Wood Combustion Systems in Alberta

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Thermochemical Processing Team Lead
Vegreville, Alberta
Alberta Innovates Family

- Focusses on economic sectors where Alberta has a competitive advantage:
  - Energy: Oil sands, oil and gas, pipelines, tight oil and fracking
  - Carbon Conversion, Capture and Storage
  - Environmental Monitoring and Management
  - Industrial Sensors
  - Advanced Materials and Manufacturing
  - Sustainable Resources: agriculture and forestry
  - Health Research and Technologies
AITF was established on January 1, 2010, when four organizations merged (Alberta Ingenuity, Alberta Research Council, iCORE and nanoAlberta).
Edmonton (Millwoods)

*520 world class scientists, engineers, technicians, and business experts*

*1 million sq ft of bench, pilot-scale and demonstration facilities*

*1000+ industry clients per year*

*90+ years of operation*

*$ 75 M fee for service*
AITF Thermochemical Expertise

- **Vegreville Location**
  - Don Harfield, P. Eng., P.M.P., Team Lead
  - Ataullah Khan, Ph.D., Pyrolysis, Activated Carbon & Catalyst Research Specialist
  - Jin Tak, P. Eng, Combustion and Chemical Engineer
  - Tim Anderson, Operations & Lab Supervisor

- **Millwoods Location**
  - Robert Wray, P. Eng., Wood Fibre & Torrefaction Specialist
  - Stephanie Trottier, P. Eng, Gasification Specialist
  - Laura McIlveen, P.Eng., Forestry Technical Specialist
Related Technical Expertise

- **Wood Combustion**
  - Lab & Pilot Scale Combustion Testing Facilities
  - Demonstration Scale Facilities (Strathcona, Camrose)
  - Client Evaluations (i.e. CHP with Organic Rankine Cycle)

- **Torrefaction**
  - Torrefied Wood Pellets & Binders

- **Slow Pyrolysis**
  - Lab, Bench, Pilot and Demonstration Scale Facilities
  - Biochar Production Facilities
  - Alberta Biochar Initiative (ABI) Founder

- **Gasification**
  - Community Power 35kw Demo Scale Facility
Related Technical Expertise

- Hydrothermal Carbonization
  - Wet Bio-Coal Conversion
  - Municipal Interest for Wet Biomass or Pathogen Containing
- Slow Release Fertilizers
- Carbon Carrier for Specialty Ag Formulations
- Recent Feasibility Studies
  - Sawmill CHP (Gasification, ORC – 3 MW)
  - Municipal Solid Waste Strategies
  - Biomass Products (Animal Bedding)
- Performance Validation & Emissions Testing
- Process Design & Mass Energy Balance Evaluations
The Composition of Wood

Thermal Stability Regimes
Biomass is a renewable, **carbon neutral GHG**, sustainable solid fuel suitable for energy generation in the form of heat and for electrical cogeneration.

**Commercially available technologies** include:

- Conventional Combustion (heat only via exchangers)
- Conventional Combustion (heat with power generation)
  - Steam powered electrical generators and steam heat
  - Organic Rankine Cycle powered electrical generators and heat
- Gasification Combustion with ORC Electrical Generation
- Anaerobic Digestion Gas Engine Power Generation
Biomass Combustion System – Sh. Park

**Centre in the Park Energy System**

- **Plant Capacity** (Nat Gas 5 MW)
- **Combustion Heat Base Load** 0.75 MW
- **Advanced Combustion System**
  - Integrated with Community Energy System
  - Secondary Air and Flue Gas Recirculation
  - Moving Ash Grate
  - Multi-Cyclone Ash Removal
  - Electro-static Precipitator
  - Continuous Opacity Meter

**Funding contribution by:**
- Western Economic Diversification Canada ($1.5 million)
- Federation of Canadian Municipalities ($350k)
Since 2007, the Strathcona County Community Energy Centre has supplied 9 community buildings (including 3 private condominiums) using natural gas boilers generating 9 MW thermal heat capacity.

