Introduction to Life-Cycle Assessment

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http://go.ncsu.edu/iswm

Slides available at
http://go.ncsu.edu/swm-lca.resouces

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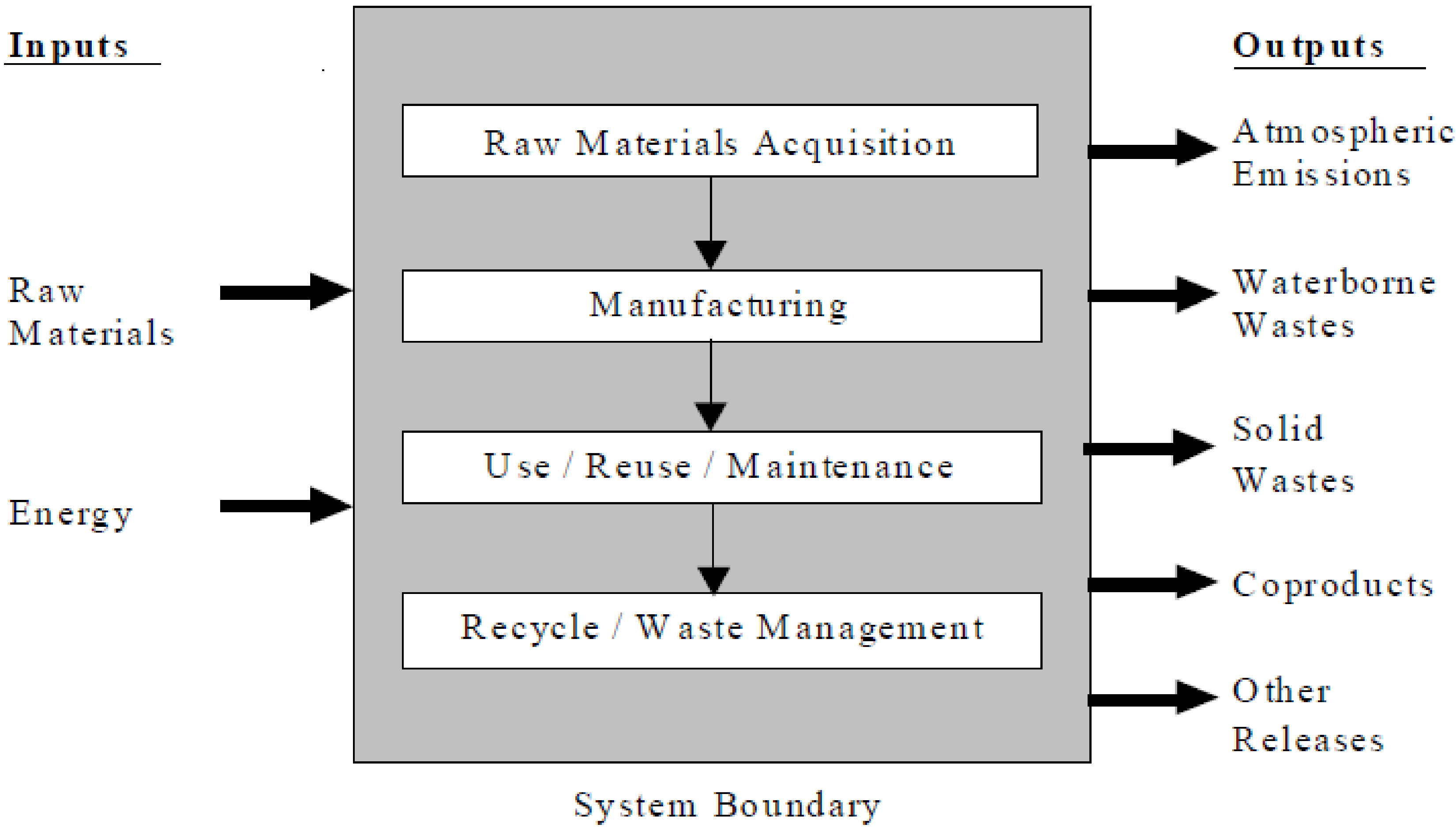
Workshop Agenda

8:30 - 9:00	Introduction to LCA
9:00 - 9:30	Biological Processes: Composting and Anaerobic Digestion
9:30 - 9:40	Break
9:40 - 10:10	Landfill
10:10 - 10:40	Material Recovery and Reprocessing
10:40 - 10:50	Break
10:50 - 11:20	Combustion
11:20 - 11:50	Integrated Assessment Case Studies
11:50 - 12:00	Final Questions

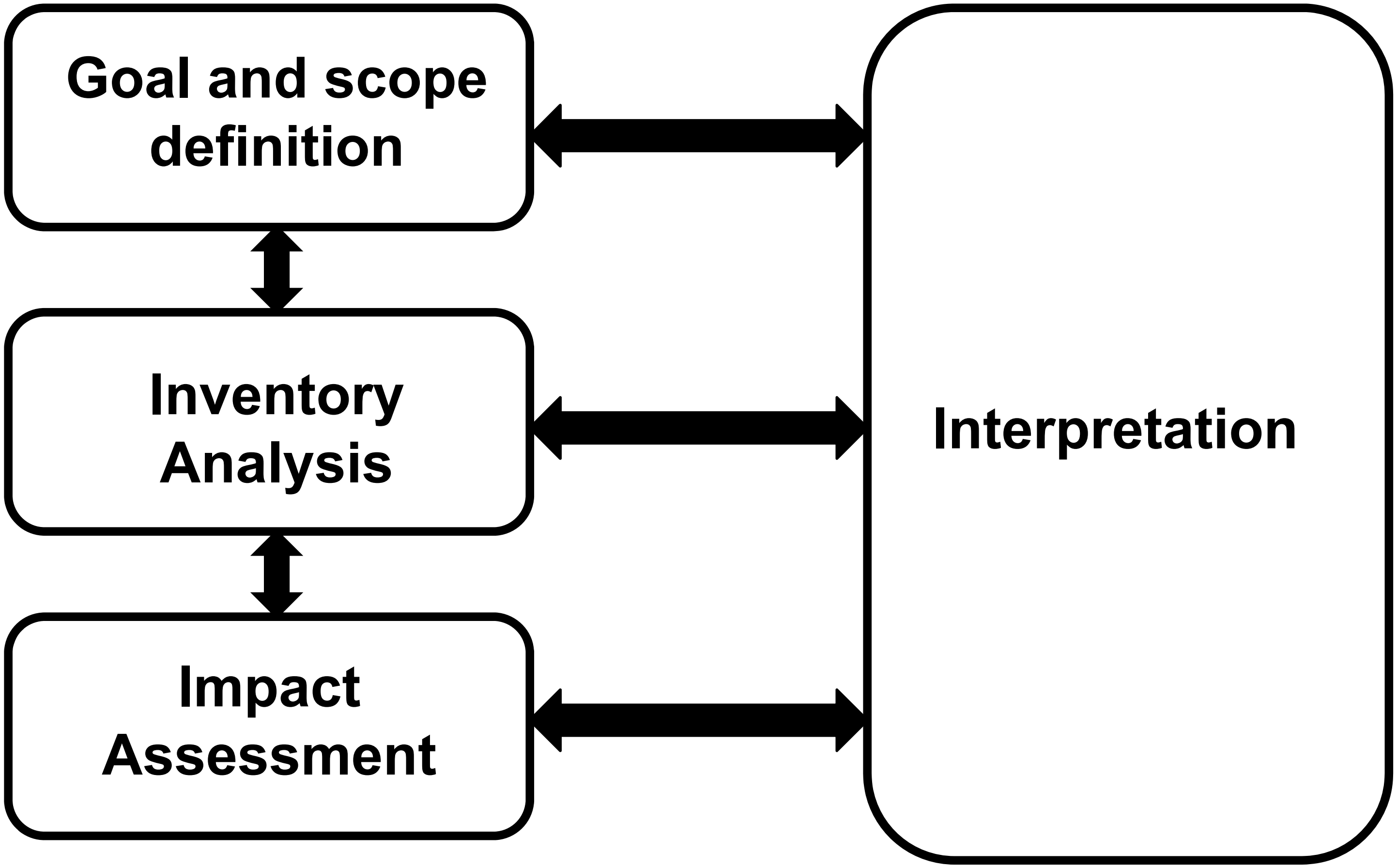
What Is Life-Cycle Assessment?

