-station operations using life cycle assessment methodology

  - Energy use
  - Water use
  - Waste

- Develop/apply tool to provide decision support for manufacturing process and process chain selection

- This tool can be used to better understand resource consumption and environmental and financial impacts of manufacturing process chains used to make a product
Process Analysis

- Each manufacturing process of the process chain must be analyzed individually
- For each process multiple inputs and outputs need to be assessed

Source: Institute for Machine tools and Industrial Management (G. Reinhart, S. Reinhardt)

Impact Analysis

- Associated impacts
  - Operating Cost
  - GWP
  - LCA tools (e.g. GaBi, Umberto, etc. can assist)
Comparing different manufacturing processes and process chains can be used to inform trade-off decisions that influence operating costs, resource consumption, and impacts on the environment.

These comparisons could also inform additional production decisions including:
- Production location
- Production floor and line layout
- Future factory planning

Production location considerations
- Local cost of resources (energy, water, etc.)
- Carbon intensity of energy mix at production location

This requires link to CAD/CAM tools.

OECD Toolkit
Basic relationships between manufacturing and the environment

(http://www.oecd-ilibrary.org/content/book/9789264077225-en)
OECD Sustainable Manufacturing

Overview of the OECD Sustainable Manufacturing Indicators

- **Inputs**
  - O1 Water intensity
  - O2 Energy intensity
  - O3 Renewable proportion of energy
  - O4 Greenhouse gas intensity
  - O5 Residuals intensity
  - O6 Air releases intensity
  - O7 Water releases intensity
  - O8 Proportion of natural land

- **Operations**
  - P1 Recycled/reused content
  - P2 Recyclability
  - P3 Renewable materials content
  - P4 Non-renewable materials intensity
  - P5 Restricted substances content
  - P6 Energy consumption intensity
  - P7 Greenhouse gas emissions intensity

- **Products**


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## Mapping Example

<table>
<thead>
<tr>
<th>Impact area</th>
<th>Nature of impact &amp; any stakeholder concerns (positive / negative)</th>
<th>Insights to potential improvements &amp; cost and benefit</th>
<th>Further information available or needed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inputs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use of harmful materials</td>
<td>Some materials might be restricted by law or toxic to health and the environment. Civic campaigns are increasingly focusing on this issue.</td>
<td>Replace with less damaging alternatives.</td>
<td>Need to explore potential providers and confirm with cost-benefit analysis.</td>
</tr>
<tr>
<td><strong>Operations</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No monitoring of energy efficiency or heat loss</td>
<td>Poor efficiency and heat loss is a waste of energy and money. Employees and purchasers are interested in our performance.</td>
<td>Basic monitoring will help to track performance and identify opportunities for improvement.</td>
<td>Find out options to monitor energy efficiency and explore how to inform and involve staff.</td>
</tr>
<tr>
<td><strong>Products</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>End product has a lot of plastic packaging</td>
<td>Current packaging is non-renewable and isn’t easily recycled. There are a growing number of customer complaints.</td>
<td>Need to look at potential for using recycled cardboard for packaging.</td>
<td>Explore cardboard packaging options and any implications for branding and product quality.</td>
</tr>
</tbody>
</table>

## Assessing impacts

### Assessing degree of impact for prioritising issues

<table>
<thead>
<tr>
<th>Impact level</th>
<th>Environmental impact</th>
<th>Business impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Results in significant damage or enhancement to the general environment and is of great concern to stakeholders.</td>
<td>Significant ramifications for business and reputation with potential for substantial losses or gains.</td>
</tr>
<tr>
<td>Medium</td>
<td>Causes some damage or enhancement to some parts of the environment and attracts some stakeholder concern.</td>
<td>Moderate ramifications for business and reputation.</td>
</tr>
<tr>
<td>Low</td>
<td>Results in minimal environmental damage or enhancement, with limited stakeholder interest.</td>
<td>Minimal ramifications for business and reputation.</td>
</tr>
</tbody>
</table>
Issue priority matrix

Normalization factors

A variety of factors may be used to normalise performance, including:

- Numbers, weight or units of products produced in the facility.
- Sales or value added in the facility.
- Person-hours worked in the facility.
- Units of function or level of services to be provided by the products produced in the facility.
- Lifetime of the products produced in the facility.

Then consider ROI!
Leveraging

What if it seems that manufacturing doesn’t really matter in the long run?!

For example … little impact over product life cycle

Recall: Use vs Manufacturing Impacts

What if you are here?

Manufacturing Phase Consumption

High

Increase Product Efficiency (Design or Mfg leveraging)

Least Sustainable (avoid)

Low

Most Sustainable

Manufacturing Phase Consumption Or Impact

Low

Increase Process Efficiency (Improve Manufacturing)

High

Impact - Manufacturing vs Use

Manufacturing phase energy requirements for VW Golf A3 Automobile (circa late 1990's)

Must include supply chain in the analysis!

Source: Volkswagen AG, and Harald Florin, PE Europe/IKP-University of Stuttgart, Germany

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Impact- Manufacturing vs Use

Life Cycle Impact of VW Golf A3 Automobile (circa late 1990’s)

Machining (not including any in supply chain) accounts for ~10% of total energy.

Let’s assume we do something to reduce machining process energy by 10% by, say, some new fancy tooling.

That will save 1% of manufacturing energy.

That accounts for 0.1% of lifecycle impact.

Why bother?!

Leveraging Manufacturing in Performance

Same size engine (displacement)

But

- Reduced friction
- Better tolerances
- Enhanced fluid flow and cooling
- Higher injection pressures
- Smaller injection orifices

All based on improved manufacturing technology.

Source: Volkswagen AG, and Harald Florin, PE Europe/IKP-University of Stuttgart, Germany

Source: K. Berger, Daimler from Giesserei 1/2005
Leveraging Manufacturing

Mfg process or System improvement

Product life cycle impact improvement

This gets us this!

- Manufacturing improvement
- Product performance improvement
- Fuel savings

- Water use/pollution reduction
- CO2/ GHG reduction
- Air pollution reduction