WPS 576 Lecture
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Life Cycle Assessment and Biofuels

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Outline

• Introduction
• Background
  – Petroleum Consumption
  – Peak Oil
• Biofuels
  – What are Biofuels
  – Biofuels Demand
  – Conversion Pathways (Difference between 1st gen vs 2nd gen)
  – Benefits and Drawbacks/Concerns
  – RIN's, GHG reduction, Carbon footprint Carbon trading
• How LCA fits into facilitating commercialization
• Key Issues
• Calculation - basic CO$_2$ emissions of petro vs biofuel (GREET)
• Case Study - LCA overview
• Summary/Glossary of Terms
Demand for Oil

- 2009 oil consumption around the world

http://www.ritholtz.com/blog/2010/06/oil-consumption-around-the-world/
Top Petroleum Consumers by Continent

- Total petroleum consumption (‘000 bbls/day) from 1980-2012
- World consumption is continually increasing
Highest Consuming Countries

- Sorted by 2012 consumption (US on rt side secondary axis-2X primary)
Petroleum Consumption per Capita

- US and Saudi Arabia are by far the largest consumers per capita
- The world consumption per capita is steady (~5bbl/person/yr)

[Graph showing oil consumption per capita for different countries over time]

Peak Oil

- Time when the maximum rate of petroleum extraction is reached
- Does not mean all of petroleum is consumed
- Peak oil depletion scenarios from different studies

Proven Oil Reserves

- Where are the oil reservoirs?

- 2012 OPEC share of oil reserves

Summary of Proven Reserve Data as of 2012[2]

<table>
<thead>
<tr>
<th>Rank</th>
<th>Country</th>
<th>Reserves</th>
<th>Reserves</th>
<th>Production</th>
<th>Production</th>
<th>Reserve/Production Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Venezuela</td>
<td>296.5</td>
<td>47.14</td>
<td>2.1</td>
<td>330</td>
<td>387</td>
</tr>
<tr>
<td>2</td>
<td>Saudi Arabia</td>
<td>265.4</td>
<td>42.20</td>
<td>8.9</td>
<td>1,410</td>
<td>81</td>
</tr>
<tr>
<td>3</td>
<td>Canada</td>
<td>175</td>
<td>27.8</td>
<td>2.7</td>
<td>430</td>
<td>178</td>
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<tr>
<td>4</td>
<td>Iran</td>
<td>151.2</td>
<td>24.04</td>
<td>4.1</td>
<td>650</td>
<td>101</td>
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<tr>
<td>5</td>
<td>Iraq</td>
<td>143.1</td>
<td>22.75</td>
<td>2.4</td>
<td>380</td>
<td>163</td>
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<tr>
<td>6</td>
<td>Kuwait</td>
<td>101.5</td>
<td>16.14</td>
<td>2.3</td>
<td>370</td>
<td>121</td>
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<tr>
<td>7</td>
<td>United Arab Emirates</td>
<td>136.7</td>
<td>21.73</td>
<td>2.4</td>
<td>380</td>
<td>156</td>
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<tr>
<td>8</td>
<td>Russia</td>
<td>80</td>
<td>13</td>
<td>10</td>
<td>1,600</td>
<td>22</td>
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<tr>
<td>9</td>
<td>Kazakhstan</td>
<td>49</td>
<td>7.8</td>
<td>1.5</td>
<td>240</td>
<td>55</td>
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<tr>
<td>10</td>
<td>Libya</td>
<td>47</td>
<td>7.5</td>
<td>1.7</td>
<td>270</td>
<td>76</td>
</tr>
<tr>
<td>11</td>
<td>Nigeria</td>
<td>37</td>
<td>5.9</td>
<td>2.5</td>
<td>400</td>
<td>41</td>
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<tr>
<td>12</td>
<td>Qatar</td>
<td>25.41</td>
<td>4.040</td>
<td>1.1</td>
<td>170</td>
<td>63</td>
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<tr>
<td>13</td>
<td>China</td>
<td>20.35</td>
<td>3.235</td>
<td>4.1</td>
<td>650</td>
<td>14</td>
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<tr>
<td>14</td>
<td>United States</td>
<td>26.8</td>
<td>4.26</td>
<td>7</td>
<td>1,100</td>
<td>10</td>
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<tr>
<td>15</td>
<td>Angola</td>
<td>13.5</td>
<td>2.15</td>
<td>1.9</td>
<td>300</td>
<td>19</td>
</tr>
<tr>
<td>16</td>
<td>Algeria</td>
<td>13.42</td>
<td>2.134</td>
<td>1.7</td>
<td>270</td>
<td>22</td>
</tr>
<tr>
<td>17</td>
<td>Brazil</td>
<td>13.2</td>
<td>2.10</td>
<td>2.1</td>
<td>330</td>
<td>17</td>
</tr>
</tbody>
</table>

