Design and Economic Evaluations of BioRefinery Operations
85% of total energy consumed by Americans comes from coal, crude oil, and natural gas.

Non-renewable energy sources will eventually diminish.

Coal, crude oil, and natural gas contribute to atmospheric pollution.
Alternative Energy Sources

- Solar – seasonal and inefficient
- Wind – unreliable and inefficient
- Biomass – readily available
**Biomass Methods**

- **Biological** – uses bacterium to break down biomass into the necessary components to form ethanol.
- **Thermochemical** - uses a gasifier in order to take the biomass and create a synthetic gas which is burned for electricity or converted to transportation fuel.
Project Breakdown

- Biomass Selection
- Gasification
- Syngas Purification
- Fisher-Tropsch (FT) Reactor
Biomass Selection

- Types of Biomass
  - Wood
  - Black liquor
  - Corn
  - Animal Waste
    - Swine
    - Poultry
    - Cattle
# Biomass Quantities

<table>
<thead>
<tr>
<th>Livestock category</th>
<th>Tons of manure per animal unit per year as excreted</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fattened cattle</strong></td>
<td>10.59</td>
</tr>
<tr>
<td><strong>Milk cows</strong></td>
<td>15.24</td>
</tr>
<tr>
<td><strong>Other beef and dairy</strong></td>
<td></td>
</tr>
<tr>
<td>Beef calves, from calving to about 500 pounds</td>
<td>11.32</td>
</tr>
<tr>
<td>Beef heifers for replacement herds</td>
<td>12.05</td>
</tr>
<tr>
<td>Beef breeding herds (cows and bulls)</td>
<td>11.50</td>
</tr>
<tr>
<td>Beef stockers and grass fed beef</td>
<td>11.32</td>
</tr>
<tr>
<td>Dairy calves, from calving to about 500 pounds</td>
<td>12.05</td>
</tr>
<tr>
<td>Dairy heifers for replacement herds</td>
<td>12.05</td>
</tr>
<tr>
<td>Dairy stockers and grass fed animals marketed as beef</td>
<td>12.05</td>
</tr>
<tr>
<td><strong>Swine</strong></td>
<td></td>
</tr>
<tr>
<td>Breeding hogs</td>
<td>6.11</td>
</tr>
<tr>
<td>Hogs for slaughter</td>
<td>14.69</td>
</tr>
<tr>
<td><strong>Poultry</strong></td>
<td></td>
</tr>
<tr>
<td>Chickens, layers</td>
<td>11.45</td>
</tr>
<tr>
<td>Chickens, pullets</td>
<td>8.32</td>
</tr>
<tr>
<td>Chickens, broilers</td>
<td>14.97</td>
</tr>
<tr>
<td>Turkeys for breeding</td>
<td>9.12</td>
</tr>
<tr>
<td>Turkeys for slaughter</td>
<td>8.18</td>
</tr>
</tbody>
</table>

**Total manure**

108.17

20.80

52.04

20.80

52.04
Biomass Location

Map of the United States showing the distribution of animal units per county or combined counties, with varying shades indicating different ranges of units.
## Manure Availability

### South Western Wisconsin

<table>
<thead>
<tr>
<th>CATTLE</th>
<th>animal units (AU) per county</th>
<th>manure per AU</th>
<th>tons manure per county per year</th>
<th>dried manure per county per year</th>
<th>availability per day assuming 260 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Confined fattened cattle</td>
<td>5000</td>
<td>10.59</td>
<td>52950</td>
<td>6354</td>
<td>24.4</td>
</tr>
<tr>
<td>Confined milk cows</td>
<td>5000</td>
<td>15.24</td>
<td>76200</td>
<td>9144</td>
<td>35.2</td>
</tr>
<tr>
<td>Other Beef and dairy cattle</td>
<td>5000</td>
<td>11.5</td>
<td>57500</td>
<td>6900</td>
<td>26.5</td>
</tr>
<tr>
<td>Totals</td>
<td>15000</td>
<td>37.33</td>
<td>186650</td>
<td>22398</td>
<td>86.1</td>
</tr>
</tbody>
</table>
Gasification