Biomass combustion heat was added to provide base load heating to existing, mitigate GHGs, and demonstrate clean bio-energy.

The Lambion Energy Solutions boiler was installed to generate 0.75 MW with advanced secondary air, moving grate, and turndown capacity to 60%.

The biomass system includes feedstock receiving & conveyor handling, a combustion boiler, and emissions control equipment.
CITP Biomass Combustion Module
CITP Biomass System Photos

Combustion Stack

Chips Inside Bin

Chip Transfer

Opacity Meter

Emissions Monitoring Console

Temporary Chip Storage
Chemical Properties of the Wood Chips and Wood Pellets

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Moisture Content on a Wet Basis (wt.%)</th>
<th>Analyses on a Dry Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C (wt.%)</td>
<td>H (wt.%)</td>
</tr>
<tr>
<td>Wood Chips Used for Tests on Oct 29 and 30, 2015</td>
<td>10.89</td>
<td>47.06</td>
</tr>
<tr>
<td>Wood Pellets Used for Tests on Nov 12 and 13, 2015</td>
<td>7.10</td>
<td>48.52</td>
</tr>
</tbody>
</table>
Wood chips and pellets do not typically create clinkers in the combustion boiler because the combustion temperature is below the ash fusion temperature at which point the initial deformation of the ash occurs.

For clinker free operation, wood feedstocks with potential high mineral content should be tested for ash fusion temperature before using.
## Energy Efficiency of the Combustion Module

<table>
<thead>
<tr>
<th>Test ID</th>
<th>Date</th>
<th>Fuel Type</th>
<th>Energy Efficiency on an Output Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total E (kW/hr) Generated</td>
</tr>
<tr>
<td>#1</td>
<td>2015Oct29</td>
<td>Wood Chips</td>
<td>929</td>
</tr>
<tr>
<td>#4</td>
<td>2015Nov12</td>
<td>Wood pellets</td>
<td>902</td>
</tr>
<tr>
<td>#6</td>
<td>2015Nov13</td>
<td>Wood Pellets</td>
<td>826</td>
</tr>
</tbody>
</table>
Excess air control can improve combustion efficiency. In this case, controlling to an air/fuel ratio of 1.9 could improve the energy efficiency to higher than 68%.
Performance Testing Findings

- All tests complied with Alberta Environment Regulations for Urban Requirements using a multi-cyclone ash collector.
- The installed Electrostatic Precipitator could further reduce the particulate matter emissions.
- The installed opacity meter could provide ongoing emissions information during normal operations.
- The biomass combustion system operated well using both wood chips and wood pellets.
- The materials feed handing system was augmented with a temporary auger system to ensure reliable operations during the testing period.
- The biomass combustion boiler performed with 62% to 67% energy efficiency with both wood chips and wood pellets.
Biomass Combustion System - Camrose

Camrose County Administration Office Complex

- Heating System (Roof Top + Wood Heat)
- Combustion Heat Base Load 135 kW
- Advanced Combustion System
  - Integrated with Office Heating System
  - Rotary Combustion Chamber
  - Secondary Air
  - Moving Ash Grate
  - Flue Gas Recirculation

KOB 150 Biomass Boiler

Biomass Storage Bin
Camrose County has been operating a KOB Pyrot 150 combustion heating system to supplement their natural gas heating system since 2008 and heats a combined floor area of 2,365 square meters of administration offices and public works shop & garage.

The contribution of the biomass heating system is approximately 10% of the total heat load over the year.
Combustion Feedstock Handling

CHIP STORAGE

SIDE VIEW

CHIP HANDLING

CHIPPED WOOD

CHIP HOPPER

VIEW FROM NORTH
Stoker Combustor (KOB)

1. Feed auger (with light barrier)
2. Moving grate
3. Primary air control valve
4. Flue gas recirculation system
5. Ignition fan
6. Deashing system
7. Secondary air control valve with rotation blower
8. Rotary combustion chamber
9. Triple-pass heat exchanger
10. Safety heat exchanger
11. Pneumatic pipe cleaning system
12. Induced draft fan

Tests by TÜV Munich

VIETSMANN
climate of innovation
Combustion Feedstock

- The woody biomass feedstock is typically chopped brush from ATCO right-of-way clearings and chopped willow from the Ohaton willow plantation located at the waste water treatment lagoon.