LCA is a process used to examine, identify, and evaluate the energy, material, and environmental implications of a material, process, product, or system across its life span from cradle to grave.



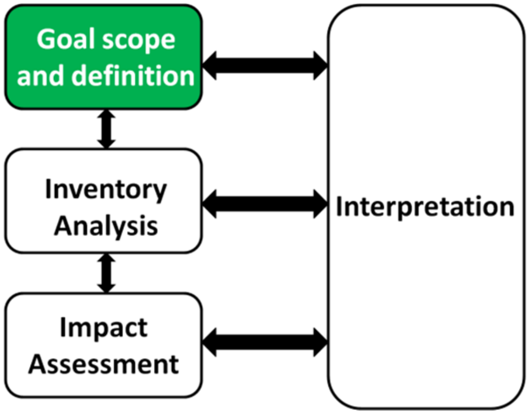
Source: EPA (2006) – LCA: Principles and Practice

LCA Stages



Sources:
Gradel and Allenby (2003). Industrial Ecology, Second Edition. Pearson Education Inc, Upper Saddle River, New Jersey.
US EPA (2006). Life Cycle Assessment: Principles and Practice. National Risk Management Research Laboratory, EPA/600/R-06/060.

Defining the Goal and Scope



- Why is the assessment being conducted?
  - Waste management vs. a packaging study vs. energy generation
- How will the results be used, and by whom?
  - Improvement assessment/data interpretation
  - Alternatives screening
    - Selected alternatives for detailed design

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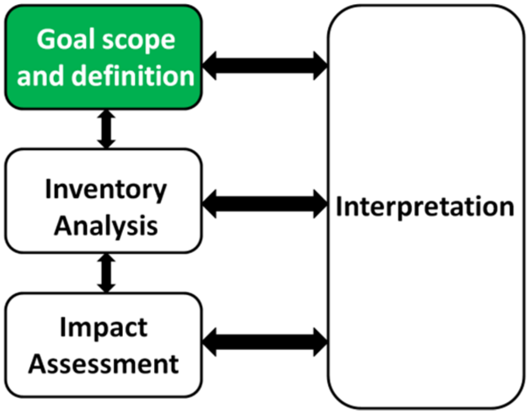
Scope Defintion

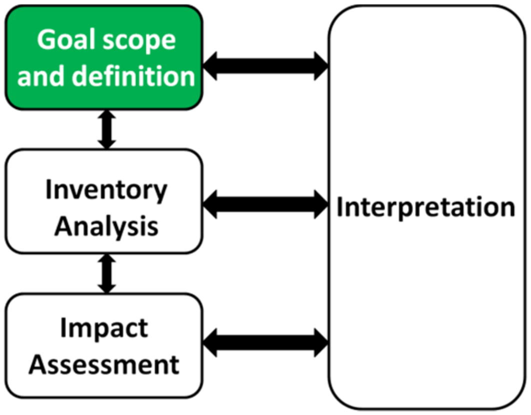


- Study objective and the functional unit
  - One ton of MSW as generated
  - One ton set out at the curb
  - One ton at the landfill
  - 1 MWh of electricity generated (electricity generation)
  - 1 m^3 of CNG produced (fuel production)
- The time scale of the study
  - Changing waste composition
  - System will be used for 20 - 30 years
- System boundaries and exchanges over boundaries
- The technologies representing the different processes
  - Existing and/or emerging technologies

Goal Definition

- The goal definition describes the purpose of the study and the decision process to which it provides environmental decision support
- LCA, particularly as applied to solid waste, is often used to compare alternatives
  - Consequential vs. attributional LCA
  - Attributional – average situation
  - Consequential – marginal changes
    - Does a landfill tax in one state decrease landfilling or increase transport across state boundaries with more emissions?
    - Electricity use/generation – Average kWh vs. Coal kWh
    - Biofuels mandates and impact on crop production/land use

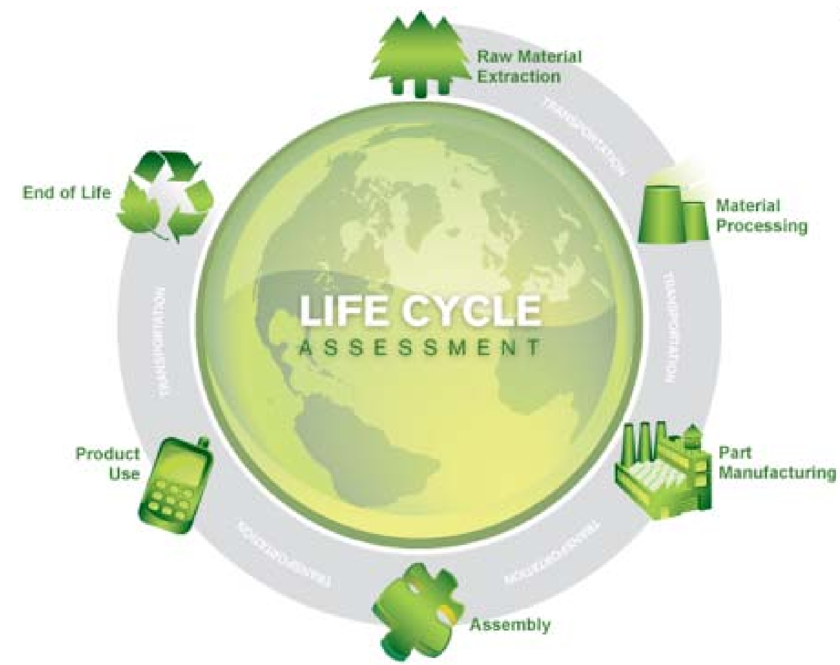
System Boundaries



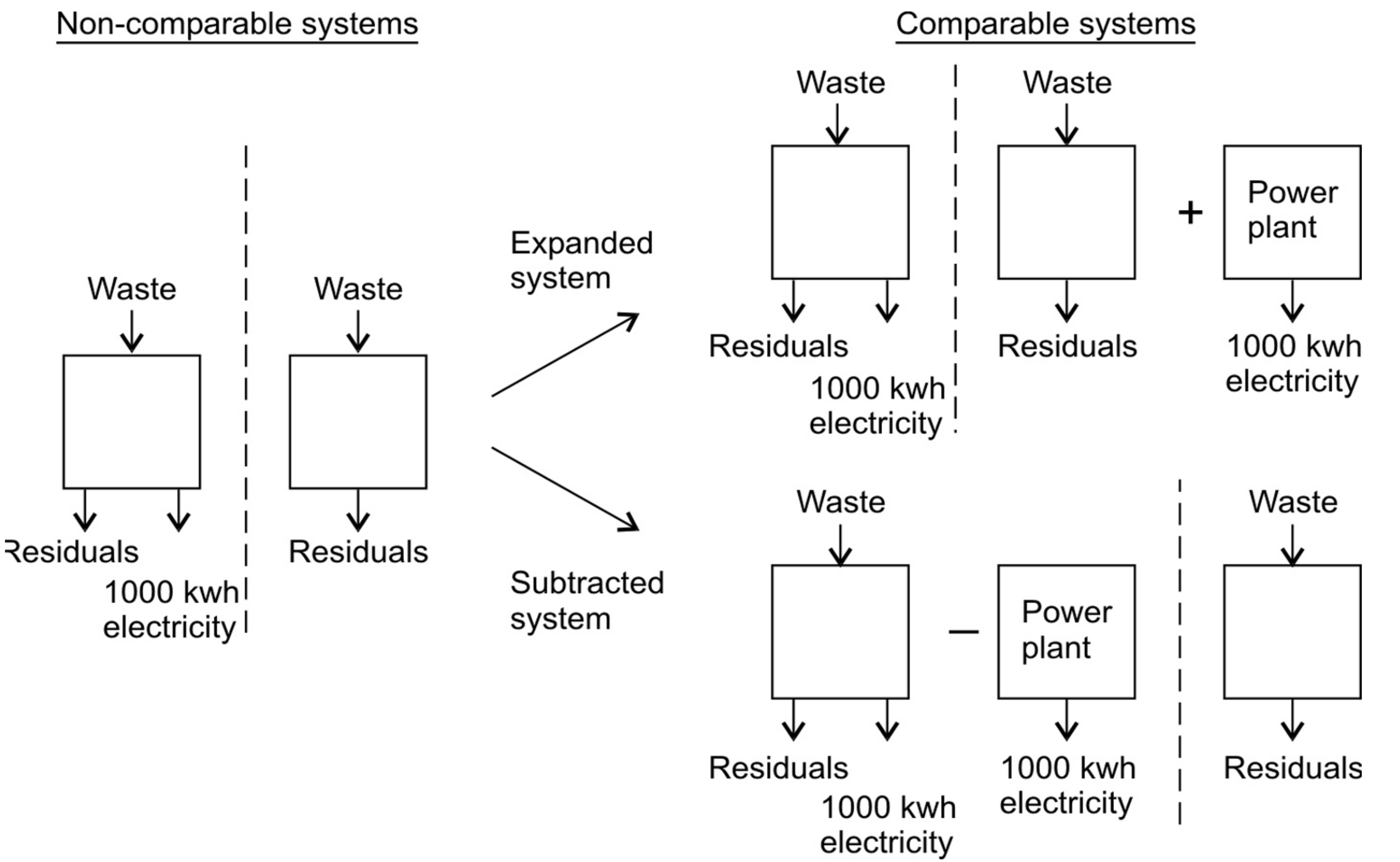
- Include all that is relevant.
- Include only what is relevant.

