Biomass energy alternatives from energy crop farming in Canada

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Resource Efficient Agricultural Production (REAP)-Canada
Ste. Anne de Bellevue, QC
REAP-Canada

- Providing leadership in the research and development of sustainable agricultural biofuels and bioenergy conversion systems for greenhouse gas mitigation
- 16 years of R & D on energy crops for liquid and solid biofuel applications
- Working in China, Philippines and West Africa on bioenergy and rural development projects
To economically provide large amounts of renewable energy from biomass we must:

1. As efficiently as possible capture solar energy over a large area
2. Convert this captured energy as efficiently as possible into a useful energy form for energy consumers
10,000 years ago humans learned to grow food from the land as a response to exhaustion of food supplies from hunter gatherer lifestyle.

10,000 years later bioenergy is emerging as a means for humans to use land to respond to the exhaustion of fossil energy supplies.

One of the greatest challenges of humanity is to effectively create economical and ecological efficient bioenergy systems from our agricultural lands around the world.
Bioenergy: Also the Solution to the Modern Farm Crisis

In 1991 the farm problems were the same as today

- Surplus production capacity
- Low commodity prices
- Either too many farmers and farmland or not enough markets
Resolving the Farm Crisis

- Farmers' problem lie not with subsidies but the surplus food production capacity of the agricultural sector
- Need to create demand enhancement outside the food sector
- Carbon trading and renewable energy incentives (REI”s) will stimulate the development of energy crop farming systems and conversion technologies
- Need parity in renewable energy incentives to enable efficient and equitable development of the bioenergy sector
Biofuels Research at REAP-Canada
Comparing C3 and C4 plants

**Cool season (C3) Plants**
- Greater chilling tolerance
- Utilize solar radiation effectively in spring and fall

**Warm season (C4) Plants**
- Higher water use efficiency (typically 50% higher)
- Can utilize solar radiation 40% more efficiently under optimal conditions
- Improved biomass quality: lower ash and increased holocellulose and energy contents
- Responsive to warming climate
Warm Season Grasses

C4 Grasses such as switchgrass are ideal bioenergy crops because of their moderate to high productivity, stand longevity, high moisture and nutrient use efficiency, low cost of production and adaptability to marginal soils.
Native Range of Promising Warm Season Grass Biomass Feedstocks

- **Prairie Sandreed** (Calamovilfa Longifolia)
- **Switchgrass** (Panicum Virgatum)
Fall Yield of Switchgrass Cultivars at Ste. Anne de Bellevue, Quebec (1993-1996)

- Energy Content of Crop per Hectare less Fossil-Fuel Energy Consumption
- Fossil Energy Consumption per Hectare Production
Switchgrass: a multi-use biomass crop

- Biofuel pellets and briquettes
- Biogas
- Cellulosic ethanol
- Green power
- Livestock bedding
- Paper
- “Straw bale” Housing
Switchgrass Bale Housing

Historical Housing
- These grass dwellings were permanent, waterproof and warm
- Underneath grass thatch covering was a sturdy wooden pole framework

Modern Housing
- First built in 2001, an advanced housing project at Kahnawake native reserve
- ~10 houses in Quebec
Warm Season Grass (WSG) Pellet Burning Stoves
Commerical Pellets: Green Heat for the Greenhouse Industry

- $1.17 billion industry
- 1200 greenhouses in Ontario covering 1044 ha
- 10,000 GJ demand/ha and a 10.5 million GJ/yr industry

~20 greenhouses converted from natural gas to crop milling residue pellets in 2006
Crop Milling Residue Products

Oat
- Oats: 65%
- Hulls: 24%
- Pin Oats: 11%

Wheat
- Flour: 75%
- Bran: 7%
- Mids: 18%
The Main Fuel in Use is Natural Gas, but where are Natural Gas Prices Headed in North America?