- Both these sources of biomass are cut and chopped into segments of approximately 2 to 3” length and stored for drying at either the County Administration location or the County Facilities location.

- For this combustion trial, the ATCO right-of-way clearings wood was used as it was much drier (27% moisture content) than the fresh cut willow (approx. 50% moisture content) from Whitecourt.
Impact of Moisture on Wood Energy

Wood Heating Values Versus Moisture Content

- Normal Operating Zone – 10 to 20%
- Limit of Operability – 35%
- Green Wood – 50%
Impact of Moisture on Heat Output

Thermal Heat Output Versus Moisture Content

- **Strathcona County**
- **City of Calgary**
- **Camrose County**

- **Normal Operating Zone** – 10 to 20%
- **Limit of Operability** – 35%
- **Green Wood** – 50%
Due to limited temperature and flow rate information, the combustion performance results were evaluated based on the following:

- **Manufacturer supplied information**
- **Development and interpretation** of the process flow information
- **Feedstock properties from lab analyses** including heating value of 19.5 MJ/kg (dry condition) and adjusting to actual moisture content
- **Mass and energy balance calculations** were based on the above properties
Combustion Performance Results

• Based on 1) the information gained during the operation on April 22, 2015, 2) information provided by Fink Machine (supplier of the KOB Pyrot system) and 3) the KOB data sheets, the output of the system is approx. 91 kW which compares to 125 kW rated continuous capacity of the unit due to the 27% moisture content of the wood.

• The continuous rated capacity of the unit was assumed to be based on an overall design efficiency of 70% (typical of this type of biomass combustion system) and dry wood feedstock.
Study Conclusions

• **Utilization of harvested willow is an effective solid biofuel** for heating of commercial buildings, however forced air ambient drying the freshly chopped wood takes significant time during the summer to prepare the wood for the winter heating season.

• **Optimization of the wood combustion system** has occurred since initial installation through operational experience.

• **The performance testing** during this project identified opportunities for further enhancement.
The biomass combustion heating system performance could be improved by:

- **Drying the wood feedstock** to less than 20% moisture content
- **Increasing the system uptime** by increasing the ready supply of dry wood feedstock
- **Screening of the oversize chopped wood** to prevent oversize material from plugging the feedstock transfer augers into the storage bin and the combustion boiler
- **Piping changes to improve heat transfer** through the glycol heat exchange system
Enhancements to the system and performance tracking could improve effectiveness:

- **Installation of thermocouples and heat meters** (including a flow meter and cumulative heat transfer) at the heat exchanger and the KOB accumulator to monitor operating conditions and ensure optimum performance.

- **Daily checks on the operating temperatures and flow rates** to track system performance and aid in troubleshooting when heating system problems arise.

- **Monthly comparison of the combustion heating system output** from the cumulative readings of the heat meters.
Fink Machine KOB Boiler Installations (72 Installations in Canada and US)

• Alberta (5 Systems)
  • Edmonton – Madsen Custom Cabinets (Pyrot 540 – 2003)
  • Camrose – County Admin Office (Pyrot 150)

• North West Territories (20 Systems)
  • Yellowknife – Airport (Pyrot 540 – 2015)
  • Various – Nine Schools (Pyrot 540, 720, 950)
  • Yellowknife - Municipal/ Commercial (Pyrot 300, 400, 720, 950)

• Yukon (1 System)
  • Whitehorse – Corrections Centre (Pyrot 950)

• British Columbia (25 Systems)
  • Fink District Energy (Pyrot 540)
  • Lake Cowichan Secondary School – (Pyrot 150)

