ME 370: The Mechanical Engineering Profession

Lecture 09: Introduction to Sustainability

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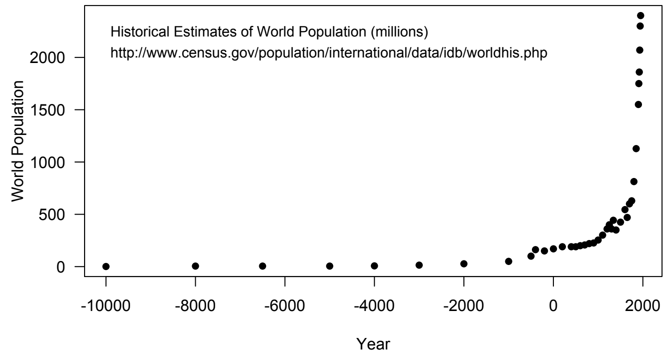
Purpose

Introduce basic principles of sustainability and link concern for sustainability to engineering practice

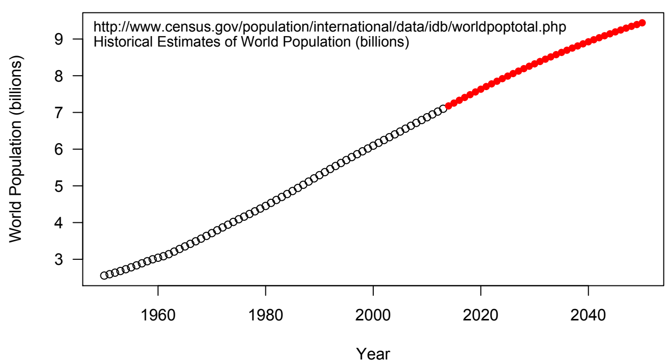
The Problems

- Population growth
- Environmental degradation
  - Climate change and its consequences
  - Pollution
  - Destruction of habitat
  - Loss of arable land
- Scarcity of resources
  - Water
  - Land
  - Energy

In the past few hundred years, human population has grown exponentially



Although the current rate of growth has stabilized, the net increase is still alarming



Make a quick estimate of energy consumption for the new humans to be added between now and 2050.

Assume that 2 x 10^9 people will be added to the planet between now and 2050

Assume that each of those people need a continuous source of electricity of 100 W (one incandescent bulb)

- How much additional energy generating capacity is needed?

Assume that nuclear power will be used to supply the energy

- How many 1GW nuclear power plants will be required to meet that need? (Assume no generation or transmission losses.)

IPAT Equation

The IPAT equation is a symbolic way of representing the interaction and amplification between the environmental impact of human activity

I = P x A x T

- I = impact
- P = population
- A = Affluence (GDP per capita)
- T = Technology

What is Sustainability?

A commonly cited definition of sustainability comes from the definition of sustainable development from the so-called Brundtland Commission

- "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains with it two key concepts:
  - the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and
  - the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs"

Source: http://www.un-documents.net/ocf-02.htm#I

What is Sustainability?

According to the ASME

- "Sustainability means engineering products and developing manufacturing processes that do not consume irreplaceable resources", https://www.asme.org/engineering-topics/sustainability

According to the ASCE

- "A set of environmental, economic and social conditions in which all of society has the capacity and opportunity to maintain and improve its quality of life indefinitely without degrading the quantity, quality or availability of natural, economic, and social resources.", http://www.asce.org/sustainability

Methods of Accounting

If sustainability is approached as an engineering problem, how do we measure progress?

