‘Woods-to-Wake’ Life Cycle Assessment (LCA) of NARA Bio-Jet

Presented by:

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**Gevo Inc.**
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Things that will be covered

- Objective and importance of LCA for the project
- Where we started
- Intermediary Environmental Assessments
  - Location and logistics analysis
  - Intermediary products
- Environmental Assessments final IPK models
  - IPK only scenario (theoretical)
  - IPK and two co-products scenario (NARA-IPK)
- Conclusion
Why Conduct an LCA

• **US Energy Independence and Security Act of 2007:**
  
  – Public procurement (Federal agency) would require an assessment of lifecycle greenhouse gas (GHG) emissions associated with the production and combustion of biofuel

  – Must establish that the GHG emission is less than or equal to emission from the equivalent conventional fuel produced from petroleum sources.

• **Subtitle A of the Act (Renewable Fuel Standard):**

  – Fuel derived from any cellulose, hemicellulose, or lignin from renewable biomass must demonstrate 60 percent reduction in greenhouse gas emission compared to the baseline greenhouse gas emission (from fossil fuels) to be considered for government contracts.
Objective: Comparative Assessment of Petro-Jet to NARA Bio-Jet

Panel A: LCA of NARA Bio Jet
- Greenhouse & Land Prep.
- Forest Stand
- Harvest Operations
- Prep. & Transport Biomass
- Pre-treatment and Bio-jet conversion
- Bio-Jet Fuel Transportation
- Bio-Jet Fuel Combustion

Emissions to Air, Water and Land
- CO₂, PM, NOₓ, SOₓ, H₂O
- Avoided pile burns of residual biomass
- Co-Products (AC and SSL)

Panel B: LCA of Petroleum Jet
- Crude Oil Extraction
- Crude Oil Transportation
- Refinery: Jet Fuel Production
- Jet Fuel Transportation
- Jet Fuel Combustion

Emissions: CO₂, PM, NOₓ, SOₓ, H₂O

Co-Products (other petroleum products)
When we started with the project …
First cut: by modifying the NREL 2011 model
We also developed environmental assessments associated with various in-woods feedstock handling and transportation systems and published those results in academic journals and industrial publications.
Environmental Assessments
Intermediary products
LCA of Fermentable Sugars for Biofuel Production

Environmental assessment of mild bisulfite pretreatment of forest residues into fermentable sugars for biofuel production

Block flow diagram of the MSB process. Negative signs on power denotes usage.
Process Contribution to Global Warming. Six main unit of the sugar process are shown with their corresponding GW impacts (measured in CO\textsubscript{2} equivalents/kg).

During life cycle of forest residual sugar, we show that the impact to global warming is within the range of other sugars made via sugar beet and sugar cane:

- S. beet sugar: 0.505 kg CO\textsubscript{2} eq
- NARA sugar: 0.353 kg CO\textsubscript{2} eq
- S. cane sugar: 0.153 kg CO\textsubscript{2} eq

We also show that the impacts on eutrophication were significantly low when compared to beet and cane sugars.
Environmental Assessments
final IPK models
System boundary for the **IPK only** scenario

**Avoided Slash Pile Burn** *(conservative est)*

**Feedstock**  
Forest to Bio-refinery Gate  
1. harvest,  
2. collection  
3. in-woods processing and  
4. transportation

**Screening and Distributn.**  
MBS Pretreatment  
Enzymatic Hydrolysis  
FRS Fermentation and Upgrade  
SSL Fermentation and Upgrade

- IPK Storage *(13.45 dry ton/hr)*
- Excess Electricity to the Grid

- Steam and Electricity Co-generator
- Waste Water Treatment
- Natural Gas
- Various Inputs and Chemicals

**Center for International Trade in Forest Products**
WoTW Contribution Analysis

<table>
<thead>
<tr>
<th>Emissions Reduction (%)</th>
<th>Global warming</th>
<th>Smog</th>
<th>Eutrophication</th>
<th>Carcinogens</th>
<th>Non carcinogens</th>
<th>Respiratory</th>
<th>Ecotoxicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feedstock handling and transportation</td>
<td>-15.4%</td>
<td>-43.6%</td>
<td>-9.6%</td>
<td>-99.3%</td>
<td>-99.1%</td>
<td>-100.0%</td>
<td></td>
</tr>
<tr>
<td>Fermentation and upgrading</td>
<td>-15.4%</td>
<td>-43.6%</td>
<td>-9.6%</td>
<td>-99.3%</td>
<td>-99.1%</td>
<td>-100.0%</td>
<td></td>
</tr>
<tr>
<td>IPK, transportation and combustion</td>
<td>-15.4%</td>
<td>-43.6%</td>
<td>-9.6%</td>
<td>-99.3%</td>
<td>-99.1%</td>
<td>-100.0%</td>
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</tr>
<tr>
<td>Avoided Biomass Burns (50%)</td>
<td>-15.4%</td>
<td>-43.6%</td>
<td>-9.6%</td>
<td>-99.3%</td>
<td>-99.1%</td>
<td>-100.0%</td>
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</tr>
</tbody>
</table>

Global warming | kg CO2 eq | kg O3 eq | kg N eq | CTUh | CTUh | kg PM2.5 eq | CTUe

Smog | Eutrophication | Carcinogens | Non carcinogens | Respiratory | Ecotoxicity
IPK only scenario: Comparative Analysis of NARA Jet vs Fossil jet