Residential Prices of Natural Gas, USA, in US Dollars per Cubic Metre, 1981-2004

Year

USD per Cubic Metre

Nominal USD per Cubic Metre
Economics of Switchgrass Production in Eastern Canada

- Fall harvesting $65-76_{CDN/tonne}
- Spring harvesting $61-81_{CDN/tonne}

### Economic Cost Breakdown for Fall Switchgrass Production

- **Land rent**: 29%
- **Harvest and transport**: 46%
- **Fertilization**: 16%
- **Establishment**: 3%
- **Misc**: 1%
- **Labour**: 5%
Bale processing at a pellet mill
Producing Rural Energy in Eastern Canada at $6/GJ

- Energy grasses grown for $70/tonne or $3.75/GJ
- Densification at $40/tonne or $2.25/GJ
- On-farm fuel at $110/tonne or $6.00/GJ
- Cheap rural energy will stimulate the entire rural economy

<table>
<thead>
<tr>
<th>Fuel Source and Cost</th>
<th>Cost for 1000 GJ Heat Demand ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating Oil ($0.60/l)</td>
<td>$27,500</td>
</tr>
<tr>
<td>Natural Gas ($0.50/m³)</td>
<td>$15,500</td>
</tr>
<tr>
<td>Corn ($140/tonne)</td>
<td>$11,000</td>
</tr>
<tr>
<td>Switchgrass Pellets ($150/tonne)</td>
<td>$9,500</td>
</tr>
<tr>
<td>Milling Residue Pellets ($125/tonne)</td>
<td>$7,000</td>
</tr>
</tbody>
</table>
Switchgrass Harvesting Operations
WSG Biomass Quality and Combustion

Problem:
- Main historic barrier with grasses has been high potassium (K) & chlorine (Cl)
- Causes clinker (agglomeration) problems and corrosion in boilers

Solution
- Use warm season grasses under delayed harvest management to leach chemicals
- Use advanced boiler & stove technology
# Biomass Quality of Switchgrass vs. Wood Pellets and Wheat Straw

<table>
<thead>
<tr>
<th>Unit</th>
<th>Wood pellets</th>
<th>Wheat straw</th>
<th>Switchgrass</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fall harvest</td>
</tr>
<tr>
<td>Energy (GJ/t)</td>
<td>20.3</td>
<td>18.6-18.8</td>
<td>18.2-18.8</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>0.6</td>
<td>4.5</td>
<td>4.5-5.2</td>
</tr>
<tr>
<td>N (%)</td>
<td>0.30</td>
<td>0.70</td>
<td>0.46</td>
</tr>
<tr>
<td>K (%)</td>
<td>0.05</td>
<td>1.00</td>
<td>0.38-0.95</td>
</tr>
<tr>
<td>Cl (%)</td>
<td>0.01</td>
<td>0.19-0.51</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Source: Samson et al., 2005
Energy Associated with Switchgrass Pellet Fuel Cycle

Energy Output:Input Ratio 14:1
Biogas From WSG’s: an Emerging Opportunity

- 3000 On-farm biogas digesters in Germany
- Energy crops (corn silage and forages) used as feedstocks along with manure
- Major R & D opportunity
Potential warm season grasses for biogas use in Canada

Switchgrass

Big Bluestem
Desirable Biomass Quality Traits for Biogas Forage Material

- Easily fermentable carbohydrates, proteins and lipids
- Low hemicelluloses
- Low lignin
- Low ash content

*Best Option: Marginal land production of high yielding, higher quality warm season grasses for livestock production*
Grass to Gas Energy Balance

- In advanced German biogas digesters, 1 tonne ensiled grass (on a dry tonne basis) produces 450 m$^3$ biogas (equal to 10.4 GJ/tonne).

- Biogas conversion recovers about 56% of the energy compared to use as a solid fuel (18.5 GJ/tonne).

