TORREFIED WOOD
A New Emerging Energy Carrier

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Research Director
Wood Pellet Association of Canada

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Presentation

• History of Torrefaction
• Torrefaction as a Technology
• Status of Torrefaction Worldwide
• The WPAC Torrefaction Project
• Torrefied Pellet Product Specification
• European SECTOR Project
# HISTORY OF TORREFACTION

<table>
<thead>
<tr>
<th>Commodities</th>
<th>Temperature °C</th>
<th>Started</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beans (coffee), nuts, seeds (hot air)</td>
<td>+190 to 280</td>
<td>1000 A.D. (Ethiopia) 1971 (Starbucks)</td>
</tr>
<tr>
<td>Thermo- wood (outdoor furniture, decks) (Steam, hot air, oil)</td>
<td>+ 180</td>
<td>1980th (Finland)</td>
</tr>
<tr>
<td>High calorific biofuels (wood, agro-mtrl) (Steam, nitrogen)</td>
<td>+ 250 to 290</td>
<td>1987 (experimentation) 2000 (targeted research) 2004 (proof of concept) 2009 (pilot scale) 2010 (demonstration) 2015 (commercialization)</td>
</tr>
</tbody>
</table>

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10 Phases of Torrefied Pellets Production

A. Pre-torrefaction reactions
   1. Fractionation to size (if required)
   2. Conventional pre-drying of feedstock

B. Inside torrefaction reactor (*inert condition*)
   3. Evaporation of residual moisture
   4. Heating of feedstock up to +100°C
   5. De-polymerization of hemi-cellulose

C. Post-torrefaction reactions (*inert condition*)
   6. Cooling and re-polymerization
   7. Crushing to size
   8. Conditioning
   9. Densification to pellets

D. Post-conditioning
   10. Cooling and dust removal
THERMAL BREAKDOWN OF WOOD COMPONENTS

CELLULOSE
HEMI-CELLULOSE
LIGNIN
WOOD
TORREFACTION RANGE

RETAINED WEIGHT IN %

°C
TORREFACTION REACTION PRODUCTS

- SOLID TORREFIED MATERIAL
  70% of weight
  - ORIGINAL AND MODIFIED SUGARS
  - NEW POLYMERS
  - CHAR
  - ASH

- LIQUID CONDENSIBLES
  20% of weight
  - WATER
  - ORGANICS
  - LIPIDS

- NON-CONDENSIBLE GAS
  10% of weight
  - CO₂
  - CO
  - CH₄
  - H₂
  - TRACE OF OTHER HIGHER ORGANICS

BIOMASS
MASS AND ENERGY BALANCE
(MATERIAL ONLY)

BIOMASS FEEDSTOCK
1.0 M 1.0 E

TORREFACTION REACTION
+ 250 to 300 °C

TORREFICTION GAS
0.3 M 0.1 E

TORREFICTIONED BIOMASS
0.7 M 0.9 E
TORREFACTION
FEEDSTOCK CONVERSION VERSUS RELATIVE ENERGY GAIN

Sweet spot

% MASS RETAINED
% ENERGY RETAINED
% CARBON RETAINED
HHV GJ/tonne
GI per Metric Tonne

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EXAMPLES OF TECHNOLOGIES & TECHNOLOGY PROVIDERS

**TORREFACTION**

<table>
<thead>
<tr>
<th>INDIRECT HEATING (THROUGH WALL)</th>
<th>DIRECT HEATING (HOT GAS TO BED)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUGER</td>
<td>GAS-LOOP LINKED TO BURNER (Low O₂)</td>
</tr>
<tr>
<td>AGRITECH</td>
<td>TUNNEL</td>
</tr>
<tr>
<td>ALLIED BLOWER</td>
<td>ALTERNA</td>
</tr>
<tr>
<td>FOX COAL</td>
<td>MOVING BED</td>
</tr>
<tr>
<td>PICHENEY</td>
<td>THERMYA</td>
</tr>
<tr>
<td>DRUM</td>
<td>MULTIPLE HEATING ZONE</td>
</tr>
<tr>
<td>TORR-COAL</td>
<td>WYSSMONT</td>
</tr>
<tr>
<td></td>
<td>INTEGRO</td>
</tr>
<tr>
<td></td>
<td>CMI-NESA</td>
</tr>
<tr>
<td></td>
<td>DRUM</td>
</tr>
<tr>
<td></td>
<td>ROTAWAVE</td>
</tr>
<tr>
<td></td>
<td>MOVING BED</td>
</tr>
<tr>
<td></td>
<td>REDWOOD</td>
</tr>
<tr>
<td></td>
<td>PICHENEY</td>
</tr>
<tr>
<td></td>
<td>DRUM</td>
</tr>
<tr>
<td></td>
<td>WESTEND</td>
</tr>
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</table>