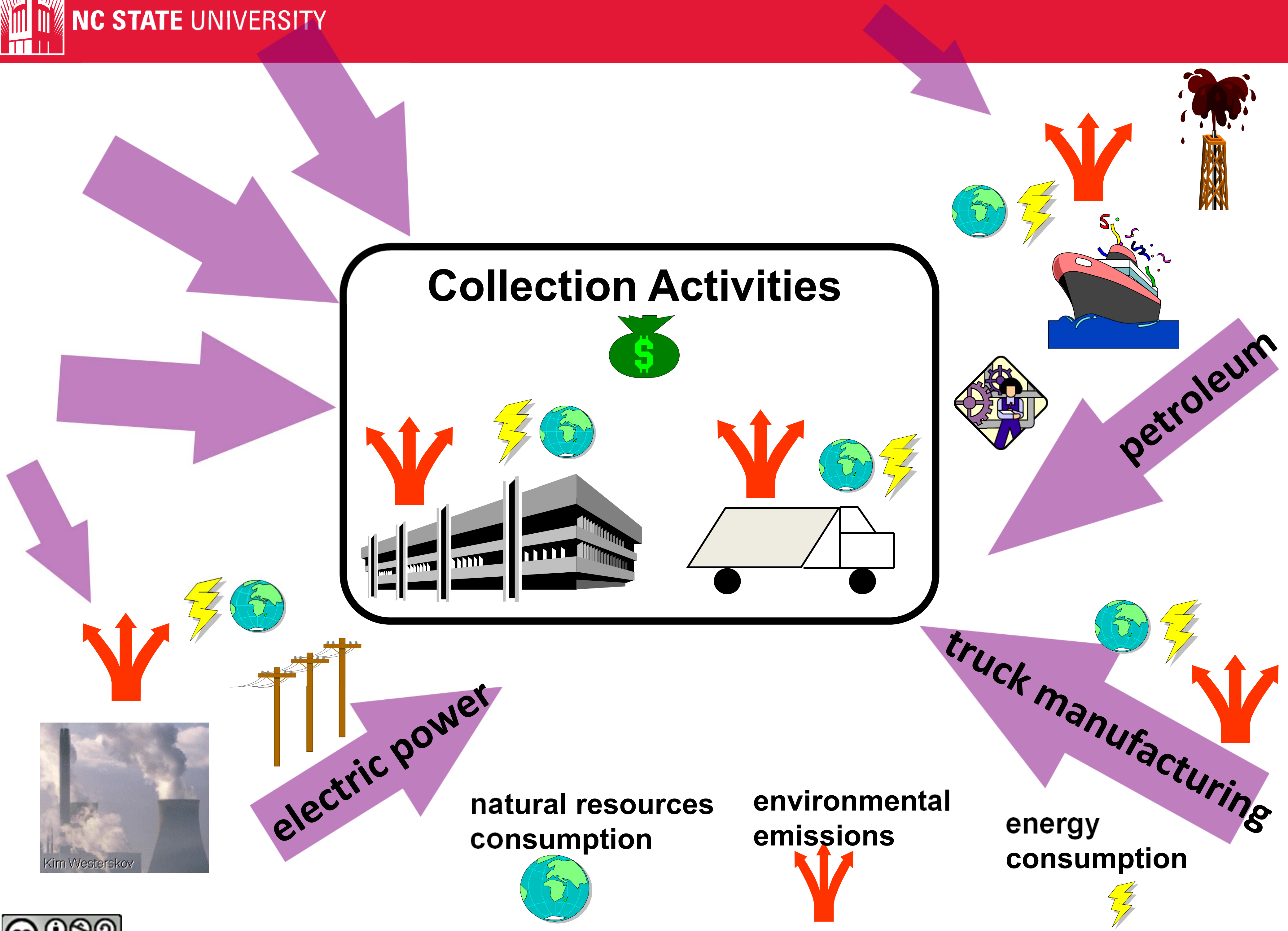
Issues to consider:

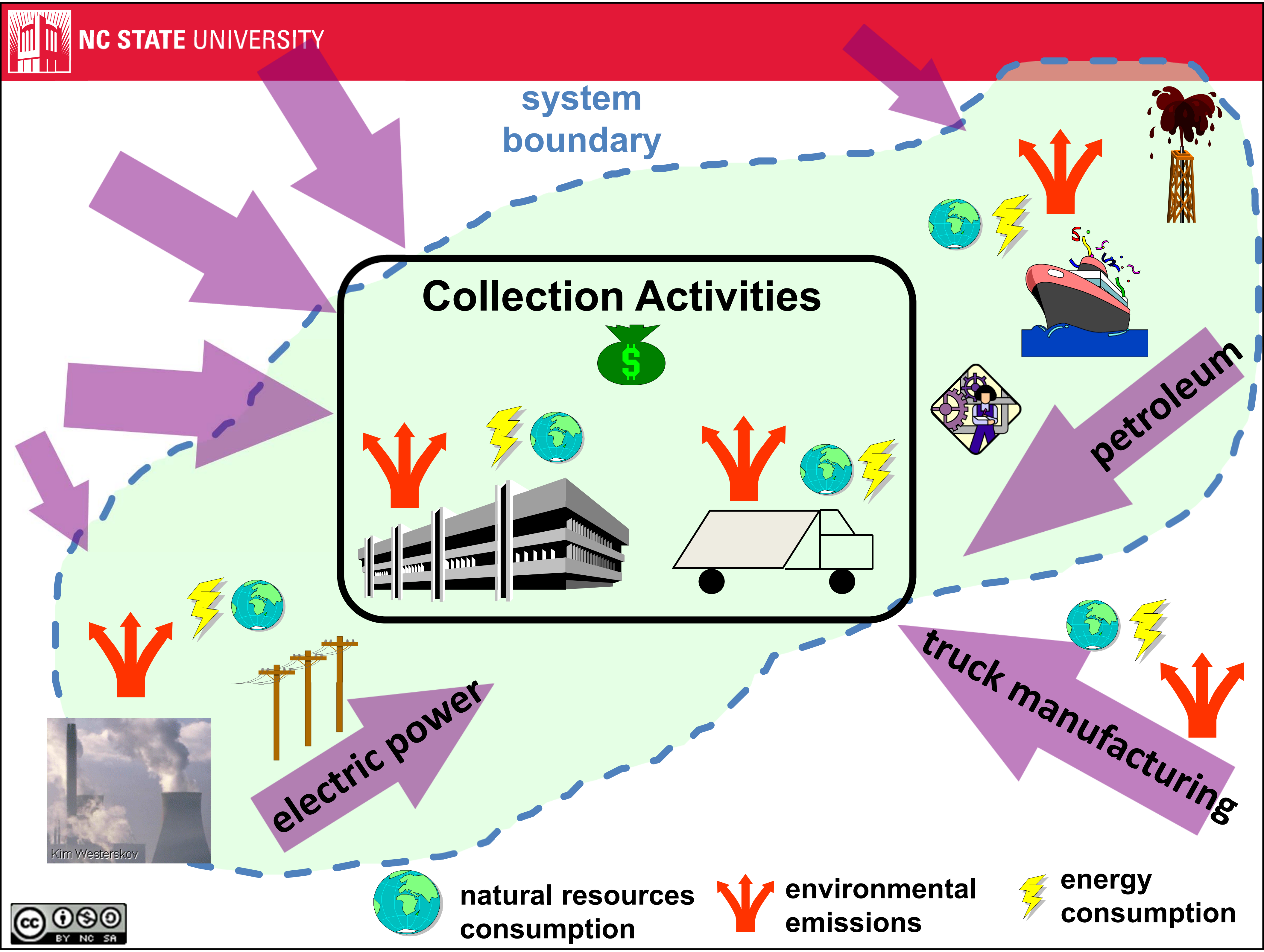
- The infinite nature of the product system/cut-of-limits