Total of top seventeen reserves: 1,324 210.5 56.7 9,010 64

Sources: OPEC Annual Statistical Bulletin 2013


http://en.wikipedia.org/wiki/Oil_reserves
What are biofuels?

• EPA defines biofuels as any fuel derived from renewable biological materials (biomass) which means it contains energy from geologically recent carbon fixation.

• ‘First-generation’ or conventional biofuels are made from sugar, starch, or vegetable oil to produce ethanol or biodiesel.

• Advanced biofuels are not yet produced commercially.
  – ‘Second generation’ biofuels, or cellulosic biofuels, are made from cellulose, which is available from non-food crops and waste biomass such as corn stover, corncobs, straw and other herbaceous crops/grasses, wood, and wood byproducts.
  – ‘Third generation’ biofuels use algae as a feedstock.

• The conversion process from biomass to biofuels can include thermal, chemical, or biological methods to produce a liquid, gas or solid fuel.

http://www.epa.gov/ncea/biofuels/basicinfo.htm
Biofuels Pathways

First Generation (Conventional)

Second Generation (Advanced)


http://www.c2es.org/docUploads/images/Fig2-BiofuelsPathways.preview.GIF
US Biofuels Demand

- Energy Independence and Security Act (EISA) 2007
- Renewable Fuels Standard (RFS) program governed by EPA
  - Updated annually to adjust and enforce yearly goals (RFS2-Mar 26, 2010)
  - Mandates 36 billion gallons min. vol. requirement of renewable fuel by 2022
    - Conventional biofuels (corn ethanol) capped at ~15 billion gallons
    - Advanced biofuels (Noncellulosic- sugarcane ethanol; Biomass-based diesel; soy, waste oil, algae)
    - Cellulosic biofuels (ethanol, diesel) 16 billion gallons by 2022
Blend Wall

- Blend Wall = total amount of ethanol that can be blended into gasoline
  - Increased from E10 to E15 (for passenger cars 2001 or later)
  - Puts a cap on the total ethanol demand (based on petroleum consumption)
  - Increased demand for E85 (85% ethanol, 15% gasoline) will allow for the US to fulfill the RFS2 cellulosic ethanol goal
Petroleum GHG Emissions

  - 6,702 million tonnes of CO₂ equivalent (total)
  - 1,877 million tonnes of CO₂ equivalent from Transportation
  - Majority CO₂, small amounts CH₄, N₂O, and hydrofluorocarbon (HFC)
- Emits anthropogenic GHG – human induced emissions that originate from non-renewable resources

http://www.epa.gov/climatechange/ghgemissions/sources/transportation.html
Biofuels GHG Emissions

• Theoretically biofuels can be carbon neutral, but consume fossil fuels and emit GHGs during harvesting, production and transportation

• Majority of GHG emissions are biogenic – produced or brought about by living organisms (biomass)
  – Using biofuels can alter the balance of the biomass carbon cycle
  – Different biomass sources can also change the carbon balance

http://www.energyfuturecoalition.org/biofuels/benefits_env_public_health.htm

http://sugarcane.org/sugarcane-benefits/greenhouse-gas-reductions
### HOW GREEN ARE BIOFUELS?