Accounting models to quantify sustainability efforts

- Triple bottom line
- Life-cycle assessment
- Cradle-to-cradle

Triple Bottom Line

A Business-scale approach to sustainability

Three P's

- Profit: The traditional bottom line of profit and loss
- People: Attempt to measure social responsibility
- Planet: Attempt to measure environmental responsibility

Challenges of this approach

- How to combine categories to account for an overall balance?
- How do you measure impacts on People and Planet?
- Non-monetary scales can be manipulated in an attempt to make organizations look good

Life Cycle Assessment

A systems-level or holistic view of sustainability analysis

Four stages of product life

- Acquisition of materials (resource extraction or recycling)
- Manufacturing, refining, and fabrication
- Use by consumers
- End-of-life disposal

Life-cycle stages of a product

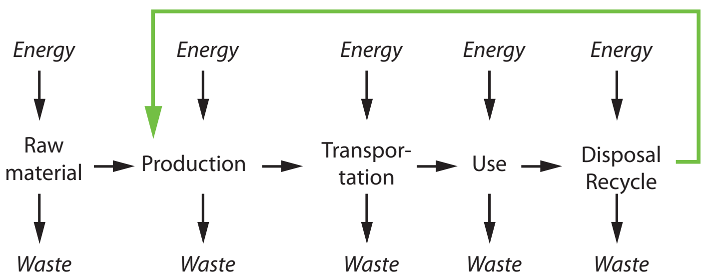
Pre-manufacturing

Manufacturing

Use

Post-Use

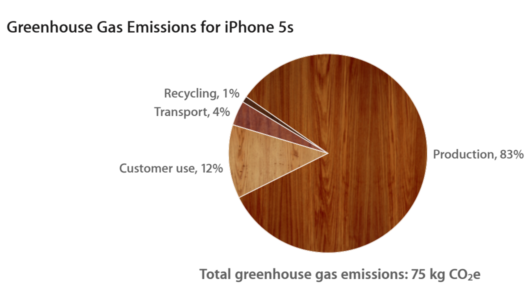
Energy is consumed and waste is produced at each stage



After Venditti, 2012

Life Cycle Assessment

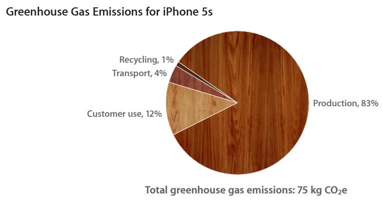
Example: Greenhouse gas emissions for iPhones

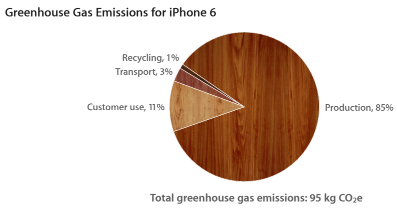


https://www.apple.com/environment/reports/

Life Cycle Assessment

Example: Greenhouse gas emissions for iPhones. Progress?





https://www.apple.com/environment/reports/

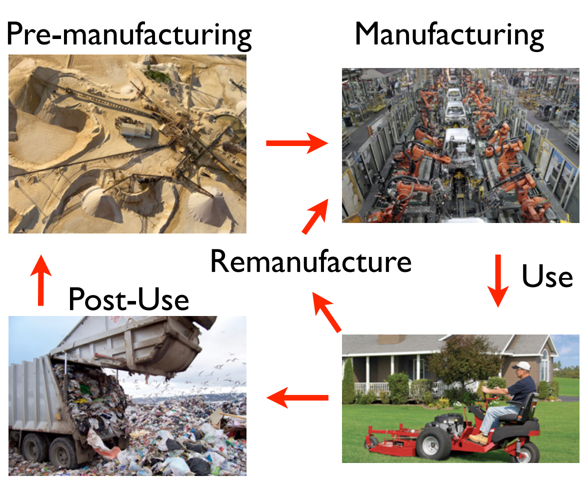
Cradle-to-Cradle

Extending Life-Cycle Assessment to close the loop

Four stages of product life

- Acquisition of materials (resource extraction or recycling)
- Manufacturing, refining, and fabrication
- Use by consumers
- End-of-life ~~disposal~~ reuse or harvest
  - recycling is not enough

Life-cycle stages of a product: closing loops



Sustainability and engineering design

Traditional design criteria

- function/performance
- cost
- reliability

Add sustainability

- minimize impact on people and environment
- minimize material usage
- minimize energy usage