• Prince Edward Island (11 Systems)
• United States (10 Systems)
Torrefaction and Biochar

The following slides are supplemental to the presentation and are provided for follow up consideration.
Products: Torrefaction and Biochar

- **Torrefaction Process and Product**
  - Heat Treatment; 250 – 350 °C
  - Brittle; Easy Grindability; Hydrophobic
  - Increases Energy Density (typically from 18 to 22 GJ/t)
  - Used as a Solid Fuel, i.e., Bio-Coal

- **Biochar Process and Product**
  - Carbon-rich Solid
  - Produced by Slow Pyrolysis (starved oxygen)
  - Similar to charcoal, except it is **used for soil amendment purposes**.
  - Environmental Applications for cleaning water, reducing odor, adsorbing toxic pollutants
  - Excess Heat Suitable for Co-Gen on Larger Facilities
Comparison of Torrefaction Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Wood</th>
<th>Wood pellets</th>
<th>Torrefaction pellets</th>
<th>Charcoal</th>
<th>Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content (% wt)</td>
<td>30 – 45</td>
<td>7 – 10</td>
<td>1 – 5</td>
<td>1 – 5</td>
<td>10 – 15</td>
</tr>
<tr>
<td>Lower heating value (MJ/kg)</td>
<td>9 – 12</td>
<td>15 - 18</td>
<td>20 – 24</td>
<td>30 – 32</td>
<td>23 – 28</td>
</tr>
<tr>
<td>Volatile matter (% db)</td>
<td>70 – 75</td>
<td>70 – 75</td>
<td>55 – 65</td>
<td>10 – 12</td>
<td>15 – 30</td>
</tr>
<tr>
<td>Density (kg/l) Bulk</td>
<td>0.2 – 0.25</td>
<td>0.55 – 0.75</td>
<td>0.75 – 0.85</td>
<td>~ 0.20</td>
<td>0.8 – 0.85</td>
</tr>
<tr>
<td>Energy density (GJ/m³) (bulk)</td>
<td>2.0 – 3.0</td>
<td>7.5 – 10.4</td>
<td>15.0 – 18.7</td>
<td>6 – 6.4</td>
<td>18.4 – 23.8</td>
</tr>
<tr>
<td>Dust</td>
<td>Average</td>
<td>Limited</td>
<td>Limited</td>
<td>High</td>
<td>Limited</td>
</tr>
<tr>
<td>Hydrosophic properties</td>
<td>hydrophylllic</td>
<td>hydrophilic</td>
<td>hydrophobic</td>
<td>hydrophobic</td>
<td>hydrophobic</td>
</tr>
<tr>
<td>Biological degradation</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Grindability</td>
<td>Poor</td>
<td>Poor</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Handling</td>
<td>Special</td>
<td>Special</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Quality variability</td>
<td>High</td>
<td>Limited</td>
<td>Limited</td>
<td>Limited</td>
<td>Limited</td>
</tr>
</tbody>
</table>

Like coffee, degree of torrefaction can be considered as light, medium and dark roast.
Biochar: Carbon-rich solid produced by low-temperature (450 to 550º C) slow pyrolysis of biomass under partial or complete exclusion of oxygen.
What is Biochar?

- **Biochar is a carbon-rich solid** produced by pyrolysis of biomass under partial or complete exclusion of oxygen. The process converts carbon in biomass into ‘recalcitrant’ carbon which resists degradation and can sequester carbon in soil for centuries.

- **Biochar** is identical to charcoal, except it is primarily used for soil amendment purposes. However, it has myriads of applications like cleaning water, reducing odor, adsorbing toxic pollutants on soil to name a few.
Biochar Properties

- Enhances water retention
- Improves soil aeration and microbial activity
- Reduces nutrient leaching (water quality impacts) due to high Cation Exchange Capacity (CEC)
- Captures organic pollutants due to high adsorptive capacity, making them less bioavailable
- Reduces chemical fertilizer requirements by retaining N and P
- Contains soluble salts of Ca, Mg and K carbonates, can effectively amend lime saline/sodic soil
Where Can We Use Biochar?

