Sustainable Design and Manufacturing: Including Environmental and Social Considerations

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Dutch officials seize cadmium-packed PlayStation kit

Sony wonders what fuss is about

By Tony Smith

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Dutch customs officers yesterday impounded 1.3 million PlayStations and 800,000 accessory packs worth over 180 million Euro ($160.25 million) after environmental protection inspectors discovered they were a potential threat to the environment.

Think-Pair-Share: Why is this bad? What is the problem? Who is to blame?
Sustainability: Common Definition

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

Sustainability: Working within the Physical Limits

Bottom-line: The extractive capability of humanity (and its industrial system) must be balanced with the regenerative capacity of the Earth.
Sustainability’s “Triple Bottom Line”

Sustainability is defined in three dimensions:

• **Environmental**
  - Destroying our resources will hurt us long term
  - Some materials already getting scarce

• **Financial**
  - Being bankrupt helps nobody

• **Social**
  - Quality of Life should go up
  - Workforce education and retention

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

“People-Planet-Profit”

“Green Economy”
Why do Businesses Care?

• **Legislation: It’s the Law!**
  – It’s the law. Clean Air Act, Clean Water Act, etc.

• **Risk & Liability: Your product can make somebody sick or kill**
  – Using hazardous materials or processes can be risky and create many liabilities

• **Customers**: Nobody wants a product that kills of injures people, animals, etc.
  – Awareness of environmental issues is increasing among customers – especially businesses
  – Industrial customers (e.g., Original Equipment Manufacturers) do not want (future) environmental liability for your product.

• **Image: Image is everything**
  – Being “green” is good.

• **ISO 14000: Your customer tells you to comply with Environmental Management Standard**
  – ISO 14000 (environmental management standards) certification has become an important element in doing business, like ISO 9000 (quality management standards).

• **It makes good business sense!**
  – Less waste = more money!
  – Driver for innovation and new creative solutions
Important Concept: Life Cycle Thinking

- Instead of “just” manufacturing, also think about environmental and social impacts during a product's use, service, and end of life.

Schematic of Product Life-Cycle


- A full assessment of impacts over a life cycle is called “Life-Cycle Assessment” (LCA) and is codified in ISO 14040 standards.
  - LCA examines the environmental burdens and impact of a product over its entire life-cycle (see ISO 14040).
• China, India, etc., are all facing severe environmental, health, and quality of life problems as a result of their industrial growth

• As a US designer and firm, you may be contributing to their problems
Material Legislation is Everywhere

- Many materials are subject to legislations/regulations because they cause harm in some way
- Major US and EU companies all comply with legislation
- For an example list of international regulations, look at automotive industry Global Automotive Declarable Substance List (GADSL):
  - 133 materials that may be in automotive parts
- You can download GADSL spreadsheet:
  - For automotive projects, check whether your design contains any of these materials
  - If so, disclose in report
EPA and Toxic Release Inventory (TRI)

• In the US, look at the EPA “list of lists” to see when you should worry about permits and special rules

• You have to fill in a TRI = Toxic Release Inventory (like a tax report) if you use certain hazardous chemicals in manufacturing and filings are posted online:
  – www.epa.gov/triexplorer/
  – Trivia: According to TRI, who do you think is a) the biggest air polluter and b) the biggest land polluter?

• Best thing is not to use any of these chemicals or let somebody else (your supplier) deal with it
RoHS is often referred to as the lead-free directive, but it restricts the use of the following six substances:

- Lead (Pb)
- Mercury (Hg)
- Cadmium (Cd)
- Hexavalent chromium (Cr6+)
- Polybrominated biphenyls (PBB)
- Polybrominated diphenyl ether (PBDE)

  - PBB and PBDE are flame retardants used in several plastics.

Lots of companies want suppliers to certify that they are “RoHS compliant”

If one part is not compliant, the whole product is not!

Make sure your design is RoHS compliant!

Check for RoHS compliance label when ordering.
Tool: Material Safety Data Sheets (MSDS)

- Check MSDS of materials if you want to be safe w.r.t. any health risks from a material you want to use in your design
  - Also think about worker safety (OSHA)

- MSDS can be obtained from material providers
  - Should be available upon request or online

- GREAT list of online MSDS and related databases is at:
  - http://www.ilpi.com/msds/

- Quick and easy online (free) MSDS database:
  - http://hazard.com/msds/

- If applicable, include MSDS in your report (appendix)
End Of Life

Linear Production: “Take, make, waste” (our current system)

Closed Loop Production (“future” system)
WEEE Directive

- The **Waste Electrical and Electronic Equipment Directive** (WEEE Directive) is the European Community directive 2002/96/EC on waste electrical and electronic equipment (WEEE) which sets collection, recycling and recovery targets for all types of electrical goods.