System expansion/substitution




Collection Activities
petroleum
electric power
truck manufacturing
natural resources consumption
environmental emissions
energy consumption
Kim Westerskov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system boundary
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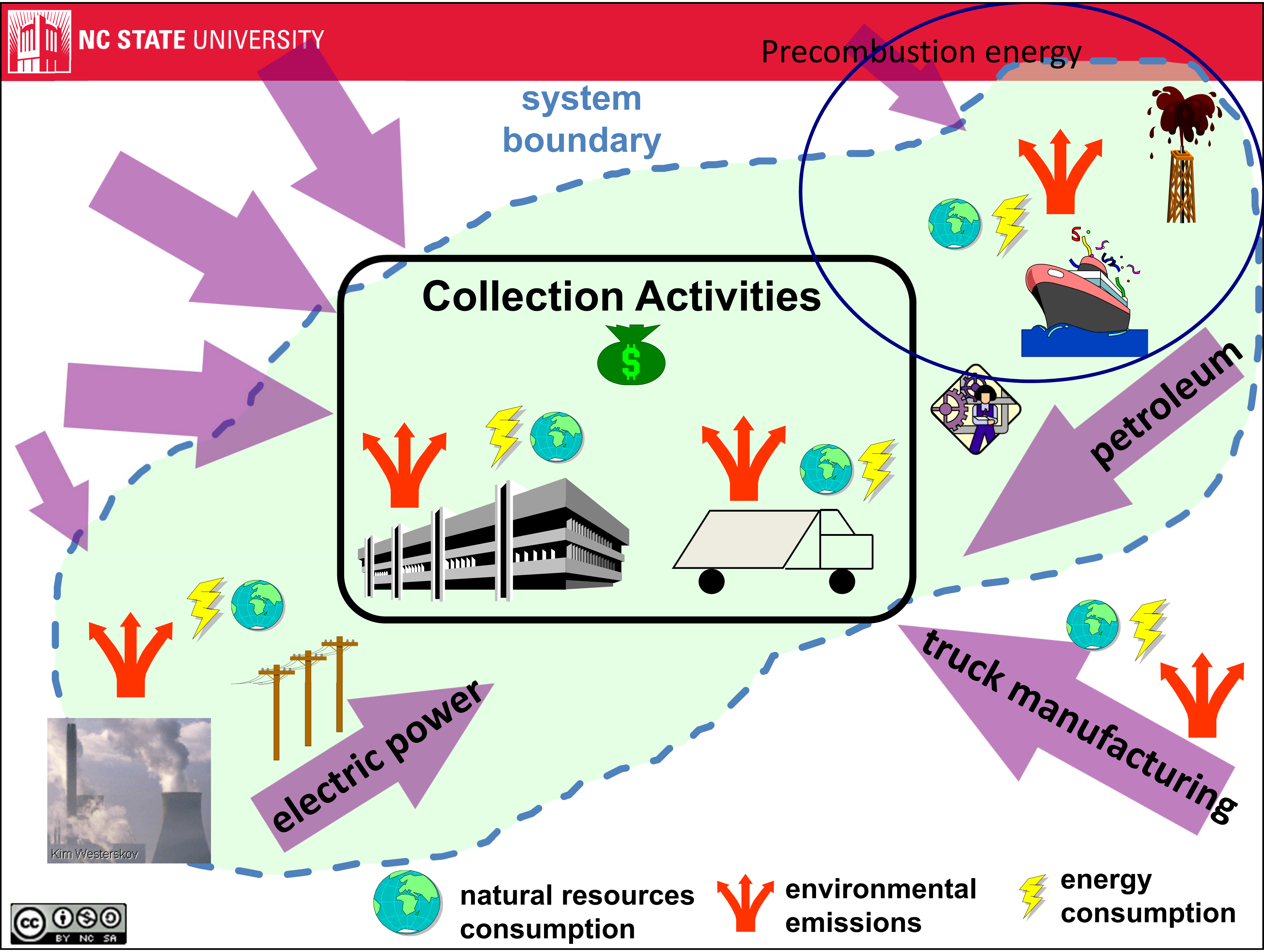

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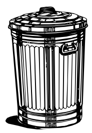
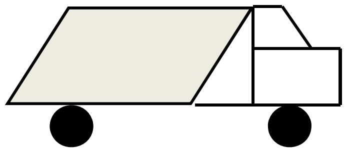
Precombustion energy
system boundary
Collection Activities
petroleum
electric power
truck manufacturing
Kim Westerskov
natural resources consumption
environmental emissions
energy consumption