*Assuming a biogas energy content of 0.0232 GJ/m$^3$*
The Thermodynamics of Switchgrass (SG) Energy Conversion Pathways

![Graph showing energy yield (GJ/ha) for different fuel types: SG Pellets, SG Biogas*, SG cellulosic ethanol, SG co-fire w/coal, Corn Ethanol. The bars are color-coded with yellow for direct biomass and green for after conversion. Preliminary Estimate is indicated for SG Biogas.](image_url)
Switchgrass Net Energy Gain by Conversion Technology

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Direct biomass</th>
<th>After conversion</th>
<th>Energy consumed during production/conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>SG Pellets</td>
<td>180</td>
<td>170</td>
<td>10</td>
</tr>
<tr>
<td>SG Biogas*</td>
<td>180</td>
<td>170</td>
<td>10</td>
</tr>
<tr>
<td>SG cellulosic ethanol</td>
<td>180</td>
<td>170</td>
<td>10</td>
</tr>
<tr>
<td>Co-firing SG w/coal</td>
<td>180</td>
<td>170</td>
<td>10</td>
</tr>
<tr>
<td>Corn Ethanol</td>
<td>180</td>
<td>170</td>
<td>10</td>
</tr>
</tbody>
</table>

*Preliminary Estimate
Energy Output/Input Ratios of Bioenergy Systems

Average of studies since 1996

- Switchgrass Pellets
- Sugarcane Ethanol
- Palm Oil
- Switchgrass co-fire w/coal
- Direct-fired Corn
- Switchgrass Ethanol
- Corn Ethanol
- Soybean Biodiesel
- Rapeseed Biodiesel

Temperate Studies
Tropical Studies

(reap-canada.com)
# Farmland in Ontario & Quebec for Energy Crop Farming

<table>
<thead>
<tr>
<th>Land use</th>
<th>Land area (‘000 ha)</th>
<th>Area for biofuels* (‘000 ha)</th>
<th>Potential grass yield** (‘000 tonnes)</th>
<th>Total potential grass yield (‘000 tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ontario</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crop land</td>
<td>2,254</td>
<td>450</td>
<td>4,192</td>
<td>8,883</td>
</tr>
<tr>
<td>Forage</td>
<td>1,261</td>
<td>504</td>
<td>4,691</td>
<td></td>
</tr>
<tr>
<td>Quebec</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crop land</td>
<td>940</td>
<td>188</td>
<td>1,748</td>
<td>5,221</td>
</tr>
<tr>
<td>Forage</td>
<td>933</td>
<td>373</td>
<td>3,473</td>
<td></td>
</tr>
<tr>
<td><strong>Ontario &amp; Quebec Total</strong></td>
<td></td>
<td></td>
<td></td>
<td>14,104</td>
</tr>
</tbody>
</table>

*Estimated 20% crop land and 40% forage land converted to bioenergy production
**Assumed yield of 9.3 tonnes/ha
## Estimated Crop Milling Residues

<table>
<thead>
<tr>
<th>Province</th>
<th>Wheat Bran &amp; Midds (tonnes/yr)</th>
<th>Oat Hull (tonnes/yr)</th>
<th>Corn Bran &amp; Screening (tonnes/yr)</th>
<th>Total (tonnes/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NS</td>
<td>28,009</td>
<td>N/A</td>
<td>N/A</td>
<td>28,009</td>
</tr>
<tr>
<td>QC</td>
<td>201,071</td>
<td>N/A</td>
<td>N/A</td>
<td>201,071</td>
</tr>
<tr>
<td>ON</td>
<td>391,029</td>
<td>25,054</td>
<td>250,936</td>
<td>667,019</td>
</tr>
<tr>
<td>MB</td>
<td>27,880</td>
<td>48,180</td>
<td>N/A</td>
<td>76,060</td>
</tr>
<tr>
<td>SK</td>
<td>64,964</td>
<td>103,491</td>
<td>N/A</td>
<td>168,455</td>
</tr>
<tr>
<td>AB</td>
<td>162,591</td>
<td>42,398</td>
<td>N/A</td>
<td>204,989</td>
</tr>
<tr>
<td>BC</td>
<td>40,150</td>
<td>N/A</td>
<td>N/A</td>
<td>40,150</td>
</tr>
<tr>
<td><strong>Canada</strong></td>
<td><strong>915,694</strong></td>
<td><strong>219,123</strong></td>
<td><strong>250,936</strong></td>
<td><strong>1,385,753</strong></td>
</tr>
</tbody>
</table>

Source: Samson et al. 2006
Potential Agri-Residues & Energy Crops Available for Bioheat use in Ontario