Sustainability and engineering design

Minimize environmental impact, material usage and energy consumption during

- Pre-manufacture (resource extraction)
- manufacture
- Primary use
- Post-use

I.S. Jawahir's 6 Rs

Conventional 3R's

- Reduce, Reuse and Recycle

I.S. Jawahir advocates adding 3 more R's

- Recover, Redesign, Remanufacture

See Section 1 in *ASME Sustainable Products and Processes Strategic Plan*, http://files.asme.org/Committees/K&C/TCOB/CRTD/30032.pdf

Rebound Effect – A challenge to sustainable improvements

- Rebound Effect reduces benefit of sustainable technology
  - Technology improvements reduce resource use
  - Resource becomes less expensive
  - Resource use increases
- Examples:
  - More energy efficient lighting can increase use of lighting
  - More energy efficient cars can cause people to drive more

Rebound effect: Improvements in lighting technology have resulted in an increase in use of artificial lighting

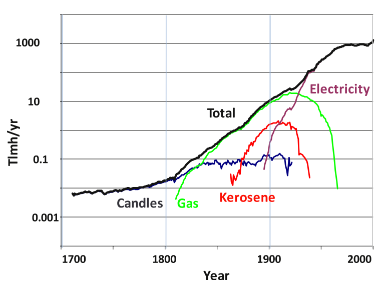


Figure 1. Three centuries of light consumption in the UK, adapted from Fouquet and Pearson (2006). The left axis has the units Tlm h/yr (teralumen-hours per year). The coloured lines represent consumption of light produced by technologies powered by particular fuels; the black line represents total consumption of light produced by all technologies. (Colour online.)

"When lighting becomes cheaper, economic agents become very creative in devising new ways to use it." Saunders and Tsao, 2012

J.Y. Tsao et al., *Solid-state lighting: an energy-economics perspective*, Journal of Physics D: Applied Physics, **43** (2010): 354001

Rebound effect: Improvements in lighting technology have resulted in an increase in use of artificial lighting

- Artificial lighting is responsible for 6.5% of global consumption of primary energy
- Historical trend is that energy use per unit of GDP for lighting has remained stable (at 0.54%) for centuries
- Increases in energy efficiency for lighting has increased the demand for lighting
- More efficient lighting has resulted in other benefits, including higher economic productivity
- We should use more efficient lighting regardless of whether it reduces global energy demand

H.D. Saunders and J.Y. Tsao, *Rebound effects for lighting*, Energy Policy, **49** (2012): 477–478

Sustainability in Engineering Practice

- Business concerns: working with suppliers
  - Manufacturing inputs with high environmental impact are likely to increase in cost
  - Disruptions to supply chains if manufacturers are using environmentally destructive processes
  - Controlling risk by vetting suppliers
- Risk of litigation
- Informed customers may punish your company/brand for bad environmental practices
  - Use sustainability to differentiate your product

Sustainability in Engineering Practice

- Need to balance short term and long term costs
  - Environmental mitigation versus reducing footprint
- Product design
  - Design for reduced material & energy consumption
  - Design for reuse/recycle/remanufacturing
- Process design
  - Reduce energy & material consumption during manufacturing, e.g. near-net shape manufacturing
  - Reduce waste due to packaging and cleaning of parts

References

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References

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10. J.Y. Tsao et al., *Solid-state lighting: an energy-economics perspective*, Journal of Physics D: Applied Physics, **43** (2010): 354001
11. H.D. Saunders and J.Y. Tsao, Rebound effects for lighting, Energy Policy, 49 (2012): 477–478

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Slides 13 and 18

- Mining: http://images.nationalgeographic.com/wpf/media-live/photos/000/010/cache/mineral-mining_1092_990x742.jpg
- Manufacturing: http://www.industry.usa.siemens.com/automation/us/en/events/ManufacturingInAmerica/PublishingImages/MiA-TTO-header-image_kuka_638_393.jpg
- Lawn mower: http://www.fowlerhadding.com/images/ProCutS.mow2.jpg
- Landfill: http://community.ashworthcollege.edu/thread/21221