Biofuels are getting a bad rap as stories of rising food prices and shortages fill the news. But the environmental, energy and land use impacts of the crops used to make the fuels vary dramatically. Current fuel sources – corn, soybeans and canola – are more harmful than alternatives that are under development.

#### FUEL SOURCES

<table>
<thead>
<tr>
<th>CROP</th>
<th>USED TO PRODUCE</th>
<th>GREENHOUSE GAS EMISSIONS*</th>
<th>USE OF RESOURCES DURING GROWING, HARVESTING AND REFINING OF FUEL</th>
<th>PERCENT OF EXISTING U.S. CROP LAND NEEDED TO PRODUCE ENOUGH FUEL TO MEET HALF OF U.S. DEMAND</th>
<th>PROS AND CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>Ethanol</td>
<td>81-85</td>
<td>high, high, high, high</td>
<td>157%-262%</td>
<td>Technology ready and relatively cheap, reduces food supply</td>
</tr>
<tr>
<td>Sugar cane</td>
<td>Ethanol</td>
<td>4-12</td>
<td>high, high, med, med</td>
<td>46-57</td>
<td>Technology ready, limited as to where will grow</td>
</tr>
<tr>
<td>Switch grass</td>
<td>Ethanol</td>
<td>-24</td>
<td>med-low, low, low</td>
<td>60-108</td>
<td>Won’t compete with food crops, technology not ready</td>
</tr>
<tr>
<td>Wood residue</td>
<td>Ethanol, biodiesel</td>
<td>N/A</td>
<td>med, low, low, low</td>
<td>150-250</td>
<td>Uses timber waste and other debris, technology not fully ready</td>
</tr>
<tr>
<td>Soybeans</td>
<td>Biodiesel</td>
<td>49</td>
<td>high, low-med, med</td>
<td>180-240</td>
<td>Technology ready, reduces food supply</td>
</tr>
<tr>
<td>Rapeseed, canola</td>
<td>Biodiesel</td>
<td>37</td>
<td>high, med, med, med</td>
<td>30</td>
<td>Technology ready, reduces food supply</td>
</tr>
<tr>
<td>Algae</td>
<td>Biodiesel</td>
<td>-183</td>
<td>med, low, low, high</td>
<td>1-2</td>
<td>Potential for huge production levels, technology not ready</td>
</tr>
</tbody>
</table>

*Emissions produced during the growing, harvesting, refining and burning of fuel. Gasoline is 94, diesel is 83.

Source: Martha Groom, University of Washington; Elizabeth Gray, The Nature Conservancy; Patricia Townsend, University of Washington; as published in Conservation Biology

http://www.geni.org/globalenergy/library/articles-renewable-energy-transmission/graphics/biofuels_compare.gif
Relating RFS2 and GHG emissions

• Impacts of Renewable Fuel Volumes Required by RFS2 in 2022
  – Reduce GHG emissions by 138 million metric tons
  – Equivalent to removing 27 million cars off the road
  – Reduce dependence on foreign oil (save $41.5 billion in 2007 dollars)
  – Increase domestic farming income (generate $13 billion in 2007 dollars)

• In addition to fuel switching, the EPA has identified other reduction opportunities within the transportation sector
  – Improving fuel efficiency by using advanced technologies, design, and materials to develop more fuel-efficient vehicles (hybrid and electric vehicles, reducing weight and aerodynamic resistance)
  – Improving operating practices that minimize fuel use through EPA’s SmartWay program that encourages sensible driving and more efficient travel
  – Reducing travel demand by employing urban planning via public transportation and building sidewalks and bike paths

http://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1006DXP.PDF
http://www.epa.gov/climatechange/ghgemissions/sources/transportation.html
Renewable Identification Number

- RIN - a serial number assigned to a batch of biofuel for the purpose of tracking its production, use, and trading
- Helps facilitate and enforce the RFS in the US

Total Available RINs to Date (as of November 7, 2013)