<table>
<thead>
<tr>
<th>Ontario</th>
<th>Crop milling residues (tonne/yr)</th>
<th>Energy grasses (tonne/yr)</th>
<th>Total (tonne/yr)</th>
<th>Total (GJ/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>667,019</td>
<td>8,883,000</td>
<td>9,550,019</td>
<td>176,675,352</td>
</tr>
</tbody>
</table>

Equivalent to 29.9 million barrels of oil a year
## Farmland in North America and Potential for Bioenergy Production

<table>
<thead>
<tr>
<th>Land use</th>
<th>Millions of Hectares</th>
<th>Area for biofuel production* (million ha)</th>
<th>perennial grass production** (million tonnes)</th>
<th>Millions Barrels of Oil Equivalent (MBOE)/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>68</td>
<td>13.6</td>
<td>80.2</td>
<td>.69</td>
</tr>
<tr>
<td>U.S.A.</td>
<td>377</td>
<td>75.4</td>
<td>610.7</td>
<td>5.23</td>
</tr>
</tbody>
</table>

* Estimated 20% land converted to bioenergy grasses
** Assumed bioenergy hay yields of 5.9 tonne/ha in Canada and 8.1 t/ha in the US and 18.5GJ/tonne of hay

Total NA production potential of grass of 5.92 MBOE is equal to 7.2% of world oil supply of 82 million barrels of oil/day
Renewable Energy Incentives for the Made in Canada Solution

Corn Ethanol (0.022GJ/L)  
$0.25/L → $11.20/GJ

Wind Power Incentives (0.0036GJ/kwh)  
$0.03/kWh → $8.33/GJ

Bioheat Pellets (18.5 GJ/tonne)  
$22.00/t → $1.19/GJ

*Ethanol subsidy based on $0.10 federal excise tax + average provincial
Cost of made in Canada GHG Offsets

To Mitigate 1 Tonne of CO₂:

Using Corn Ethanol instead of Petroleum:
  Requires 42GJ of Corn Ethanol @ 24.09KgCO₂/GJ
  Cost- $465

Using Wind Power instead of average grid Electricity*:
  Requires 18 GJ of Wind Power @ 55.46KgCO₂/GJ
  Cost- $150 (versus coal power it is ~$45/t)

Using Biomass Pellets instead of NG, LNG, Coal and Heating oil requires 14GJ of Pellets @ 69.49KgCO₂/GJ
  Cost- $17

*The approximate electrical mix for Ontario is: 27% hydro-power, 39% nuclear, 13% coal, 13% oil, 6% natural gas and 2% other (NRC, 2000).
A major GHG Reduction strategy for Canada

If 80.2 MT of energy grasses were used for bioheat and biogas and average tonne biomass used displaced 1.28t of CO$_{2e}$/tonne:

102.7 MT of CO$_{2e}$ mitigated/yr

The Agriculture Sector produced 62 MT of CO$_{2e}$ in 2003. A 20% land conversion to energy grasses could reduce GHG emissions from land use and ruminant livestock production ~ 20% overall or:

12.4 MT of CO$_{2e}$ mitigated/yr

Total GHG Mitigation is : 115.1 MT of CO$_{2e}$ mitigated/yr

Net cost is $1.76 billion/yr and $15 tonne CO$_{2e}$
Summary and Conclusions

- Bioheat and biogas are 2\textsuperscript{nd} generation biofuels that have superior fuel cycles than 1\textsuperscript{st} generation biofuels.
- Bioheat is the most efficient land use strategy producing 7.5 more net energy gain than ethanol from annual grains.
- 1/6\textsuperscript{th} of Canada’s total GHG emissions could be eliminated through dedicating 20\% of Canada’s farmland production capacity into 2\textsuperscript{nd} generation biofuel systems.
Governments can encourage efficient energy crop farming technologies through renewable energy incentives (need parity!)

Cost of GHG abatement from efficient use of REI’s could be as little as $1.8 billion/yr for a 115 million tonne “Made in Canada” solution

“Dream no little dreams” and a new age of green prosperity can emerge in the world
Thank You!

Bioenergy Funding Partners

- Canadian Farm Business Management Council
- OMAFRA: Alternative Renewable Fuel Research Fund
- Natural Resources Canada