- Marginal and Industrial Land Reclamation
- **Waste Water Treatment** (oil sands tailings ponds)
- **Emissions Control** (air filtration)
- **Lake Restoration** (toxic algae control)
- **Specialty Carbons** (food processing)

Soil remediation in NWT

*Biochar – Chicken Soup for the Soil!*
Where Can We Use Biochar?

- Greenhouse/Hydroponic Growth Media
- Agricultural Soil Amelioration
- Horticultural Soil Amendment
- Slow Release Fertilizers
- Biochar Product Blends
Figure 5. Correlation of the oxygen to carbon (O:C) molar ratio and predicted half-life of synthetic biochar in various laboratory incubations from the literature studies presented in Table 2 (n = 35). The sole exception to these divisions were biochars from Hamer et al.; shown in the rectangle [94].
Alberta Biochar Initiative (ABI)

- Pre-Commercial Demonstration Project (3 Yr)
- Initially Federally Funded by WD – $ 900k
- Partners: AITF, Lakeland College, Industry
- Two Mobile Demo Units (0.5 tonne/day biochar output)
- Carbon Sequestration and GHG Mitigation
- Biochar Network & Partnership Engagement
- Successfully Concluded Funding Period June 2015
- Continuing With Partners to Commercialize Biochar
CFIA Approval – Biochar!!!

- CFIA considers ‘Biochar’ as a supplement under the Federal Fertilizer Act and requires specific registration prior to sale/import or prior to environmental release in Canada.
- **Air Terra** with AITF assistance pioneered Biochar Registration with CFIA in Canada.
- **Air Terra Biochar** approved December 2015.
- CFIA non-compliance could result in product detention and prosecution.
- AITF assisting with other CFIA applications.
# Air Terra Biochar - Specifications

<table>
<thead>
<tr>
<th>Biochar</th>
<th>Average Result</th>
<th>Air Terra Product Min. Guarantee</th>
<th>Max. Allowable Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Proximate Analyses wt.% dry basis (db)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volatile Matter</td>
<td>8.5 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash</td>
<td>6.7 %</td>
<td>≤ 25 %</td>
<td></td>
</tr>
<tr>
<td>Fixed Carbon</td>
<td>84.8 %</td>
<td>≥ 70 %</td>
<td>IBI Class 1 (&gt; 60 %)*</td>
</tr>
<tr>
<td><strong>Ultimate Analyses wt.% (db)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>84.56 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>0.68 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>7.84 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>0.22 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Atomic Ratios</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H/C</td>
<td>0.1</td>
<td>IBI guidelines* require biochar H/C\textsubscript{org} ratio ≤ 0.7</td>
<td></td>
</tr>
<tr>
<td>O/C</td>
<td>0.07</td>
<td>Biochar with O/C atomic ratio &lt; 0.2, have an estimated half-life (T\textsubscript{1/2}) &gt; 1000 year [Carbon Management 2010, 1, 289]</td>
<td></td>
</tr>
<tr>
<td><strong>Toxicity Bio-Assay</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germination Rate</td>
<td>100 %</td>
<td>Radish seed germination rate in biochar relative to quartz sand control</td>
<td></td>
</tr>
<tr>
<td><strong>Toxicants</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polycyclic Aromatic Hydrocarbons - PAHs</td>
<td>1.6 mg/kg</td>
<td>&lt; 20 mg/kg IBI guideline*</td>
<td></td>
</tr>
<tr>
<td>Dioxins</td>
<td>Not detected</td>
<td>&lt; 9 ng/kg IBI guideline*</td>
<td></td>
</tr>
<tr>
<td>Furans</td>
<td>Not detected</td>
<td>&lt; 9 ng/kg IBI guideline*</td>
<td></td>
</tr>
<tr>
<td>Poly Chlorinated Biphenyls - PCBs</td>
<td>Not detected</td>
<td>&lt; 0.5 mg/kg IBI guideline*</td>
<td></td>
</tr>
<tr>
<td>Heavy Metals</td>
<td>Within max. allowable conc.</td>
<td>Below CFIA T-4-093 standard threshold</td>
<td></td>
</tr>
</tbody>
</table>
Other Beneficial Pyrolysis Applications