<table>
<thead>
<tr>
<th>Fuel Category</th>
<th>Assignments</th>
<th>Total Generated</th>
<th>Total Retired</th>
<th>Total Available</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Assigned</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Separated</td>
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<tr>
<td>Cellulosic Biofuel</td>
<td>Assigned</td>
<td>294,554</td>
<td>0</td>
<td>0</td>
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<tr>
<td>(D3)</td>
<td>Separated</td>
<td>NA</td>
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<td>0</td>
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<tr>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>36,480</td>
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<td>258,074</td>
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<td>Biomass-Based Diesel</td>
<td>Assigned</td>
<td>2,115,362,278</td>
<td>25,023,854</td>
<td>17,249,456</td>
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<td>(D4)</td>
<td>Separated</td>
<td>NA</td>
<td>20,419,305</td>
<td>19,749,172</td>
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<td></td>
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<td></td>
<td>204,387,419</td>
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<td></td>
<td></td>
<td></td>
<td>1,828,533,072</td>
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<td>Advanced Biofuel</td>
<td>Assigned</td>
<td>514,847,899</td>
<td>1,885,066</td>
<td>22,616,949</td>
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<tr>
<td>(D5)</td>
<td>Separated</td>
<td>NA</td>
<td>5,079,718</td>
<td>40,279,160</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>12,322,627</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>432,664,379</td>
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<tr>
<td>Renewable Fuel</td>
<td>Assigned</td>
<td>10,940,469,288</td>
<td>42,154,761</td>
<td>21,162,455</td>
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<tr>
<td>(D6)</td>
<td>Separated</td>
<td>NA</td>
<td>123,217,076</td>
<td>284,661,724</td>
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<td>709,006,038</td>
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<td></td>
<td></td>
<td></td>
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<td>9,760,267,234</td>
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<tr>
<td>Cellulosic Diesel</td>
<td>Assigned</td>
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<td>(D7)</td>
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<td>8,332</td>
<td>0</td>
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<td></td>
<td></td>
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<td>0</td>
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<tr>
<td>Total RINs</td>
<td>Assigned</td>
<td>13,571,251,611</td>
<td>217,788,112</td>
<td>405,718,916</td>
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<tr>
<td>Assigned and</td>
<td>Separated</td>
<td></td>
<td></td>
<td>12,947,744,583</td>
</tr>
<tr>
<td>Separated</td>
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</tr>
</tbody>
</table>

http://www.epa.gov/otaq/fuels/rfsdata/2013emts.htm
RINs

- Developed under the EPAct 2005 required by the EPA’s RFS
- EPA authorized to set annual quotas dictating the percentage of the total amount of motor fuels consumed in the US must by biofuels

- Defined in the RFS2 regulations: 40 CFR 80.1426
- The number is defined as follows

  RIN: KYYYYCCCCCFFFFFFBBBBDSSSSEEEEEEE

  - K = Code distinguishing assigned RINs from separated RINs
  - YYYY = Calendar year of production or import
  - CCCC = Company ID
  - FFFF = Facility ID
  - BBBB = Batch number
  - RR = Code identifying the Equivalence Value (how many RINs shall be generated for each gallon of renewable fuel)
  - D = Code identifying the renewable fuel category
  - SSSSSSSSS = Start of RIN block
  - EEEEEEEEE = End of RIN block

http://www.epa.gov/otaq/fuels/rfsdata/index.htm
RINs

- Function as form of a government sanctioned environmental ‘currency’
- Anyone registered with the EPA can buy and sell RINs
  - Example: A RIN credit is earned when a petroleum refiner blends the required amount of renewable fuel into their gasoline. Petroleum refiners can get around blending renewables into gasoline themselves by purchasing excess RINs from refiners who have used more renewable fuel than was required of them.
- It is a simple idea, but the technical aspects are intricate and complex
- Renewable Volume Obligations (RVO) issued to refinery or imported fuel

http://www.eia.gov/todayinenergy/detail.cfm?id=11511
Biofuels LCA

• Different types of LCA’s can be applied to different areas of the biofuels production process
  – Biomass Feedstock Production (cradle-to-gate)
  – Delivered Biomass to Biofuel Conversion Pathway (gate-to-gate)
  – Full Biofuel Conversion (cradle-to-gate) also called Well-to-Pump (WTP)
  – Biofuel Production and Use (cradle-to-grave) also called Well-to-Wheel (WTW)

