Producing Liquid Fuels from Pyrolysis of Woody Biomass: Aspen and SimaPro LCA

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Fast pyrolysis:

Bio-oil is dark brown liquid which is an emulsion comprised of a complex mixture of organic compounds and water.

Fast Pyrolysis

Biomass → 400 – 650 °C → Absence of O₂

- Moisture content < 10%
- Particles size < 3mm
- Residence time: 0.5 - 2 Sec

Syngas + Bio-oil vapors → Cool and condense

Liquid (Bio-oil) → Solid products (char)
Techno economic analyses:

- Several researchers have performed techno-economic analyses for pyrolysis oil production.

- Costs to produce bio-oil vary depending on the following factors.
  - Feedstock, moisture content, chip size, plant scale, etc.

- Mullaney and Farage (2002) estimated that the bio-oil cost for 110-gt/d facility was $1.21/gal

- For 440-gt/d facility cost was $0.89/gal or $0.16/MMBtu, assuming feed feedstock cost $18 gt

- Ringer et al. (2007) developed an Aspen model of 540-dt/d pyrolysis facility, and based on $30/dt cost was $1.12, LHV
Life cycle assessment (LCA):

• Several techno economic analyses have been performed to determine the cost of producing fast pyrolysis bio-oil.

• However, no LCA analyses have been performed.

Objective

• Perform an LCA analysis for the production of bio-oil
Method and scope:

• Ringer et al. (2006) developed ASPEN-Plus® model at 540 dt/d for bio-oil production was modified to 2000 dt/d scale with feedstock cost increased from $30 to $50/dt.

• Mass and energy balance data from the adapted Ringer et al. Aspen for LCA analysis.

• Biomass collection for harvesting whole trees, chipping and loading feedstock were combined with Aspen process modeling to develop cradle to grave impacts for bio-oil production.

• LCA analysis to estimate environmental impacts in the form of emissions, fossil fuel use, resource consumption and global warming impacts were provided by SimaPro 7.
Production of bio-oil:

- Production of bio-oil was divided into five unit processes for Aspen analysis
  1. Feedstock preparation and drying.
  2. Pyrolysis reactor
  3. Quench condenser
  4. Char recovery and
  5. Furnace process (heat/energy generation)
Bio-oil Aspen model:

1. FEED HANDLING & DRYING
   - Wood chips @ 100% moisture

2. PYROLYSIS
   - Dried wood chips @ 7.5% moisture
   - Bio-oil vapors and syngas
   - Heat from char furnace

3. QUENCH
   - Bio-oil & syngas

4. RECOVERY
   - syngas
   - Ash - landfill
   - Hot air from cooling the product vapors

5. CHAR FURNACE
   - Char

Utilities
- Condenser cooling water to utilities
- Steam and electricity

BURNER / BOILER
- Steam turbine
- GENSET
- ELECTRICITY
Production of bio-oil:

• Cradle-to-grave system boundary for the production of bio-oil
  • Processes for harvesting, chipping and loading biomass onto trucks; transportation to pyrolysis facility
  • Production of bio-oil with heat and energy generation accounting for associated emissions
  • Combustion of bio-oil to produce heat
Cradle-to-grave SimaPro system boundary:

- Forest operations
- Whole Tree Chipping
- Dryer
- Pyrolysis Reactor
- Quench
- Recovery
- Furnace

Material flows:
- Heat flows
- Electricity flows
- Bio-oil

- Wood Chips, 100% MC
- Chips, 7.5% MC

Bio-oil combusted in industrial boiler

Air emissions
Water emissions
Solid waste (ash)

Electricity
Assumptions for the SimaPro model:

- Feedstocks obtained from whole tree chipping (southern pine forests) and include bark and 50% water; chips were dried to 7.5% MC.

- Emissions associated with the combustion of syngas were equivalent to the combustion of natural gas.

- All heat energy and electricity necessary for the production of the bio-oil was self-generated as indicated by the Aspen model results.

- HHV for bio-oil was assumed to be 18 MJ/kg compared to 45.5 MJ/kg for refined fuel oil (RFO); bio-oil density was assumed to be 10 lb/gal or 1.2 kg/L.
Assumptions, cont’d:

- Life cycle impact assessments (LCIA) were performed using the Tool for the reduction and assessment of chemical and other environmental impacts (TRACI 2)

- TRACI is a LCIA methodology developed by US EPA specifically for the US for input parameters consistent with US locations

- Cradle-to-grave impact assessment comparisons were conducted between bio-oil and RFO

- Aspen values for the recovery efficiency of bio-oil from oven-dry wood chips was 59.7%. Other yields for char, ash and syngas were 15.3, 0.9 and 13.0 %, respectively
Cradle-to-grave energy requirement:

- Cradle-to-grave energy requirement for bio-oil and RFO for each life cycle stage (performed only at pyrolysis facility or refinery; harvesting and crude oil extraction not included)
Cradle-to-grave global warming:

- Cradle-to-grave global warming potential for bio-oil and RFO for each life cycle stage.

![Bar chart showing global warming potential for bio-oil and RFO](chart.png)

**Global Warming Potential (kg CO₂ eq./MJ)**

- CO₂ Absorption
- Transport
- Fuel Combustion
- Fuel Production
- Extraction

**Biomass utilization of CO₂**

**Bio-oil**
CO₂ emissions:

- CO₂ emissions calculated from global warming potential for bio-oil and RFO.

![Chart showing CO₂ emissions comparison between bio-oil and RFO](chart.png)

- Bio-oil emissions: 0.190 kg CO₂/MJ
- Biomass absorption: 0.0323 kg CO₂/MJ
- Bio-oil emissions (net): 0.158 kg CO₂/MJ
- RFO emissions: 0.115 kg CO₂/MJ
- Replacing RFO emissions by bio-oil emissions (net): 0.083 kg CO₂/MJ
Summary:

- A 2000 dt/d Aspen model was adapted to simulate the processes and costs to produce bio-oil.

- Life cycle inventory for production of bio-oil during pyrolysis was developed with Simapro to analyze resource use and energy consumption inputs and emissions to air, water and land.

- Bio-oil from pine chips showed much improved life cycle GHG emissions compared to RFO.

- Bio-oil has near carbon neutrality.

- Substituting bio-oil for RFO reduces CO₂ emissions by 0.083 kg CO₂ /MJ of fuel consumption.
Summary, cont’d:

- Energy required for bio-oil production used 89% of the total energy required from self generated fuel.
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