Lecture 7: Life Cycle Inventory: LCA Stages: Raw Materials and Energy
Raw Materials:

- **Primary materials**: materials that have not been recycled/reused
- **Secondary materials**: materials have been recycled/reused

**Secondary materials are of especial importance since they can:**
- Reduce the requirements of primary materials
- Have significantly different acquisition processes relative to primary materials: with different environmental impacts
  - Different transportation modes
  - Different collection baskets
  - Different quality and purity
- Reduce waste
Renewable vs Non-renewable Materials:

- A **nonrenewable resource** is a natural resource which cannot be reproduced, grown, generated, or used on a scale which can sustain its consumption rate; once depleted there is no more available for future needs.

- A **renewable resource** is a natural resource with the ability to reproduce through biological or natural processes and replenished with the passage of time.
Every American born in 2008 is estimated to use the following amounts of nonfuel mineral commodities in their lifetime for their necessities, lifestyles, and health.

<table>
<thead>
<tr>
<th>Mineral commodity</th>
<th>Amount required over a lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum (bauxite)</td>
<td>5,677 pounds</td>
</tr>
<tr>
<td>Cement</td>
<td>65,480 pounds</td>
</tr>
<tr>
<td>Clays</td>
<td>19,245 pounds</td>
</tr>
<tr>
<td>Copper</td>
<td>1,309 pounds</td>
</tr>
<tr>
<td>Gold</td>
<td>1,576 ounces</td>
</tr>
<tr>
<td>Iron ore</td>
<td>29,608 pounds</td>
</tr>
<tr>
<td>Lead</td>
<td>928 pounds</td>
</tr>
<tr>
<td>Phosphate rock</td>
<td>19,815 pounds</td>
</tr>
<tr>
<td>Stone, sand, and gravel</td>
<td>1.61 million pounds</td>
</tr>
<tr>
<td>Zinc</td>
<td>671 pounds</td>
</tr>
</tbody>
</table>


http://minerals.usgs.gov/graunted.html
How much copper ore do we have left?

• It is not possible to know exactly.
  – known deposits are being worked and new methods of copper extraction are being developed e.g. using bacteria to 'eat' the copper out of low grade ore
  – some deposits do not contain enough copper to make them economic to extract
  – there are many copper deposits that have not yet been found
  – deposits are still being built up on the seabed
Non-renewable Materials: Crude Oil

Crude Oil Definition: A mixture of hydrocarbons that exists in liquid phase in natural underground reservoirs and remains liquid at atmospheric pressure after passing through surface separating facilities.

http://www.consumerenergyreport.com
Non-renewable Materials: Crude Oil

Source: United States Energy Information Administration
Non-renewable Materials: Crude Oil
At present consumption, when would proved reserves of crude oil run out?
Renewable Materials:

- Agricultural products
- Forest biomass
- Fish and animals
- Water
- However, note that any of these materials can be non-renewable in specific situations/locations under specific conditions (non-sustainable consumption practices)
Non-Renewable and Renewable Energy Resources:

• Non-renewable
  – Fossil fuels (coal and oil)
  – Natural Gas
  – Nuclear Power

• Are there examples of renewables for the above list?

• Renewable
  – Solar energy
  – Geo thermal
  – Wind
  – Hydropower
  – Biomass

• What are the issues with renewables?
Primary Raw Materials:

- Cultivation, harvesting, replenishing
  - Farm products
  - Forest products
  - Wildlife

- Mined/Collected
  - Fossil fuels
  - Ores
  - Water
  - Air
Inputs for Basic Raw Materials:

- **Energy Utilization**
  - Electrical energy in kWh
  - Other energy sources in appropriate units, gallons of fuel, cubic feet of gas
  - Renewable energy
  - Non-renewable energy

- **Materials Consumed**
  - Pesticides, fertilizers, water, …

- **Harvesting/Processing/Transportation**

- **Infrastructures required**
  - Roads, buildings, drilling rigs,
  - Equipment to explore, mine, extract, harvest materials
Outputs for Basic Raw Materials:

- Air emissions
- Waterborne emissions
- Solid waste
- Other environmental releases
- Habitat changes
- Land use changes
- Aesthetic changes
- Raw material consumption
LCA Information for Basic Raw Materials:


**U.S. Life Cycle Inventory Database**

NREL and its partners created the U.S. Life Cycle Inventory (LCI) Database to help life cycle assessment (LCA) practitioners answer questions about environmental impact. This database provides individual gate-to-gate, cradle-to-gate and cradle-to-grave accounting of the energy and material flows into and out of the environment that are associated with producing a material, component, or assembly in the U.S.

The goals of the U.S. LCI Database project are:

- Maintain data quality and transparency
- Cover commonly used materials, products, and processes in the United States with up-to-date, critically reviewed LCI data
- Support the expanded use of LCA as an environmental decision-making tool
- Maintain compatibility with international LCI databases
- Provide exceptional data accessibility
- Be fully and sustainably supported
- Support U.S. industry competitiveness.

