A Mobile Pyrolyzer for Converting Agricultural and Forestry Residues into Liquid Bio-Oil and Bio-Char

Franco Berruti, Cedric Briens, Federico Berruti, Lorenzo Ferrante

Institute for Chemicals and Fuels from Alternative Resources (ICFAR)
Faculty of Engineering, The University of Western Ontario
London, Ontario N6A 5B9 – Canada
Motivation: why convert biomass?

- Alternative to fossil fuels
- Energy independence
- Global demand for:
  - alternative sources of renewable carbon dioxide neutral (or negative) energy and for green chemicals.
  - increased utilization of agricultural products, co-products and residues.
  - reduced emissions from combustion or composting of residues from agricultural and forestry materials.

Issues with biomass conversion

- Competition with food use.
- Requires land, energy, fertilizer.
- Fertilizer and pesticides bring extra pollution.
- Processing requires energy.
- Low energy density.
- Expensive and polluting transportation to a central processing location.
- Seasonal.
Residual Forestry Biomass

- Low value, bulky biomass is commonly left on site and flared due to cost of transport
- Drop-and-leave is a fire hazard
- Piling and burning is costly, releases gaseous pollutants, and wastes energy
But.....Biomass Removal

- Productivity may decline with excessive removal
- Sustainable bioenergy means avoiding nutrient removal!
Residual Agricultural Biomass

- Available only during a short time of the year
- Often source of pollution and diseases
- Often required landfilling
- Composting generates CO$_2$ and methane
Residual Agricultural Biomass

- ...burning is not an option!!!
How can we handle biomass?

- **Option 1:** Gathering and transportation of low energy density and bulky biomass

- **Option 2:** Distributed “oil wells”

  - Gathering and transportation of high energy density bio-oil
  - Bio-char
Our Approach

- **Small Scale In-Situ** Conversion of Agricultural Crops, Residues & other Biomass sources into Bio-Oil via Fast Pyrolysis.

  - Self-sufficient in energy
  - No competition with food
  - Compact, mobile, easy to operate: No need to transport biomass
  - Reduces chemical fertilizers
  - Heat Recovery
  - 20%
  - 60%
  - 20%
  - 60%

Agricultural Waste → Pyrolysis Unit → Bio-Oil → Solid Residue → Gases → Fuels → Food Additives → Pharmaceuticals → Fertilizer
Agri-Therm unit: Mobile Pyrolysis

- 10 t/day of biomass feed
- Inexpensive
- Easy to Operate
- Easy to Maintain
- Single Person Operation
- Single User or Cooperative
Pyrolysis

- Chemical decomposition of any organic materials in the absence of oxygen

- Products:
  - Gases (non-condensable vapors)
  - Liquid Bio-oils (condensable vapors)
  - Solids: char and ash
Integrated Biorefinery

Distributed Production “Oil Well”

Centralized Processing “Refinery”

Mobile Pyrolyzer
In-situ processing

Crude
Bio-Oil

INTEGRATED BIOREFINERY

Bio-Char

MATERIALS

ENERGY

CHEMICALS

FUELS

Food waste, agro residues, non-food crops, grasses
Agri-Therm unit: Mobile Pyrolysis
Mobile Pyrolysis Unit: Reactor

- Pyrolysis reactor
- Burner
- Lift tube
- Pyrolysis reactor
New patented technology

- Fluidized beds of sand
- Annulus for pyrolysis
- Central furnace for combustion of gases
  - Provides the energy needed for pyrolysis
  - Fuels:
    - Propane for pre-heating,
    - recycled pyrolysis gases in steady state conditions.
- Lift tubes used to increase heat transfer
  - Experiments: 16 tubes increase heat transferred by 1 order of magnitude
The Plant on the Trailer
(8 m x 2.4 m)
The Reactor System
Opportunities

Wine Grape

Wine

Grape Skins and Seeds
12.2 million tonnes worldwide

Corn

Bio ethanol

Dried Distiller’s Grains
35 million tonnes in North America

Sugarcane

Sugarcane Juice

Sugarcane Field Residues and Bagasse
800 million tonnes worldwide

Forest Resources

Pulp and Paper

Forestry Residue
Several hundred million tonnes worldwide
Residues of Bio-Diesel Industry

Using biomass residues that are waste products from already existing processes

Palm tree’s fruit harvested for palm oil production

Produces empty fruit bunches which are a bio-residual waste

Can be converted to a high energy bio-oil
Feedstocks

- **Canada**
  - Forestry residues
  - Tobacco
  - Hemp
  - Distillers’ grains & corn stover
  - Chicken litter
  - Apple pomace
  - Grape residues
  - Flax straw
  - Food waste
  - Coffee grounds
  - Wastewater treatment plant sludge