• These differences allow certified LCA practitioner to target the important environmental impacts for different audiences
  – Biomass Farmer (plantation owner)
  – Biofuels Producer (biofuel refinery)
  – Biofuels End User (driver of biofuel-powered vehicle)
  – Supply Chain Owners (fueling station, transportation)
Biofuels and LCA

• Must prove that biofuels provide economical benefit to get investors and build demand for production

• Must prove biofuels provide environmental benefit over traditional petroleum fuels (gasoline) and corn ethanol (food v fuel debate)

• Possible objectives:
  – Identify feedstock production scenarios with lowest environmental impact
  – Evaluate the impacts of land use change
  – Determine conversion technologies with lowest environmental impacts
  – Evaluate impacts of biofuel combustion compared to gasoline
  – Determine environmental impacts of total biofuel production process
  – Identify hotspots for the environmental impacts of biofuel production

http://www.life.illinois.edu/delucia/Publications/Davis%20LCA%20TiPS.pdf
Biofuels LCA Challenges

- Biofuels LCAs have the potential to be very complex with many energy and GHG requirements (input) and emissions (outputs)
  - Different background colors with larger radii indicate increasing complication
  - Simplest=biofuel crop yield, inputs of GHG would include the CO2 required for photosynthesis and outputs of GHG would include CO2 from autotrophic and heterotrophic respiration, as well as NOx and CH4 fluxes from the soil
  - Complex=includes economic and policy influences and land-use change accompanied with a full cradle-to-grave product analysis

http://www.life.illinois.edu/delucia/Publications/Davis%20LCA%20TiPS.pdf
Biofuels LCA Challenges

• The sustainability of biofuels is challenged by the varied perspectives of diverse disciplines that contribute to biofuels research.

• Most LCAs are performed by practitioners whose expertise does not cover the full range of the product chain and the wide range of specialists interested in the assessment of biofuels:
  – Biomass growth and harvesting – ecologists, plant scientists, biological and agricultural engineers
  – Conversion technologies – engineers
  – Use and distribution – economists and policy-makers

• Most biofuels LCAs recognize that plant growth consumes some GHG emissions, but do not consider this holistic approach.

• Accurate data on conversion yields and predictions of future system parameters can be very difficult and can greatly impact the LCA results.

• More collaboration required basic scientists and LCA practitioners to incorporate LCA concepts in early phases of technology evaluation.

http://www.life.illinois.edu/delucia/Publications/Davis%20LCA%20Tips.pdf
7 Grand Challenges for LCA of Biofuels

• By applying the LCA approach McKone and Horvath identified the following challenges that biofuels face:
  – Understanding farmers, feedstock options, and land use
  – Predicting biofuel production technologies and practices
  – Characterizing tailpipe emissions and their health consequences
  – Incorporating spatial heterogeneity in inventories and assessments
  – Accounting for time in impact assessments
  – Assessing transitions as well as end states
  – Confronting uncertainty and variability

• Remember LCA is an iterative process and can be a very useful tool in making decisions on where to allocate resources, where to make investments, what process information to collect, risk assessment
Class Exercise: GREET

- Greenhouse gases, Regulated Emissions, and Energy use in Transportation
- Developed by Argonne National Laboratory, sponsored by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE); first model introduced in 1996
- Free to public, allows to evaluate over 100 fuel pathways and vehicle cycle
- Calculates separately for each fuel and vehicle combination
  - Consumption of total energy (energy in non-renewable and renewable sources), fossil fuels (petroleum, natural gas, and coal together), petroleum, coal and natural gas.
  - Emissions of CO2-equivalent greenhouse gases - primarily carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O).
  - Emissions of six criteria pollutants: volatile organic compounds (VOCs), carbon monoxide (CO), nitrogen oxide (NOx), particulate matter with size smaller than 10 micron (PM10), particulate matter with size smaller than 2.5 micron (PM2.5), and sulfur oxides (SOx).