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## COMMERCIALIZATION PROJECTS (selected)

<table>
<thead>
<tr>
<th>Party</th>
<th>Demo tech</th>
<th>Target date</th>
<th>Capacity tonne/h</th>
<th>Party</th>
<th>Demo tech</th>
<th>Target date</th>
<th>Capacity tonne/h</th>
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<tbody>
<tr>
<td>Torr-coal</td>
<td>Torr-coal</td>
<td>2010/11</td>
<td>4.5</td>
<td>Agritech</td>
<td>Torre-tech</td>
<td>2011</td>
<td>5</td>
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<tr>
<td>4Energy</td>
<td>Stramproy</td>
<td>2010/11</td>
<td>5.5</td>
<td>RFT</td>
<td>RFT</td>
<td>2012</td>
<td>5</td>
</tr>
<tr>
<td>Torrsys</td>
<td>Torrsys</td>
<td>2011/12</td>
<td>5</td>
<td>Stramproy</td>
<td>Stramproy</td>
<td>2010/11</td>
<td>5.5</td>
</tr>
<tr>
<td>EBES</td>
<td>ACB</td>
<td>2012</td>
<td>1.5</td>
<td>New Earth</td>
<td>ECO-PYRO</td>
<td>2012</td>
<td>2</td>
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<tr>
<td>Integro</td>
<td>Wyssmont</td>
<td>2010/11</td>
<td>2</td>
<td>ECN</td>
<td>BO2</td>
<td>2012</td>
<td>5</td>
</tr>
<tr>
<td>Konza</td>
<td>Konza</td>
<td>2012</td>
<td>10</td>
<td>IDEMA</td>
<td>Thermya</td>
<td>2011</td>
<td>2.5</td>
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<tr>
<td>Topell</td>
<td>Torbed</td>
<td>2011</td>
<td>8</td>
<td>Atmosclear</td>
<td>Airless</td>
<td>2011</td>
<td>5</td>
</tr>
<tr>
<td>ETPC</td>
<td>BioEndev</td>
<td>2013</td>
<td>4.5</td>
<td>Diacarbon</td>
<td>Diacarbon</td>
<td>2014</td>
<td>8</td>
</tr>
<tr>
<td>BTG</td>
<td>BTG</td>
<td>2014</td>
<td>5</td>
<td>CanBiocoal</td>
<td>Rotawave</td>
<td>2011</td>
<td>12</td>
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<tr>
<td>Foxcoal</td>
<td>Foxcoal</td>
<td>2010/11</td>
<td>4.2</td>
<td>C2SKY</td>
<td></td>
<td>2011</td>
<td>5</td>
</tr>
<tr>
<td>Biolake</td>
<td>ECN</td>
<td>2011</td>
<td>5</td>
<td>WPAC</td>
<td>TBA</td>
<td>2012</td>
<td>5</td>
</tr>
</tbody>
</table>

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Implementation Challenges

A. Particle size
   1. Mass flow limitation

B. Consistency of feedstock particle size
   2. Heat Transfer variations = uneven carbonization
   3. Clogging or channeling of mass flow

C. Closing of gas-loop
   4. In-effective use of volatile calorific content
   5. Condensation in ductwork

D. Reactor vessel
   6. Control strategy (time & temperature)
      - moisture variations, particle size, volatile content
   7. Fouling

E. Densification
   8. High temperature of feedstock
   9. Highly reactive dust (risk of fires and explosions)
PELLETS MADE FROM UBC TORREFACTION