- **Conversion of Crumb Rubber** (Emergent Waste Solutions - Vegreville)
- **Reduction in Landfill Volumes** (Innovative Reduction Strategies - Edmonton)
- **Energy Densification** (Torrefied Wood Pellets)
- **Pyrolysis Oil** Based Liquid Fuels
- **Bio-Oil** Green Phenols Based Glues
- **Gasification Syngas** Conversion to Methanol
Pilot Scale – Product Development
Specialty Applications

Continuous Pyrolysis
AITF Biochar Production

- Co-founder of the Alberta Biochar Initiative
- Two ABI demonstration scale pyrolysis units located in Vegreville (commissioned in 2013)
- Produced and analyzed a wide variety of biochars produced from varying feedstock materials and pyrolysis conditions
- Analytical lab & established quality standards
Biochar Applications

- Greenhouse/Hydroponic Growth Media
- Agricultural Soil Amelioration
- Horticultural Soil Amendment
- Slow Release Fertilizers
- Advanced Carbons

Solonetzic soil  Biochar at 60 tons/ha  Sawdust
Biochar Applications

- Land/Tailing Pond Reclamation
- Waste Water Treatment (oil sands tailings)
- Emissions Control (air filtration)
- Lake Restoration (toxic algae control)

*Biochar – Chicken Soup for the Soil!*
Conclusions

Biomass Combustion and Pyrolysis Suitable for:
- **Distributed Heating Systems** (i.e. Combustion)
- **Power Co-Generation** (i.e. Electrical Off/On Grid)
- **Torrefied Biofuels** (i.e. Biocoal)
- **Pyrolysis Products** (i.e. Biochar, Bio-Oil and Syn Gas)
- **Biochar**
  - **Soil Amendments** (and Carbon Sequestration)
  - **Greenhouse Growth Media**
  - **Base for Activated Carbons**
Thank You!

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Presentation to 9th Annual Biomass Workshop
Morden, Manitoba – March 11, 2016
Supplementary Slides
Growth Medium in Hydroponics (AITF)

Tomato Trial in Vegreville 2010
Cucumber Trial in Vegreville, 2010
Biochar Soil Benefits and GHG Impacts

**Crop and Soil Benefits**
- Enhances crop productivity, Reduces soil erosion
- Improves soil tilt (compaction), fertility, water retention
- Reduces need for fertilizer inputs
- Provides high surface area and porous network for microbes to flourish
- Reduces leaching of nitrogen and phosphorus

**GHG Impacts**
- Nitrous oxide emissions reduced by 50-80%
- Some evidence of methane suppression
- Stability, longevity, recalcitrance
- Soil carbon pool
Biochar previously used in a hydroponic greenhouse growth experiment was used on a remote site in NWT to ameliorate fine texture marginal soil and to enhance a phytoremediation trial that was treated with BioBoost®

- Significantly reduced F2/F3 petroleum hydrocarbon in the soil after 2 years
Biochar in Reclamation Case Study #2

- Remote sump site (2.5 ha) with borrow pit in NWT
  - Fine texture soil with little topsoil
  - In 2010, site was seeded with native grass mixture
  - In 2012, biochar added and planted with 7 woody species
  - Overall, biochar had a net positive effect on vegetative growth and soil bulk density and moisture holding capacity
Using a subsoiler, incorporated biochar into the Bnt horizon of a solodized solonetz in Bruce, Alberta (near Vegreville)

Increased biomass yield and plant survival were observed in 60t/ha treatment

Biochar likely increased water holding capacity and root zone expansion in the Bnt horizon