A Solid Waste Management Alternative

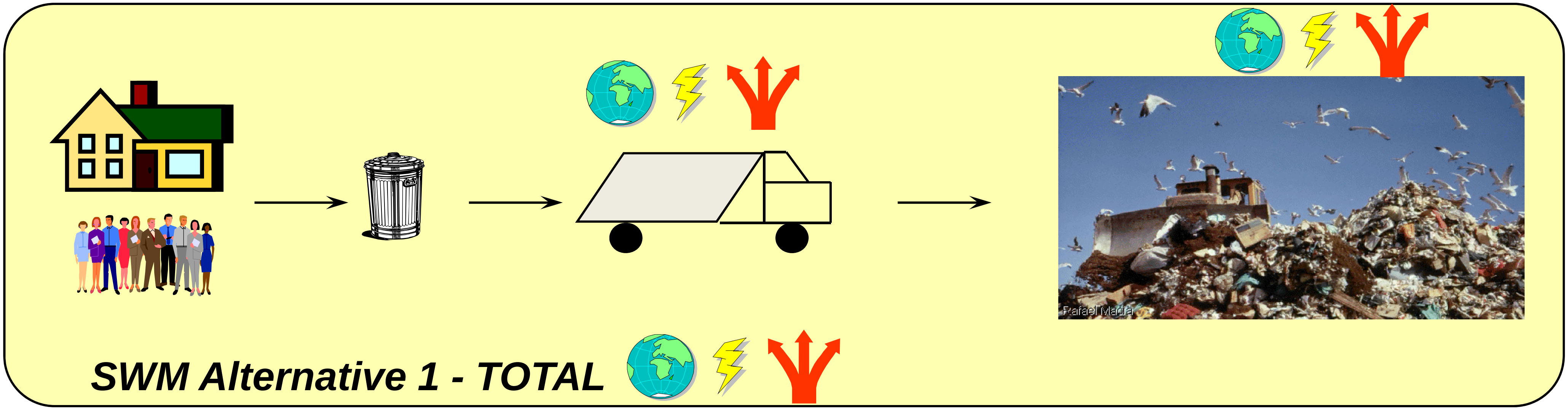


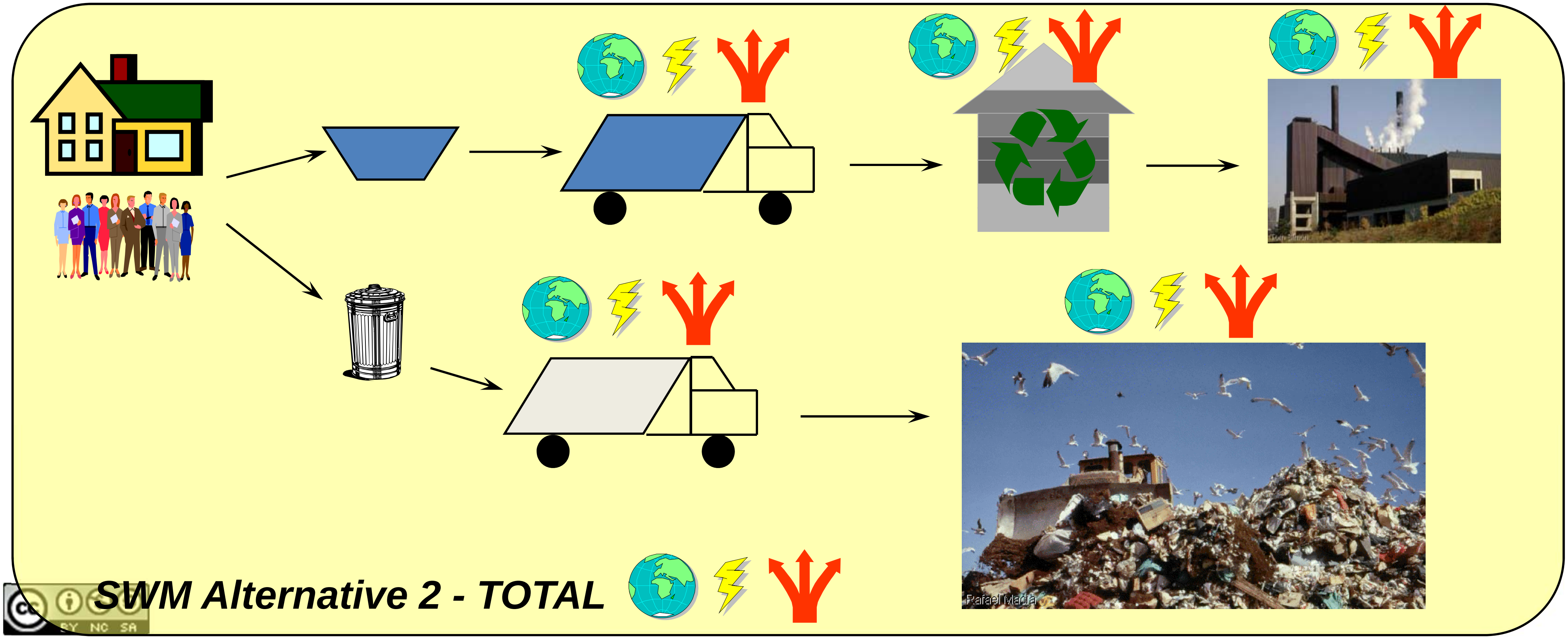


MSW Generation

Mixed Waste Collection

Landfill Disposal


SWM Alternative 1 - TOTAL


SWM Alternative 2 - TOTAL

Assessment criteria

Global impacts

- Global warming
- Ozone depletion

Regional impacts

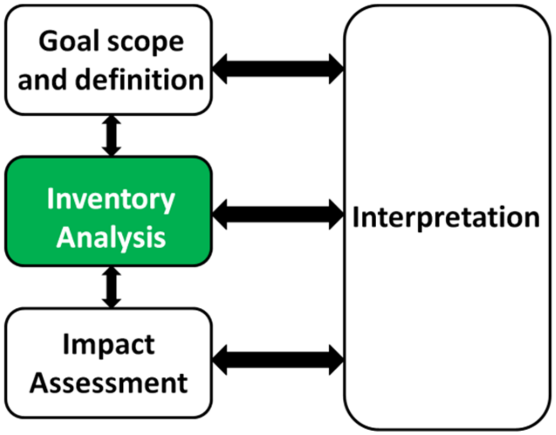
- Smog formation
- Acidification
- Terrestrial and aquatic eutrophication
- Human toxicity

Local impacts

- Land use
- Odor
- Stored toxicity
- Spoiled groundwater resources

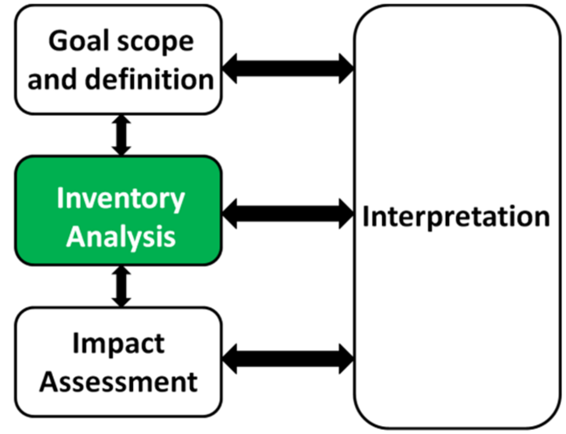
Resource Depletion (oil, coal, aluminum, P, freshwater, forest biomass)

Inventory Analysis



- Often referred to as a Life-Cycle Inventory (LCI).
- Describe all of the inputs and outputs in a product's life cycle from cradle to grave
- Inputs include materials and energy
- Outputs include the desired products as well as by-products and wastes
- Quantifies resource and energy consumption, and environmental emissions associated with all processes in a system
  - emissions are post-treatment
    - apply to collection, MRF, landfill, combustion