<table>
<thead>
<tr>
<th>Environmental Impact</th>
<th>NARA Jet</th>
<th>Fossil Jet</th>
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<tbody>
<tr>
<td>kg CO₂ eq</td>
<td>91.61%</td>
<td>22.07%</td>
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<tr>
<td>kg O₃ eq</td>
<td>94.95%</td>
<td>100%</td>
</tr>
<tr>
<td>kg SO₂ eq</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>kg N eq</td>
<td>-8.55%</td>
<td>80.49%</td>
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<tr>
<td>Emissions</td>
<td>CTUh</td>
<td>CTUh</td>
</tr>
<tr>
<td>Acidification</td>
<td>80.49%</td>
<td>100%</td>
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<tr>
<td>Carcinogenic</td>
<td>100%</td>
<td>-100%</td>
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<tr>
<td>Non-carcinogenic</td>
<td></td>
<td></td>
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<tr>
<td>Respiratory effects</td>
<td></td>
<td></td>
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<tr>
<td>Ecotoxicity</td>
<td></td>
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</tbody>
</table>

- Global warming
- Smog
- Acidification
- Eutrophication
- Carcinogenic
- Non-carcinogenic
- Respiratory effects
- Ecotoxicity

LCA of NARA Bio Jet

LCA of Petroleum Jet

IPK with 50% slash pile burn

Kerosene jet fuel
Incorporating Avoided Impact of Slash Pile Burning

Avoided Slash Pile Burn (conservative est)

Feedstock Forest to Bio-refinery Gate
1. harvest, 2. collection, 3. in-woods processing and 4. transportation

- Screening and Distributn. 91%
- MBS Pretreatment 73%
- Enzymatic Hydrolysis
- FRS Fermentation and Upgrade 78%
- SSL Fermentation and Upgrade 91%
- Lignosulfonate 91% (31.57 dry ton/hr)
- Hog Fuel 9%
- Boiler Steam Generator
- Waste Water Treatment
- Electricity from Grid & Natural Gas
- Various Inputs and Chemicals

Activated Carbon (7.5 dry ton/hr)
IPK Storage (13.45 dry ton/hr)

Various Inputs and Chemicals

NARA
Comparative environmental assessment of Jet-A vs NARA IPK

- Global warming
- Smog
- Acidification
- Eutrophication
- Carcinogenics
- Non carcinogenics
- Respiratory effects
- Ecotoxicity

<table>
<thead>
<tr>
<th>Category</th>
<th>NARA Biojet</th>
<th>NARA BioJet Conservative</th>
<th>Petro-Jet</th>
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<tr>
<td>kg CO2 eq</td>
<td>28%</td>
<td>29%</td>
<td>95%</td>
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<tr>
<td>kg O3 eq</td>
<td>73%</td>
<td>82%</td>
<td>92%</td>
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<tr>
<td>kg SO2 eq</td>
<td>85%</td>
<td>87%</td>
<td>85%</td>
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<tr>
<td>kg N eq</td>
<td>4%</td>
<td>63%</td>
<td>63%</td>
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<tr>
<td>CTUh</td>
<td>63%</td>
<td>63%</td>
<td>-10%</td>
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<tr>
<td>kg PM2.5 eq</td>
<td>5%</td>
<td>19%</td>
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NARA Biojet

USDA

NARA
Geo-Spatial air pollution for slash burn

Baseline PM2.5 Concentrations
(November 7th Western Washington)

μg/m³

- 0.6 - 10
- 10.01 - 15
- 15.01 - 25
- 25.01 - 35.5 Above WHO Guideline
- 35.51 - 55.4 Above EPA "Unhealthy for Sensitive Groups" Guideline
- 55.41 - 150.4 Above US EPA "Unhealthy" Guideline
### People affected by PM2.5 greater than 25 micrograms/cubic meter (µg/m^3)

<table>
<thead>
<tr>
<th>Burn Date</th>
<th>Burn Day</th>
<th>Baseline w/out burns affected people</th>
<th>Baseline with burns affected people</th>
<th>Additional people affected from the added piles burns PM2.5 &gt;25 µg/m^3</th>
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<tbody>
<tr>
<td>Nov. 1</td>
<td>305</td>
<td>245,028</td>
<td>259,650</td>
<td>14,622</td>
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<tr>
<td>Nov. 2</td>
<td>306</td>
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<td>Nov. 3</td>
<td>307</td>
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<td>21</td>
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<td>Nov. 4</td>
<td>308</td>
<td>371,046</td>
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<td>Nov. 5</td>
<td>309</td>
<td>0</td>
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<td>Nov. 6</td>
<td>310</td>
<td>885,655</td>
<td>904,431</td>
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<td>Nov. 7</td>
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<td>3,600</td>
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<td>Nov. 10</td>
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<td>Nov. 27</td>
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<td>386</td>
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<td>Nov. 28</td>
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<td>39,811</td>
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<td>Nov. 29</td>
<td>333</td>
<td>1,430,332</td>
<td>1,460,917</td>
<td>30,585</td>
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</tbody>
</table>

29 Day total number of additional affected people from pile burns= 438,591

A NARA bio-refinery established at the proposed scale will avoid 400,000 person-days of exposure greater than WHO recommended air pollution

3 of the days during the burn period contributed ~80% of the population impact
Concluding remarks

• The comparative analysis of petroleum and residual biomass-based jet fuel reveals 70% - 80% reduction in global warming potential (GWP)
  – This result is significantly better than the US Environmental Protection Agency mandated 60% GWP reduction.

• Important environmental benefits associated with avoided slash pile burns are
  – Improved local air and water quality
  – Beneficial local health impacts

• NARA biojet fuel results in substantial reduction in the ‘carcinogenics’, ‘non carcinogenics’, ‘smog’ and ‘ecotoxicity’ impacts.

The positive local environmental benefits make residual woody biomass a much more environmentally appealing feedstock for bio-energy production than fossil fuel-based alternatives.
Acknowledgement

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Thank you