- A process where a complex carbon based material is partially combusted with limited oxygen to create an energy rich gaseous fuel source.
- Syngas can be directly burned as a fuel source or can be further modified into liquid based transportation fuels.
- Types of Gasifiers
  - Steam Reforming
  - Fixed Bed
  - Fluidized Bed
Cow Manure Gasification

- **Slagging:**
  - Temperature 1350-1400°C
  - Syngas:
    - 26.9% molar carbon monoxide
    - 6.1% carbon dioxide
    - 17.1% hydrogen
    - 49.9% nitrogen

- **Non-slagging:**
  - Temperature 800-900°C
  - Syngas:
    - 30.2% molar carbon monoxide
    - 5.5% carbon dioxide
    - 25.7% hydrogen
    - 38.6% nitrogen

- Design – Fluidized Bed Single Throat Updraft Style
Gasification Design

Pretreatment and Transportation

Gasification
Syngas Purification

- Ash removal
- Hydrogen Sulfide (H2S) removal
- Water-Gas Shift (WGS) reaction:

\[
\text{CO} + \text{H}_2\text{O} \leftrightarrow \text{CO}_2 + \text{H}_2
\]
In the FT Reactor Hydrogen and Carbon Monoxide combine to form a variety of Hydrocarbons ranging from C1 to C30.

1. Paraffins
   
   \[(2n+1)\text{H}_2+n\text{CO} \rightarrow \text{C}_n\text{H}_{2n+2}+n\text{H}_2\text{O}\]

2. Olefins
   
   \[2\text{nH}_2+n\text{CO} \rightarrow \text{C}_n\text{H}_{2n}+n\text{H}_2\text{O}\]

3. Water-gas shift
   
   \[\text{CO}+\text{H}_2\text{O} \rightarrow \text{CO}_2+\text{H}_2\]
Different types of reactors

- There are currently four different types of FT reactors in commercial use:
  - Sasol Circulating Fluidized Bed Reactor
  - Sasol Advanced Synthol Reactor
  - Tubular Fixed Bed reactor
  - Sasol Slurry Phase Distillate Reactor.

- The first two reactors are operated at high temperatures (320°C - 350°C) and are thus called HTFT reactors.

- The latter two are operated at lower temperatures (220°C - 250°C) and are called LTFT reactors.
For our model we assumed one overall reaction. The iron catalyst was chosen based on its low cost, low operating temperature, ability to perform WGS.

The product distribution in mole percent was based on the carbon number and experimental data of the ratios of alkenes and alcohols to alkanes.
## Preliminary Costing

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Purchase Cost</td>
<td>$78,043,378.</td>
</tr>
<tr>
<td>Bare Module Cost for Equipment/Installation</td>
<td>$164,692,757.</td>
</tr>
<tr>
<td>Direct Permanent Investment</td>
<td>$321,150,876.</td>
</tr>
<tr>
<td>Total Permanent Investment</td>
<td>$481,726,314.</td>
</tr>
<tr>
<td>Working Capital</td>
<td>$72,258,947.</td>
</tr>
<tr>
<td><strong>Total Capital Investment</strong></td>
<td><strong>$553,985,261</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Capital Investment</td>
<td>$553,985,262</td>
</tr>
<tr>
<td>years</td>
<td>10</td>
</tr>
<tr>
<td>payment per day</td>
<td>$196,670</td>
</tr>
<tr>
<td>Biodiesel Production</td>
<td>8007.6</td>
</tr>
<tr>
<td>$ cost per gallon</td>
<td>$25</td>
</tr>
</tbody>
</table>
Process is feasible

Project needs further research to actually define the economic viability

With the increase of cost of oil, the process will become more economically viable

This process provides a very attractive approach to production of renewable fuels similar to existing oil, coal, and natural gas derivatives.
More accurate gasifier model.

FT reactor section modeled in Hysys

More in depth FT reactor model.

A further refining of the specific type of fuel that will be produced

More comprehensive cost analysis

– Comparison to simply burning the syngas
Acknowledgements

- Dr. Jeffrey Zalc
  – BP
- Andy Aden
  – NREL
- Doug Rundell
  – BP

- Dr. Javad Abbasian
  – IIT
- Dr. Suresh Babu
  – GTI
- Noel Gollehen
  – DOA
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