Read the plan to achieve the goals of the LCI Database Project in the [U.S. Life Cycle Inventory Database Roadmap](http://www.nrel.gov/lci/roadmap/).
LCA Information for Basic Raw Materials:

- Ecoinvent, European LCI database
LCA Information for Basic Raw Materials: US LCI: Overall Theme

• Which has the least impact on the environment, plastic or paper, cellulose insulation or fiberglass insulation, carpet or wood flooring?
• No final answer, each product has advantages and disadvantages when it comes to its environmental impact.
• The science of sustainability is not exact, but we are working on tools to give us better answers to environmental impact questions.
• The U.S. Life-Cycle Inventory (LCI) Database project is providing essential data to support those tools.
LCA Information for Basic Raw Materials: US LCI

- Database is composed of LCI data modules.
  - Inputs from technosphere (The part of the physical environment affected through building or modification by humans.)
  - Inputs from nature
  - Outputs to nature
  - Outputs of process (products)
- Modules can be cradle-to-gate or gate-to-gate or cradle to grave
LCA Information for Basic Raw Materials: US LCI

- Note, in some cases, inputs/outputs to nature are qualified
LCA Information for Basic Raw Materials: US LCI

- Modules as building blocks
- The scrap steel processing module calls for electricity per unit reference flow of product, and obtains inventory data for that electricity from the electricity generation module
LCA Information for Basic Raw Materials: US LCI

• Aggregate Modules: combined data for several modules into one
  – Convenience
  – Only available at an aggregated level

• Example: kiln dried softwood lumber from the Pac. NW combines
  – Forest resources (forest mgmt and harvesting)
  – Sawing
  – Kiln drying
  – Planning
  – Energy Production
  – Transportation

• Since the individual modules are also available, then a user can pick and choose individual modules to produce a specific “aggregated module” correct for a certain application
LCA Information for Basic Raw Materials: US LCI

- Modules supplied without allocations between co-products
- Allows the users to apply allocation methods as they see fit and to undertake sensitivity analysis on allocation methods
LCA Information for Basic Raw Materials: US LCI

- Database: https://www.lcacommons.gov/nrel/search
LCA Information for Basic Raw Materials: US LCI

- Example: corn stover, ground and stored

<table>
<thead>
<tr>
<th>DATASET TYPE</th>
<th>CATEGORY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Transportation</td>
<td>Air Transportation (1)</td>
</tr>
<tr>
<td></td>
<td>Chemical Manufacturing (84)</td>
</tr>
<tr>
<td></td>
<td>Crop Production (34)</td>
</tr>
<tr>
<td></td>
<td>Elec. Equip., Appliance, and Comp. Mnf. (2)</td>
</tr>
<tr>
<td></td>
<td>Fabricated Metal Product Manufacturing (1)</td>
</tr>
<tr>
<td></td>
<td>Forestry and Logging (50)</td>
</tr>
<tr>
<td></td>
<td>Mining (except Oil and Gas) (5)</td>
</tr>
<tr>
<td></td>
<td>Nonmetallic Mineral Product Mnf. (2)</td>
</tr>
<tr>
<td></td>
<td>Oil and Gas Extraction (3)</td>
</tr>
<tr>
<td></td>
<td>Paper Manufacturing (1)</td>
</tr>
<tr>
<td></td>
<td>Petroleum and Coal Products Mnf. (2)</td>
</tr>
<tr>
<td></td>
<td>Primary Metal Manufacturing (22)</td>
</tr>
<tr>
<td></td>
<td>Rail Transportation (1)</td>
</tr>
<tr>
<td></td>
<td>Rail Transportation Equipment Manufacturing</td>
</tr>
<tr>
<td></td>
<td>(1)</td>
</tr>
<tr>
<td></td>
<td>Truck Transportation (102)</td>
</tr>
<tr>
<td></td>
<td>Utilities (125)</td>
</tr>
<tr>
<td></td>
<td>Waste Management and Remediation Service (22)</td>
</tr>
<tr>
<td></td>
<td>Water Transportation (5)</td>
</tr>
<tr>
<td></td>
<td>Wood Product Manufacturing (60)</td>
</tr>
<tr>
<td></td>
<td>biomass (21)</td>
</tr>
</tbody>
</table>

U.S. Life-Cycle Inventory Database

Search for (Advanced Search) (New search)

1,967 records found

Transport, single unit truck, short-haul, diesel powered, West
- General Freight Trucking
- Other Transit and Ground Passenger Tran

Phenol formaldehyde, at plant
- Plastics Material and Resin Mnf.
- Other Non-Ferrous Metal Mnf.