#1 RAW
#2 240°C
#3 270°C
#4 300°C
#5 340°C
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Measure</th>
<th>Wood</th>
<th>Wood Pellets</th>
<th>Torrefied Pellets</th>
<th>Charcoal</th>
<th>Fossil Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calorific value (HHV)</td>
<td>GJ/metric tonne</td>
<td>9 to 12</td>
<td>17 to 20</td>
<td>21 to 24</td>
<td>26 to 30</td>
<td>17 to 30</td>
</tr>
<tr>
<td></td>
<td>BTU/lbs</td>
<td>3,833 to 5,150</td>
<td>7,296 to 8,584</td>
<td>9,013 to 10,300</td>
<td>11,160 to 12,876</td>
<td>7,296 to 12,876</td>
</tr>
<tr>
<td>Moisture</td>
<td>% of weight</td>
<td>30 to 50</td>
<td>4 to 10</td>
<td>1 to 5</td>
<td>1 to 5</td>
<td>10 to 15</td>
</tr>
<tr>
<td>Fixed carbon</td>
<td>% of weight db</td>
<td>20 to 25</td>
<td>20 to 25</td>
<td>28 to 35</td>
<td>85 to 87</td>
<td>50 to 55</td>
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<tr>
<td>Volatiles</td>
<td>% of weight db</td>
<td>70 to 75</td>
<td>70 to 75</td>
<td>55 to 65</td>
<td>10 to 12</td>
<td>15 to 30</td>
</tr>
<tr>
<td>Bulk Density</td>
<td>kg/m³</td>
<td>200 to 250</td>
<td>650 to 725</td>
<td>700 to 800</td>
<td>180 to 240</td>
<td>800 to 850</td>
</tr>
<tr>
<td>Hardgrove Grindability Index</td>
<td>HGI</td>
<td></td>
<td></td>
<td></td>
<td>&gt; 45</td>
<td>&gt; 50</td>
</tr>
<tr>
<td>Deflagration index (K&lt;sub&gt;st&lt;/sub&gt;)</td>
<td>bar.m/sec</td>
<td>100</td>
<td>140 to 160</td>
<td>&gt; 160 ?</td>
<td>&gt; 180</td>
<td>120 to 140</td>
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<tr>
<td>Electrostatic propensity</td>
<td></td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
<td>Very high</td>
<td>Moderate</td>
</tr>
<tr>
<td>Hygroscopic properties</td>
<td></td>
<td>Hydrophilic</td>
<td>Hydrophilic</td>
<td>Hydrophobic ?</td>
<td>Hydrophobic</td>
<td>Hydrophobic</td>
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<tr>
<td>Leaching</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Self-heating</td>
<td></td>
<td>Moderate</td>
<td>High</td>
<td>?</td>
<td>Extreme</td>
<td>High</td>
</tr>
<tr>
<td>Off-gassing</td>
<td></td>
<td>Extreme</td>
<td>Extreme</td>
<td>?</td>
<td>Extreme</td>
<td>High</td>
</tr>
<tr>
<td>Oxygen depletion</td>
<td></td>
<td>Extreme</td>
<td>Extreme</td>
<td>?</td>
<td>Extreme</td>
<td>High</td>
</tr>
</tbody>
</table>

1000 Btu/lb = 2.33 gigajoules per tonne (GJ/t)
1 GJ/tonne = 429.2 Btu/lbs
WPAC TORREFIED PELLETS PROJECT

• 5 metric tonne per hour (30-35,000/y)
• Integration with existing pellet plant (Premium Pellet Ltd in Vanderhoof, BC)
• Selection of technology in August 2011
• Operating during 2012
• Financing; federal, provincial, private
• Seeking collaboration with power company
THE “SECTOR” PROJECT IN EUROPE

• European industry/research torrefaction project
• Management by German Biomass Research Center (DBFZ)
• Collaboration Consortium members

RWE                  EON                  BIOS
Vattenfall           ECN                  BE2020
Topell               TFZ                  TUW
ETPC                 DBFZ                 TUHH
VTT                  DTI                  Procede
IFK                  OFI                  IEN
CENER                DB                   DRC/WPAC
THE “SECTOR” PROJECT IN EUROPE

- Driving torrefaction to large scale commercialization
- Broad range of feedstock (wood, agro)
- 10% co-firing = 100 Mt dry feedstock = 1,000 torrplants (100k/ea)
- Development of recipes for a few standard qualities of fuel
- Development of standard testing methods
- Development of large scale safe handling and storage
- Value chain evaluation of large scale deployment policies
- Development of LCA model and sustainability criteria (env/soc)
THE “SECTOR” PROJECT IN EUROPE

• **Potential Canadian Participation**
  – Sharing of results from R&D in industry, institutes and universities

• **Benefits to the Canadian economy and industry**
  – Europe is largest market for Canadian pellets
  – Staying close to demand by large users of next generation biofuels
  – Exchange of experts and expert knowledge
    • Feedstock evaluation, torrefaction, logistics, combustion, sustainability
  – Avoid “re-inventing the wheel”
  – Stay alert of potential trade barriers before they happen
  – Technological feed-in to the WPAC Torrefaction Project
  – Participation in Round-Robin tests of materials and test methodologies
Torrefied Pellets – Silver Bullet? The **SECTOR** and the **WPAC Projects** will likely tell us.