- **Original Equipment Manufacturers** are responsible for appropriate collection and treatment.

- Each country can have different implementation.

- **Think about how you will ensure that your (electronic) product will not end up on a landfill and can be recycled.**
Energy

• Energy is something we use a lot and comes from different sources with different consequences (including death)

• Much of our energy comes from materials

• Using energy has environmental consequences:
  – Air pollution
  – Green house gas emissions
    • Example: gasoline => 19.564 lbs CO2/gallon
  – Water consumption

• DoE Energy Information Agency (EIA)
  – One of the best sources to find all kind of info on energy
    http://www.eia.doe.gov/
Product Use Phase – Try to save energy!

• Typically, any energy consuming product has the largest environmental impact in its use phase
  – Exceptions always exist

• Conservation is good!
  – Every kWh or Joule saved by the product saves another 2-3 upstream

• Beware of “rebound effect”
  – You created a more efficient product, but now it is going to be used more
The Water Dimension

- Water is becoming more and more important
- Water is consumed everywhere in a product life cycle, incl. in energy production
  - Water Consumption: Freshwater withdrawals which are evaporated, incorporated in products and waste
  - Water Use (withdrawal): Water that goes into a system. Most of this typically leaves the system as waste water

<table>
<thead>
<tr>
<th>Stage</th>
<th>Water Consumption (Liters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Material Production</td>
<td>5,569</td>
</tr>
<tr>
<td>Direct Parts Production</td>
<td>902</td>
</tr>
<tr>
<td>Direct Vehicle Assembly</td>
<td>670</td>
</tr>
<tr>
<td>Direct End of Life</td>
<td>259</td>
</tr>
<tr>
<td><strong>Indirect: Material Production</strong></td>
<td><strong>11,859</strong></td>
</tr>
<tr>
<td><strong>Indirect: Parts &amp; Assembly</strong></td>
<td><strong>5,757</strong></td>
</tr>
<tr>
<td>Total</td>
<td>76,981</td>
</tr>
</tbody>
</table>

Typical water consumption from electricity generation is around 0.5 gallons/kWh for thermo-electric plants.

Example - Two Automotive Parts

- Simple question: What is better?
  - Virgin manufacturing & disposal
  - Recycling
  - Remanufacturing

... and by how much?

NSF Grant # 0522116
Refining processes have the highest energy consumption

De-Materialization should be higher priority from an energy point of view → product design

Machining processes energy consumption is low

Al Process Energy Consumption (kWh/ton)

ALUMINUM TRANSFER CASE PRODUCTION PROCESSES

ELECTROLYSIS ALUMINA PRODUCTION SORTING MELTING CASTING CLEANING MACHINING Recy/dispo

Ore extracting Remanufacturing

ALUMINUM SALABLE ALUMINUM kWh/ton

15 000 14 000 5 000 1 400 450 38 20 14 4

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Steel Processing Energy Consumption