Data for Inventory Analysis

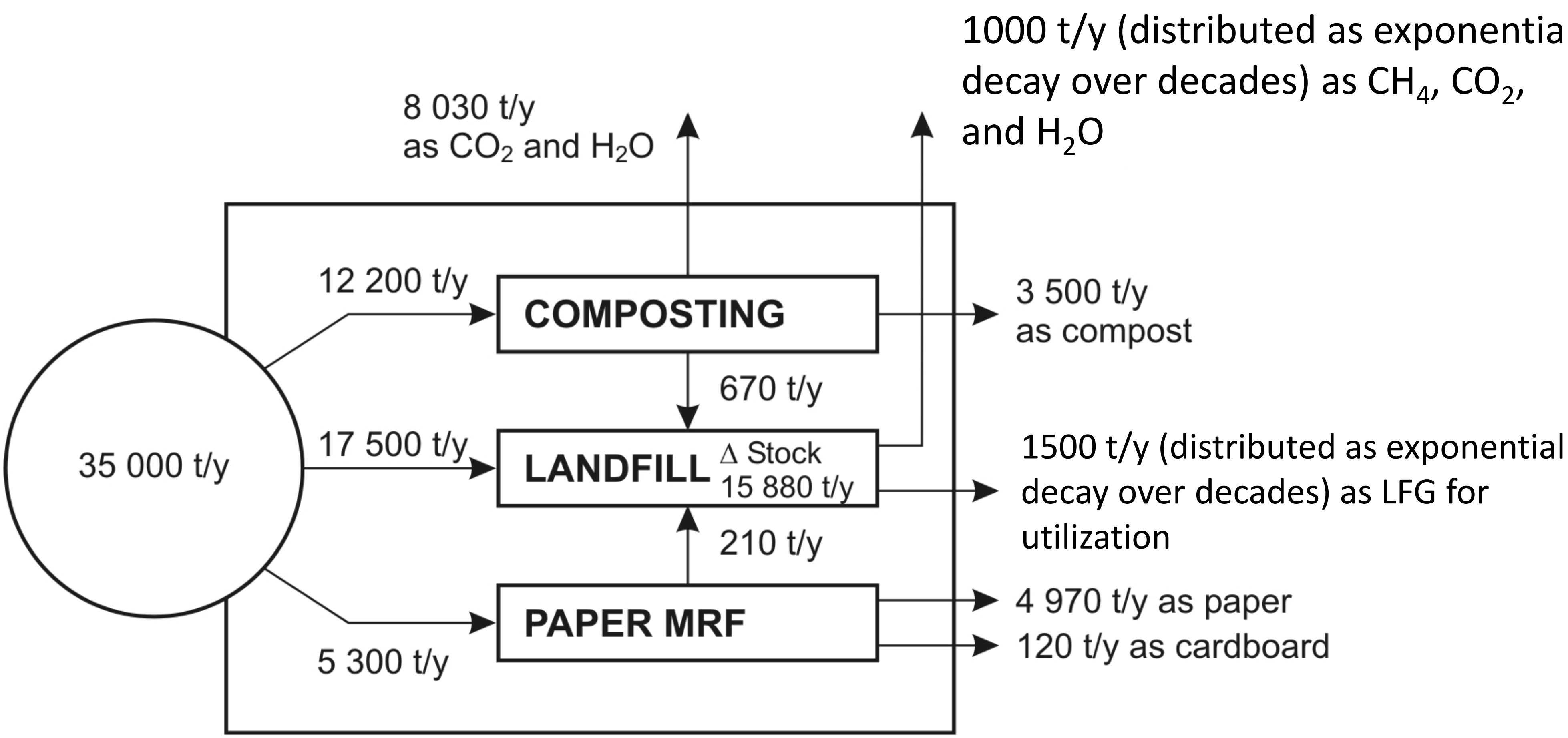


Literature
- extrapolation from similar processes
- papers, books
- databases
  - ecoinvent (commercial) - http://www.ecoinvent.org/
  - NREL (free) - https://www.lcacommons.gov/nrel/

Questionnaires
- data sought upstream (contractors)
- send questionnaire and follow up (often visit)

Estimates
- Modeling from process knowledge
- Measurements
- average performance

Example: Mass balance

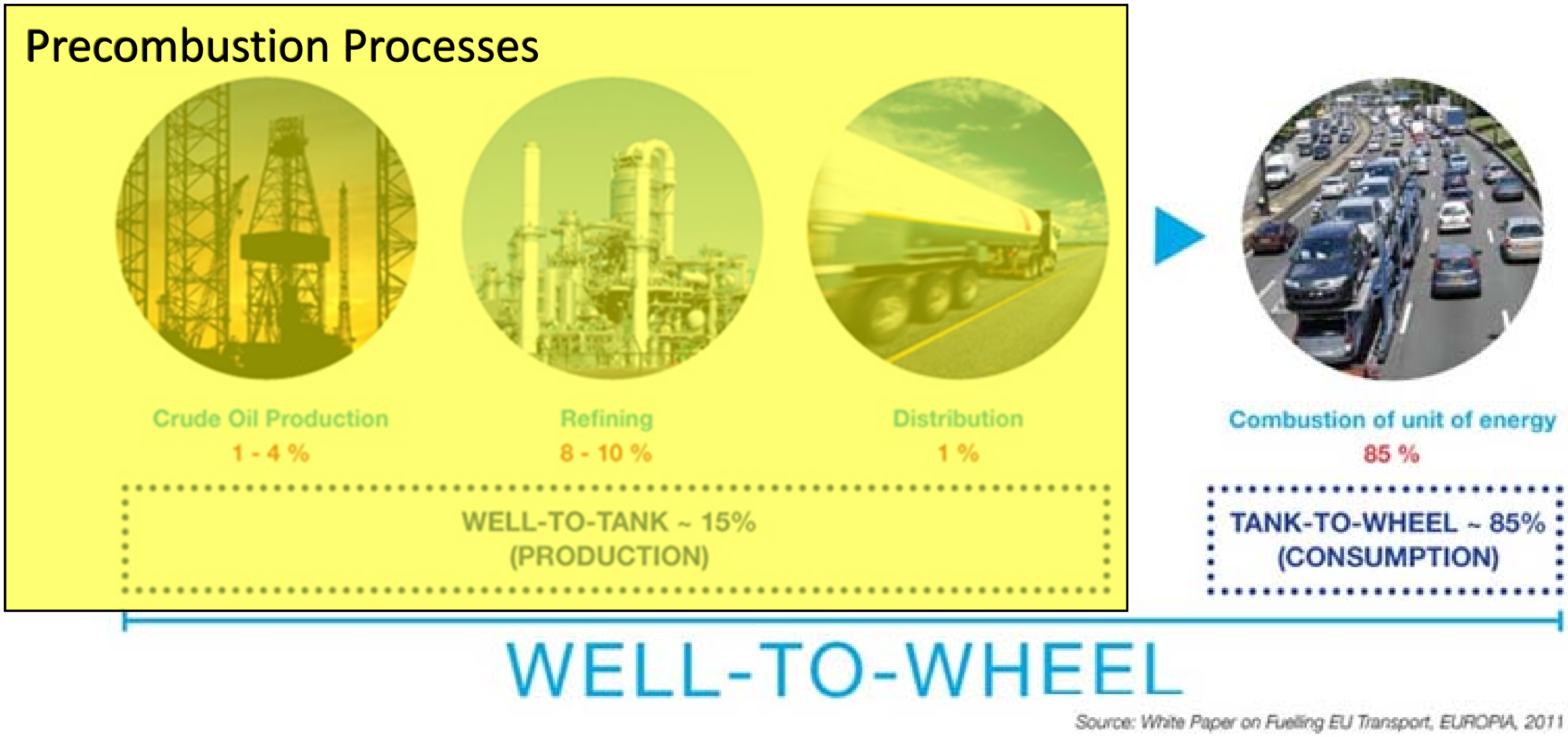


Mass balances, energy and emissions

- **Mass balance:**
  - All generated waste as well as residues from treatment are tracked (nothing forgotten)
  - All emissions can be conceptually identified by evaluating all discharges from the waste system, intended or unintended
- **Energy budgets:**
  - All energy (fuels, electricity etc.) inputs and outputs from each process are quantified
  - All energy containing outputs can be utilized
- **Emission accounts:**
  - Direct environmental loads can be monitored, assessed and maybe reduced
  - Indirect or pre-combustion emissions are included

Precombustion Emissions

- Precombustion or "well-to-pump" or "well-to-tank" emissions are the emissions associated with extracting, processing, and transporting fuels (e.g., coal, diesel, natural gas) prior to use.



Recycling and Beneficial Use

- When recyclables are converted to new products:
  - resource consumption and emissions are associated with recyclables collection, separation, and reprocessing
  - some extraction, processing, and transportation of virgin materials is avoided which reduces resource consumption and emissions
- Combustion is a net producer of energy and this offsets energy produced from utilities
- Landfill gas can also be converted to energy

Net Emissions from energy recovery = Emissions from energy generation from waste – emissions from energy generation from the energy grid (average or marginal)