http://greet.es.anl.gov/
Class Exercise: GREET

- Compare the energy and emissions from well-to-wheel:
  - Conventional gasoline from conventional crude oil
  - Corn ethanol
  - Cellulosic ethanol from forest residues

http://greet.es.anl.gov/
Class Exercise: GREET

- Conventional gasoline from conventional crude oil

http://greet.es.anl.gov/
Class Exercise: GREET

- Corn ethanol

http://greet.es.anl.gov/
Class Exercise: GREET

• Cellulosic ethanol from forest residues
  – Data Editors
  – Vehicles (Well-to-Wheel)
  – Add Vehicle
  – Select category (Ethanol)
  – Select pathway mix (from drop-down menu on right)
    • Forest Residue Fermentation to Ethanol
  – Results → Calculate
  – Add as New
  – WTW, select new vehicle to view energy and emissions

http://greet.es.anl.gov/
LCA Case Study

Life Cycle Assessment of Wood Chips for Biofuels Production in Northeast Region of US

Binod Neupane and Anthony Halog (Ph. D.)
School of Forest Resources, Forest Bioproducts Research Initiative
University of Maine, Orono ME 04469 (2009)

- Eco-indicator 99 based cradle-to-gate analysis (from trees to woodchips)

http://www.lcacenter.org/LCA9/presentations/47.pdf
LCA Case Study

• Goal and Scope
The primary goal and scope of this study is to assess the potential environmental life cycle impacts and resource consumptions in producing wood chips for biofuels production. We are interested to know:
1. Which are the activities in the life cycle that contribute the most to the environmental impact associated with woodchips?
2. Where the improvement possibilities are in the life cycle of woodchips production?

• Functional Unit
The functional unit is 4m³ of hardwood woodchips composed of 42.6% cellulose, 29.7% hemicellulose, 27.5% lignin and 0.2% ash on dry weight basis. This functional unit was chosen to align with The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model to produce to one million BTU of energy

• Assumptions
1. Co-products allocation in processing woodchips is based on Rural Technology Initiatives calculations (bark 20%, saw dust 8% and shavings 5%)
2. Primary transportation from felling site to facility is assumed 90km which is considered economically feasible in Maine [8]

http://www.lcacenter.org/LCA9/presentations/47.pdf
LCA Case Study

- System Boundary

Fig 1: System boundary and process flow of artificial regeneration scenario

Fig 2: System boundary and process flow of natural regeneration scenario
LCA Case Study

- Life Cycle Impact Assessment (LCIA) for artificial regeneration

Figure 3: Characterized impact factors in artificial regeneration scenario generated by SimaPro eco-indicator 99

http://www.lcacenter.org/LCA9/presentations/47.pdf
LCA Case Study

- Normalized artificial regeneration

Fig 4: Normalized impact factors in artificial regeneration scenario generated by SimaPro eco-indicator 99z
LCA Case Study

- Natural regeneration LCIA

Fig 5: Characterized impact factor for natural regeneration scenario generated by SimaPro eco-indicator 99

http://www.lcacenter.org/LCA9/presentations/47.pdf
LCA Case Study

- Normalized natural regeneration

Fig 6: Normalized impact factors for natural regeneration scenario generated by SimaPro eco-indicator 99
LCA Case Study

• Conclusions
  – Dominant environmental impacts for both cases are the fossil fuel use and respiratory inorganics created
  – The life cycle phases of transportation and harvesting/processing contributed to the most to the environmental impacts
  – Acidification/eutrophication and climate change had relatively small contributions
  – The recommendation for reducing these impacts is to increase the fuel efficiency associated with harvesting and transportation
Summary

- Petroleum consumption
- Peak oil
- Biofuels
- First generation
- Second generation
- EPA
- RFS
- Blend Wall
- GHG
- Anthropogenic
- Biogenic
- RIN
- RVO
- GREET
- Biofuels LCA, Hot Spots