Soybean oil, crude, degummed, at plant
- Oilseed (except Soybean) Farming
- Specify the type of farm

Palm kernels, at plant
- Oilseed (except Soybean) Farming
- Specify the type of farm

Poly styrene, high impact, resin, at plant, CTR
- Petrochemical Manufacturing
- Specify the type of petrochemical manufacturing

Electricity, at eGrid, HIMS, 2008
- Utilities
- Specify the type of utility

Forest residue, processed and loaded, at landing system
- Logging
- Specify the type of logging activity

Anode, at plant
- Misc. Fabricated Metal Product Mnf.
- Specify the type of fabricated metal product

Combustion, wet wood residue, AP-42
- Other Electric Power Generation
- Specify the type of electric power generation

Dry veneer, at plywood plant, US SE
- Softwood Veneer and Plywood Mnf.
- Specify the type of veneer and plywood manufacturing

Soybean grains, at field
- Soybean Farming
- Specify the type of soybean farming

Deliming, slide boom delimber
- Logging
- Specify the type of logging activity
LCA Information for Basic Raw Materials: US LCI

- Example: corn stover, ground and stored

<table>
<thead>
<tr>
<th>Activity</th>
<th>Modelling</th>
<th>Admin Info</th>
<th>Exchanges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>corn stover, ground and stored</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Category</td>
<td>biomass - production</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Description</td>
<td>Taken from Sheehan, Corn Stover Ethanol LCA. (Directly from TEAM). The corn steep liquor production involves the steeping of harvested corn for a period of from 24 to 48 hours in a light sulfurous acid solution. The production of sulfuric acid was assumed to be negligible. The only emissions were SOx from the steeping tanks. Emission factors provided by USA EPA AP-42. All of the production burdens from corn are assumed to be allocated to the production of the steeping liquor.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td>RNA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geography Comment</td>
<td>North America</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infrastructure Process</td>
<td>False</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quantitative Reference</td>
<td>corn stover, ground and stored</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
LCA Information for Basic Raw Materials:

- **Example:** corn stover, ground and stored

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Flow</th>
<th>Category</th>
<th>Type</th>
<th>Unit Amount</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>corn stover, carted</td>
<td>root/Flows</td>
<td></td>
<td>ProductFlow</td>
<td>t</td>
<td>1.28e+00 comes in wet</td>
</tr>
<tr>
<td>Dummy_agricultural machinery, general, production</td>
<td>root/Flows</td>
<td></td>
<td>ProductFlow</td>
<td>kg</td>
<td>9.00e-01</td>
</tr>
<tr>
<td>Dummy_conveyor belt, at plant</td>
<td>root/Flows</td>
<td></td>
<td>ProductFlow</td>
<td>m</td>
<td>3.47e-05 conveyor for storage</td>
</tr>
<tr>
<td>Dummy_conveyor belt, at plant</td>
<td>root/Flows</td>
<td></td>
<td>ProductFlow</td>
<td>m</td>
<td>3.47e-05 conveyor for grinder in-feed system</td>
</tr>
<tr>
<td>Dummy_dried roughage store, non ventilated</td>
<td>root/Flows</td>
<td></td>
<td>ProductFlow</td>
<td>m3</td>
<td>1.17e-07</td>
</tr>
<tr>
<td>Dummy_fodder loading, by root/Flows self-loading trailer</td>
<td>root/Flows</td>
<td></td>
<td>ProductFlow</td>
<td>m3</td>
<td>2.78e+00 loading to storage</td>
</tr>
<tr>
<td>Dummy_loading bales</td>
<td>root/Flows</td>
<td></td>
<td>ProductFlow</td>
<td>p</td>
<td>1.43e+00 loading bales for grinder. Calculation of number of bales comes from 2000 lbs of corn stover divided by weight per bale. Trailer volume is 2511 ft^3 (INL table 4-5), density is 12 lbs/ft^3 dry (=20 wet at 40% moisture).</td>
</tr>
<tr>
<td>electricity, at grid, US, 2008</td>
<td>root/Flows</td>
<td></td>
<td>ProductFlow</td>
<td>kWh</td>
<td>3.26e+00 Electricity needed for twine removal</td>
</tr>
<tr>
<td>electricity, at grid, US, 2008</td>
<td>root/Flows</td>
<td></td>
<td>ProductFlow</td>
<td>kWh</td>
<td>6.13e+01 Electricity needed for dust collection</td>
</tr>
<tr>
<td>grinding</td>
<td>root/Flows</td>
<td></td>
<td>ProductFlow</td>
<td>sh</td>
<td>9.31e-01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Outputs</th>
<th>Flow</th>
<th>Category</th>
<th>Type</th>
<th>Unit Amount</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>corn stover, ground and stored</td>
<td>root/Flows</td>
<td></td>
<td>ProductFlow</td>
<td>t</td>
<td>1.00e+00</td>
</tr>
<tr>
<td>Water</td>
<td>air/unspecified</td>
<td>ElementaryFlow</td>
<td>kg</td>
<td>2.80e+02 water dried per ton of final moisture corn stover.</td>
<td></td>
</tr>
</tbody>
</table>
Summary terms

- Primary materials
- Secondary materials
- Non-renewable
- Renewable
- Technosphere
- Aggregated model
- US LCI
- ecoinvent