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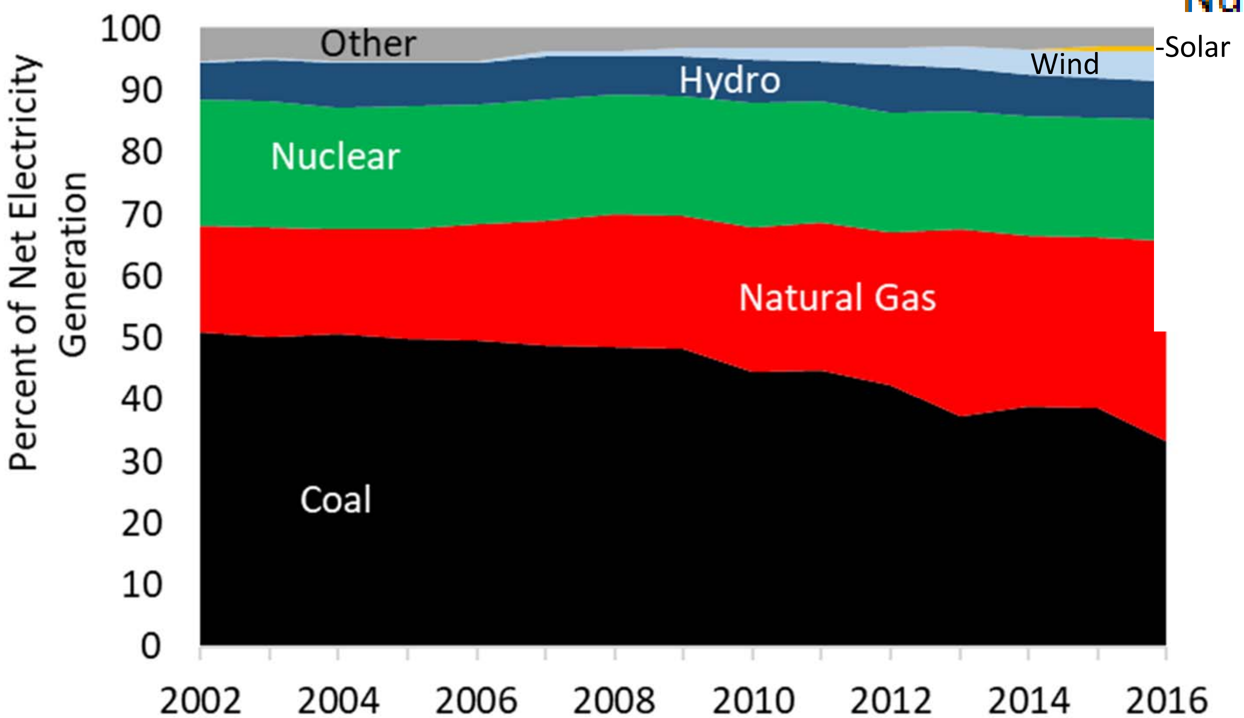
Material substitution - processes/crediting

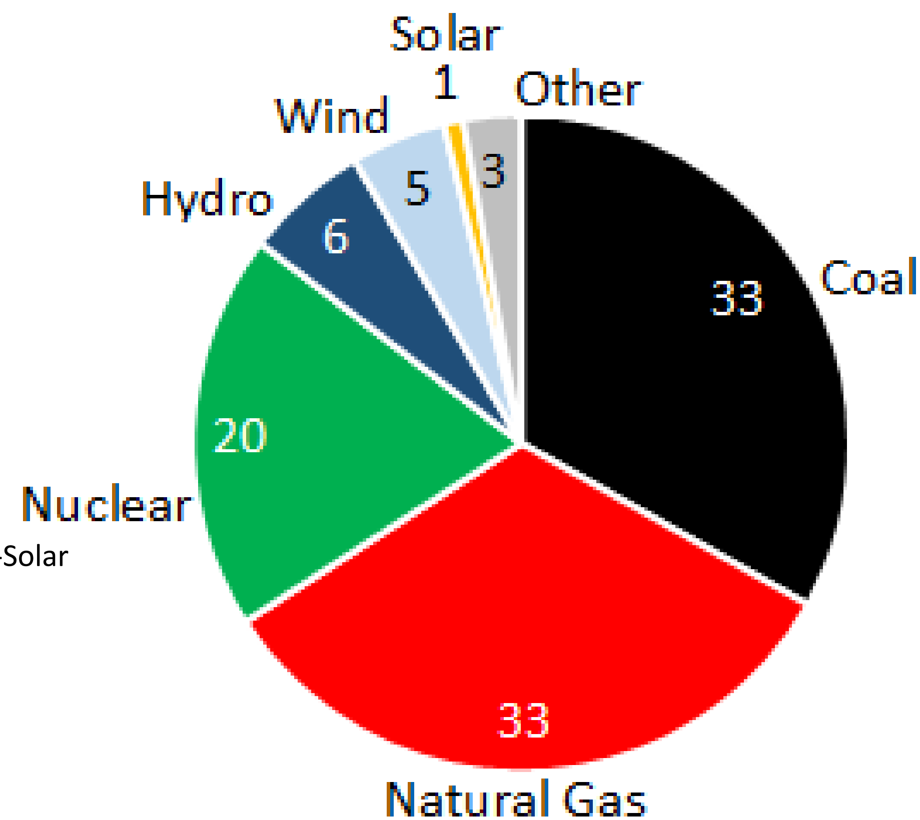
Material recycling:

Net Emissions = Emissions from processing recovered materials – emissions from avoided virgin production

- If the reprocessing and the virgin production takes place at the same plant and in the same process, then estimation of the benefits of recycling is possible and likely to be correct
- If the reprocessing takes place at a separate plant (e.g. paper mill) there is no direct link between reprocessing and the avoided virgin production and the avoided virgin production and benefits are more difficult to estimate.

The Electric Grid

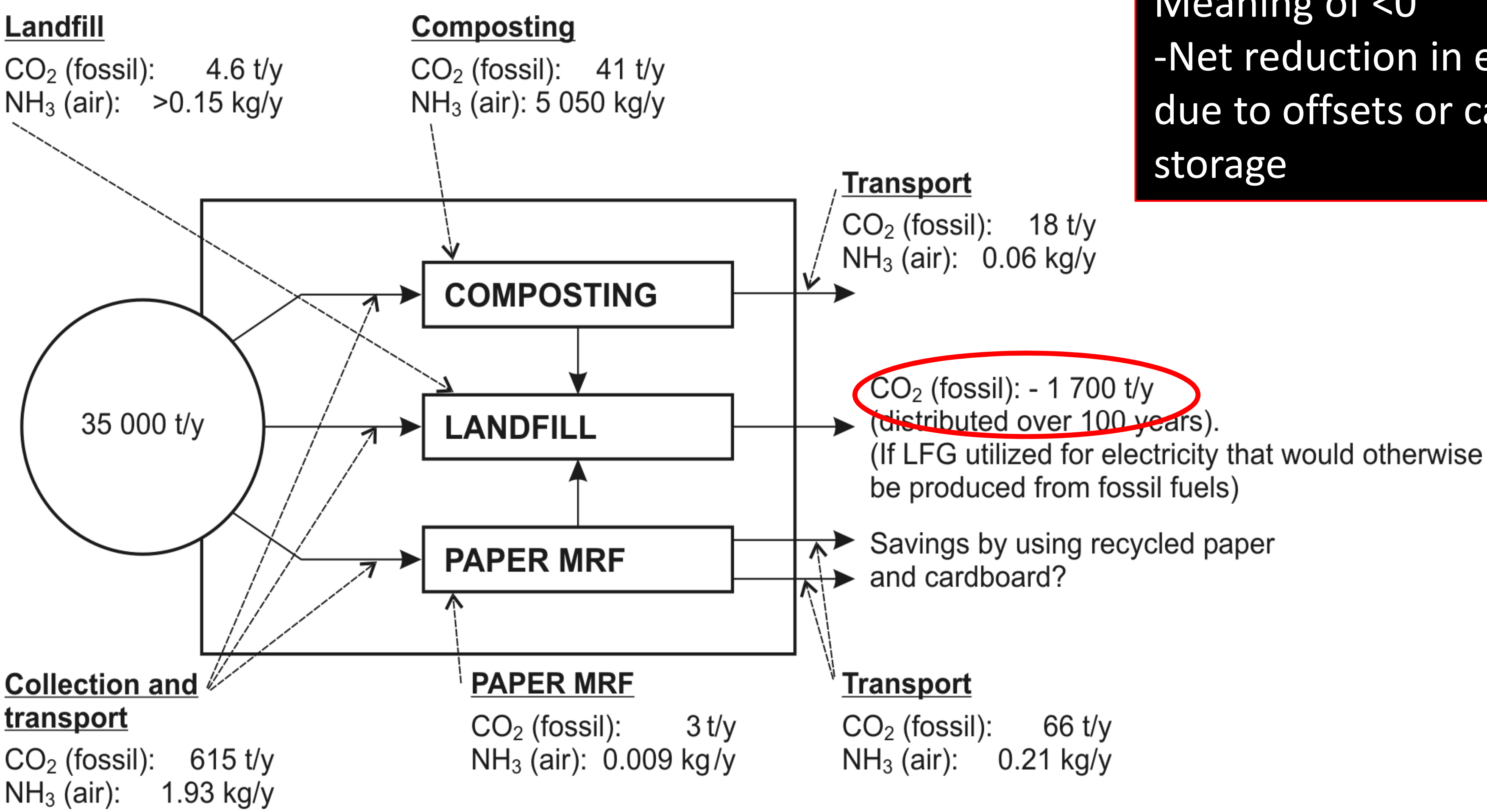




2016 US Electric Grid Mix

http://www.eia.gov/electricity/

Example: Emission account



Meaning of <0
-Net reduction in emissions due to offsets or carbon storage

Net Emissions from energy recovery = Emissions from energy generation from waste – emissions from energy generation from the energy grid (average or marginal)