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

Refining processes have the highest energy consumption

Machining processes energy consumption is low

STEEL PRODUCTION PROCESSES

NSF Grant # 0522116
Energy Consumption in Manufacturing Sectors

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

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

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

## Regional Variation in Electricity CO₂ Emissions

<table>
<thead>
<tr>
<th>Region</th>
<th>Carbon Dioxide (Metric tons/ MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) New York, Connecticut, Rhode Island, Massachusetts, Vermont,</td>
<td>0.466</td>
</tr>
<tr>
<td>New Hampshire and Maine</td>
<td></td>
</tr>
<tr>
<td>(2) New Jersey, Delaware, Pennsylvania, Maryland, West Virginia,</td>
<td>0.782</td>
</tr>
<tr>
<td>Ohio, Indiana and Michigan</td>
<td></td>
</tr>
<tr>
<td>(3) Illinois and Wisconsin</td>
<td>0.638</td>
</tr>
<tr>
<td>(4) Missouri, Kentucky, Virginia, Arkansas, Tennessee, North Carolina,</td>
<td>0.69</td>
</tr>
<tr>
<td>South Carolina, Louisiana, Mississippi, Alabama and Georgia</td>
<td></td>
</tr>
<tr>
<td>(5) Florida</td>
<td>0.678</td>
</tr>
<tr>
<td>(6) Texas</td>
<td>0.73</td>
</tr>
<tr>
<td>(7) Oklahoma and Kansas</td>
<td>0.867</td>
</tr>
<tr>
<td>(8) North Dakota, South Dakota, Nebraska, Minnesota and Iowa</td>
<td>0.875</td>
</tr>
<tr>
<td>(9) Colorado, Utah, Nevada, Wyoming and Montana</td>
<td>0.909</td>
</tr>
<tr>
<td>(10) New Mexico and Arizona</td>
<td>0.658</td>
</tr>
<tr>
<td>(11) Oregon, Washington and Idaho</td>
<td>0.147</td>
</tr>
<tr>
<td>(12) California</td>
<td>0.35</td>
</tr>
<tr>
<td>(13) Hawaii</td>
<td>0.858</td>
</tr>
<tr>
<td>(14) Alaska</td>
<td>0.749</td>
</tr>
<tr>
<td>(15) U.S. Territories</td>
<td>0.858</td>
</tr>
<tr>
<td>U.S. Average</td>
<td>0.676</td>
</tr>
</tbody>
</table>

Relocating manufacturing to a locality with renewable power often has a larger carbon footprint effect than any process efficiency improvement.

GA Power Plant Bowen (Cartersville):
- CO2 emission: 0.9 kg/kWh
- H2O evaporation: 0.4 gallons/kWh

[http://www.eia.doe.gov/oiaf/1605/emission_factors.html](http://www.eia.doe.gov/oiaf/1605/emission_factors.html)
Opportunities

• Think “holistically” about your product.
• Your product is part of a bigger system
  – Thus, think “system” instead of “product”
• Thinking bigger may actually reduce cost
  – Can you reuse parts?
  – Can you lease instead of sell/buy?
  – Is the product really the end, or is it just a provider of a function?
Importance of Sound Engineering

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

<table>
<thead>
<tr>
<th></th>
<th>Ford F-450/550</th>
<th>Class 6 Ford F-650</th>
<th>Class 7 Ford F-750</th>
<th>Class 8 (Freightliner Day Cab)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSRP (New)</td>
<td>$42,295/$45,240</td>
<td>$54,167</td>
<td>$55,448</td>
<td>$140,000</td>
</tr>
<tr>
<td>Price w/ Incentives</td>
<td>$33,760/$36,463</td>
<td>$43,334</td>
<td>$44,358</td>
<td>$87,000</td>
</tr>
<tr>
<td>Curb Wt.</td>
<td>17,950 – 19,000 lbs. (GVWR)</td>
<td>9,300 lbs.</td>
<td>9,300 lbs.</td>
<td>16,000 lbs.</td>
</tr>
<tr>
<td>Gross Combined Wt. Rating</td>
<td>24,000 – 33,000 lbs.</td>
<td>50,000 lbs.</td>
<td>50,000 lbs.</td>
<td>80,000+</td>
</tr>
<tr>
<td>Towing Wt.</td>
<td>24,800 lbs.</td>
<td>40,700 lbs.</td>
<td>40,700 lbs.</td>
<td>57,000 lbs.</td>
</tr>
<tr>
<td>Max Payload</td>
<td>16,800 lbs.</td>
<td>27,700 lbs.</td>
<td>27,700 lbs.</td>
<td>44,000 lbs.</td>
</tr>
<tr>
<td>Output</td>
<td>325-362 hp</td>
<td>325 hp</td>
<td>325 hp</td>
<td>410-550 hp</td>
</tr>
</tbody>
</table>
In Closing

• In your project, you can
  1. Check and include MSDS sheets for potential problem materials
  2. Check for RoHS compliance when ordering (electronic) parts
  3. Quantify and minimize amount of materials used
  4. Quantify and minimize energy consumption
  5. Minimize wasteful manufacturing processes
  6. Increase recyclability by reducing number of different materials
  7. Avoid sourcing parts from questionable companies
  8. Etc.

• Think about and discuss the social and environmental consequences of your products
  – positive and negative

• But don’t forget the basics – good engineering & decision making is good for people-planet-profit!