- **Rest of world**
  - Sugarcane plant and bagasse
  - Rice straw
  - Coffee husks
Bio-oil Yields from Dry Distillers’ Grains versus Temperature at 2 different vapour residence times

![Graph showing Bio-Oil Liquid Yield, Bio-char Yield, and Gas Yield versus Pyrolysis Temperature in °C. The graph includes data points for two vapour residence times: 2s and 5s.]
Experimental Results

Product Yields: Liquid

Liquid Bio-oil Yields of Different Biomass Resources
Residence Time: 5 seconds

<table>
<thead>
<tr>
<th>Biomass Resource</th>
<th>Pyrolysis Temperature, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDGS</td>
<td>400 450 500 550 600</td>
</tr>
<tr>
<td>Forestry Residue</td>
<td>25 30 35 40 45 50</td>
</tr>
<tr>
<td>Sugar cane Bagasse</td>
<td>35 37 38 40 42 45</td>
</tr>
<tr>
<td>Grape Residue</td>
<td>40 45 50 55 60 65</td>
</tr>
</tbody>
</table>

Graph showing liquid bio-oil yield (%) vs. pyrolysis temperature (°C) for different biomass resources.
Experimental Results

Product Yields: Solid Char

Solid Char Yields of Different Biomass Resources
Residence Time: 5 seconds

Solid Char Yield, %

Grape Residue
Sugarcane Bagasse
DDGS
Forestry Residue

Pyrolysis Temperature, °C
Experimental Results

Gas Yields of Different Biomass Resources
Residence Time: 5 seconds

<table>
<thead>
<tr>
<th>Pyrolysis Temperature, °C</th>
<th>Grape Residue</th>
<th>Sugarcane Bagasse</th>
<th>Forestry Residue</th>
<th>DDGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>5</td>
<td>15</td>
<td>25</td>
<td>40</td>
</tr>
<tr>
<td>450</td>
<td>10</td>
<td>20</td>
<td>30</td>
<td>45</td>
</tr>
<tr>
<td>500</td>
<td>15</td>
<td>25</td>
<td>35</td>
<td>50</td>
</tr>
<tr>
<td>550</td>
<td>20</td>
<td>30</td>
<td>40</td>
<td>55</td>
</tr>
<tr>
<td>600</td>
<td>25</td>
<td>35</td>
<td>45</td>
<td>60</td>
</tr>
</tbody>
</table>
Self sustainability: Lab scale testing

Grape skins, energy balance at different reactor temperatures (5s vapor residence time, 1 kg/hr feed rate)
(-●--) Heat required for pyrolysis; (■■) energy contained in the product gas (■■■) energy contained in the bio-oil


Possible uses of bio-oil

- Pharmaceuticals and Nutraceuticals
- Food Additives
- Chemicals
- Pesticides
- Fuel
### Valuable biochemicals in bio-oil

<table>
<thead>
<tr>
<th>Chemical</th>
<th>From</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smoke flavor</td>
<td>Wood</td>
</tr>
<tr>
<td>Browning agents</td>
<td>Sucrose, cellulose</td>
</tr>
<tr>
<td>Paclitaxel (taxol)</td>
<td>Yew, bark, twigs, needles</td>
</tr>
<tr>
<td>Betulin</td>
<td>Birch bark</td>
</tr>
<tr>
<td>Maltol</td>
<td>Larch bark, Pine and balsam fir needles</td>
</tr>
<tr>
<td>Quinine</td>
<td>Calisaya bark</td>
</tr>
<tr>
<td>Salicylic acid</td>
<td>Sweet birch bark</td>
</tr>
<tr>
<td>Nicotine</td>
<td>Tobacco leaves</td>
</tr>
<tr>
<td>Caffeine</td>
<td>Coffee waste</td>
</tr>
</tbody>
</table>

Many more chemicals will be identified in the future.
Bio-oils produced by Colorado potato beetles

Tobacco waste
Both nicotinic and non-nicotinic fractions are effective

Control

Coffee grounds
Fuel

• Research on making bio-oil compatible with oil refinery streams:
  • Catalytic hydrogenation to remove oxygen
    • Suitable catalyst?
    • If hydrogen comes from natural gas, nearly 50% of the energy content of the upgraded bio-oil will come from a fossil fuel
    • Can hydrogen be generated by reforming low value aqueous bio-oil fractions?
  
• Research on increasing stability and heating value and reducing acidity
Pyrolysis as a carbon sequestration process...