The Output of Inventory Analysis…

	Alternative A		Alternative B	
Substance	To air	To water	To air	To water
	g	g	g	g
Ammonia	3.2E-04	5.9E-04	3.7E-05	4.2E-05
Arsenic (As)	3.7E-06		1.4E-07	
Benzene	6.0E-02		5.0E-02	
Lead (Pb)	1.3E-05		6.1E-07	
Cadmium (Cd)	6.3E-07		3.1E-08	
Carbon Dioxide	2.6E+02		4.5E+01	
Carbon Monoxide (CO)	5.4E-01		1.5E-01	
Chlorine (Cl2)	5.6E-04		4.6E-04	
Chromium (Cr VI)	1.9E-06	6.0E-04	7.3E-08	
Nitrous oxide (N2O)	2.3E-02		3.3E-03	
Dioxin	1.0E-12			
Copper (Cu)	6.5E-06		2.9E-07	
Mercury (Hg)	6.1E-07		2.3E-08	
Methane	6.8E-03		1.2E-03	7.9E-06
Nickel (Ni)	1.7E-04		8.2E-06	
Nitrogen oxide (NOx)	1.9E+00		3.0E-01	
NMVOC	2.3E-01		3.9E-02	
Nitric acid	8.0E-02		8.5E-02	
Hydrochloric acid	2.4E-02		1.9E-02	
Selenium (Se)	1.2E-06		7.8E-08	
Sulphur dioxide (SO2)	6.9E-01		1.2E-01	
Toluene	5.7E-02		4.8E-02	
Zinc (Zn)	2.3E-05		9.9E-07	

How do we use this data to meet LCA goal?

Source: M. Hauschild, DTU

Impact Assessment Makes Sense of the Inventory

Inventory Results

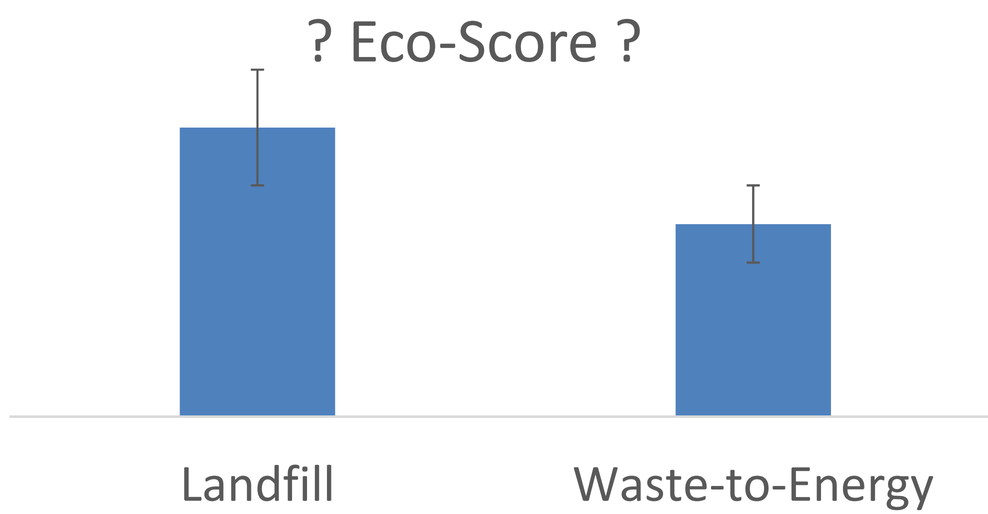
Category	Emission	Units	Landfill	Waste-to-Energy
Air	CO2, fossil	kg	0.016	0.18
	nitrogen oxides	kg	9.7E-05	-0.0012
	NMVOC	kg	1.9E-05	-0.00014
	particulates, < 2.5 um	kg	1.2E-05	-0.00037
	sulphur dioxide	kg	6.0E-05	-0.0018
	carbon monoxide	kg	5.6E-05	-0.0011
	lead	kg	1.0E-08	-3.8E-07
	methane	kg	0.021	-0.0010
	N20	kg	4.2E-06	2.1E-05
	particulates	kg	2.5E-05	-0.00072
	particulates >10 um	kg	9.4E-06	-0.00028
	particulates, >2.5 um and <10	kg	3.1E-06	-7.8E-05
	zinc	kg	2.2E-08	-1.2E-06
Water	BOD	kg	0.018	0.0017
Soil	cadmium	kg	5.3E-11	-1.1E-10
Resources	land occupation	m2a	0.0067	-0.80
	water	m3	0.00028	0.00037

Classification and Characterization

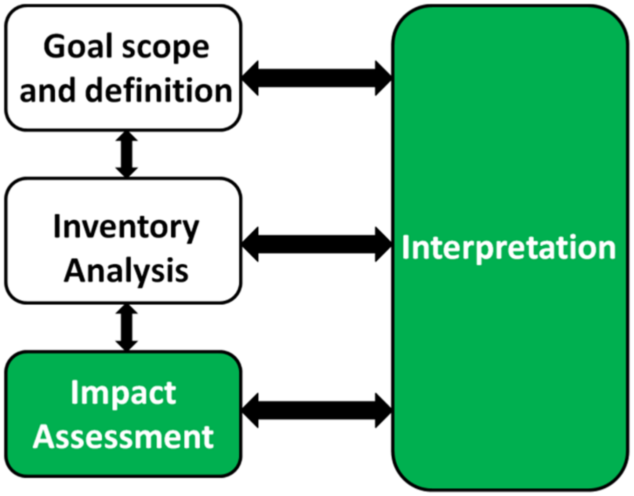
Characterization Results

Environmental Impact	Units	Landfill	Waste-to-Energy
Global Warming Potential	kg CO2-Eq	0.55	0.15
Fossil Fuel Use	MJ-Eq	0.28	-3.2
Acidification	moles of H+-Eq	0.0084	-0.15
Smog Formation	kg NOx-Eq	0.00016	-0.0011
Human Toxicity	CTU	1.5E-06	7.7E-07
Water Use	m3	0.00028	0.00037

Normalization and Weighting



Purpose of Impact Assessment



How do we use inventory data to make a rational, defensible decision among a set of alternatives?

We must quantify:

1. The environmental influences of relevant activities on specific environmental properties
2. The relative changes in the affected environmental properties can be given some type of priority ranking

.. This constitutes life-cycle impact assessment (LCIA)

Typical LCIA Categories

- Global warming
- Acidification
- Eutrophication
- Stratospheric ozone depletion
- Ecotoxicity
- Human toxicity
- Land use
- Water use
- Resource use

Interpretation

- Consider goal, scope and results together
- Improvement assessment
- Sensitivity analysis: Address uncertainty (boundary choices, incomplete inventories, data uncertainty)
- Decision support regarding environmental issues: unmodeled issues
  - Political
  - Social
  - Economic

Limitations

- The decisions on what inventory parameters are most critical may be site-specific
  - NOx may be more important in some areas of U.S. than others; so too for water consumption
    - Multi-criteria decision-making
  - emissions location: local/global
- Similar data across unit operations must be available to do meaningful comparisons

How Can It Be Applied?

- Evaluation of alternate solid waste management strategies
  - Improvement assessment
- Guide for product design or product use
- Present policy makers with sound technical information in an easily understood format
- The life-cycle framework offers an opportunity to present credible information
- Hopefully, we will be able to use this framework to bring science and policy together

Questions?

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