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PROJET TROTTIER POUR L'AVENIR ÉNERGÉTIQUE

TROTTIER ENERGY FUTURES PROJECT

Sustainable Use of Biomass in a Low-Carbon Canada

December 6, 2012

DIALOGUE REPORT

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Carbon Talks is a partnership with Simon Fraser University's Centre for Dialogue, in collaboration with SFU's Beedie School of Business, the School for Public Policy and the School for International Studies. Our goal is to advance Canadian global competitiveness by shifting to a low-carbon economy.

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Elodie Jacquet served as primary rapporteur for the session and wrote this dialogue report. Ralph Torrie, Mitchell Beer, Shannon Moore, Blake Anderson, Claire Havens, and Tyler Bryant provided revisions and edits. This report was formatted by Christopher Gully.

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The views in this publication reflect the ideas generated in the course of the dialogue session. They do not reflect the views of Carbon Talks staff, funders, collaborators, SFU Centre for Dialogue or the Trottier Energy Futures Project.

In This Dialogue Report

This report provides an account of the invitational dialogue, "Sustainable Use of Biomass in a Low-Carbon Canada," which took place December 6, 2012 at the Old Mill Inn in Toronto. The dialogue was convened by Carbon Talks and the Trottier Energy Futures Project (TEFP) and was facilitated by Carbon Talks, to better understand the quantities of bioenergy feedstock that might be available and sustainable in a low-carbon Canada.

The TEFP's mandate is to chart a course for Canada to cut its greenhouse gas (GHG) emissions by 80% below 1990 levels by 2050. To achieve that target, the country will require wider use of biomass fuels to meet demands that cannot be easily or affordably converted to electricity. In this context, dialogue participants expressed hopes centred on the sustainability of ecosystems and communities and the development of sound policies and new technologies. Their concerns had to do with the sustainability of rural Canadian communities, forest conservation and ecology, climate change challenges, policy, and the cost and efficiency of new biofuels. To set the context for the day, participants also produced a timeline of the people, events, and policies that have shaped the use of bioenergy in Canada over time.

Dialogue discussion focused on drivers of demand of bioenergy, such as climate change, global economics, and the cost and availability of fossil fuels. A list of principles was developed around the necessity to account for the carbon debt associated with shorter-term biomass harvesting and use, and to arrive at separate approaches for forest and agricultural feedstocks. The group explored factors that determine sustainable extraction limits for biomass feedstocks, and pointed to the need for reliable resource inventories. A scenario-building exercise challenged participants to outline options for increasing biomass energy production from different feedstocks while addressing several key concerns, including plausibility, GHG emissions reductions achieved in each scenario, and the benefit and pitfalls of increased production. Scenarios were developed for agricultural and forest feedstocks.

Toward the end of the day, dialogue participants put forward their personal recommendations to governments, business, academia, civil society, the Trottier Project, the David Suzuki Foundation, and the Canadian Academy of Engineering. The recommendations centred on the need to accurately determine the sustainable volume of bioenergy feedstocks and support their commercialization. They expressed support for expanded research, wider partnerships among sectors, and credible, practical messaging. These recommendations and other results of the dialogue will inform the TEFP's continued work on low-carbon energy futures.

Introduction

The Trottier Energy Futures Project (TEFP) has identified a number of distinct challenges that will have to be addressed on the road to a sustainable, low-carbon energy future for Canada. Among these is the development and growth of bioenergy as a low-carbon substitute for fossil fuel.

One central issue in achieving this goal will be determining the sustainable volume of biomass feedstock that Canada can realistically produce, within the constraints of current technology. Most of the biomass used for energy in Canada is derived from forest waste, which represents about 25 to 30 million dry tonnes a year. In a low-carbon energy scenario, Canada could need as much as 100 to 200 million dry tonnes of primary feedstock per year. This steep increase in production would be a game-changer for the industries involved, and for the communities, ecosystems, and economies that depend on or are affected by forestry and agriculture.

The participants were asked to examine some of the following questions:

How big could the primary supply of biomass for energy be in 2050?

- What is the gross production of biomass in Canada?
- What are the ecological limits to sustainable production?

How much biomass could be available for energy applications, given:

- Competing uses
- Impacts on other sectors
- Social license issues and limits to growth
- Fundamental economic constraints
- Environmental impacts
- Other factors?

How might these limits be addressed or affected by:

- Emerging technologies?
- Changes in cultivation practices or industrial processes?
- Land use decisions and constraints?
- Concerns about emissions or other environmental impacts?
- Other factors?

In the different sectors and communities where bioenergy production would scale up in a low-carbon energy scenario:

- How will greater demand for biomass feedstocks shift production priorities and affect communities that have grown up around biomass for food and fibre? What are the foreseeable benefits and pitfalls of these changes?
- What are the competing demands for feedstock in each major production sector (agriculture, forestry, energy from waste)?
- How (and within what limits) can forest and agricultural biomass be developed in a way that enhances the sustainable prosperity of those ecosystems, in harmony with other established production chains?
- Are there opportunities to balance competing demands for the land and water required to support bioenergy production at a level that is consistent with a low-carbon energy future?

Are there best practices or pilot projects, in Canada or internationally, that can help shape our understanding of the sustainable limits on bioenergy production?

The participants were then asked to work on possible scenarios for the sustainable development of biomass feedstocks, and put forward recommendations for further research and modeling.

This intimate roundtable dialogue was facilitated by Carbon Talks. Invited guests included industrial leaders, a woodlot owner, a forest ecologist, a representative from the agricultural sector, academics, a member of a non-profit think tank, and professional engineers. The discussion was governed by Chatham House Rule (see Appendix C) to enable everyone to speak freely and off the record. Although none of the information in this report is attributed by name, this is a full report of the content of the session.

Methodology

Participant Affiliation	Number
Academics	3
Woodlot owners	1
Engineering	2
Forest ecology	1
Biochar sector	1
Non-profit think-tanks	3
Agricultural sector – farmers	1
Bioenergy industry	2
Forestry industry	1
Bioenergy consultants	1
Energy policy experts	1
Total	**17**

The dialogue was designed by Carbon Talks and facilitated by Shauna Sylvester, Executive Director of Carbon Talks and a Fellow at the SFU Centre for Dialogue. Elodie Jacquet (Carbon Talks) and Mitchell Beer (Trottier Energy Futures Project) served as primary rapporteurs. Participants were chosen from a long list of individuals involved in the production or study of bioenergy feedstocks.

To ensure an open and candid discussion, the dialogue was governed by Carbon Talks' Terms of Engagement and Chatham House Rule (see Appendix C). One week prior to the session, participants were provided with a discussion guide written by the Trottier Energy Futures Project team that outlined the conversion pathways and end uses for the various bioenergy feedstocks, the history of bioenergy demand in Canada, the basis for considering biomass a biogenic fuel, the potential scale of bioenergy demand in a low-carbon energy future, and the factors that will determine the sustainable supply of bioenergy feedstock.

The agenda (see Appendix B) was designed to enable maximum participant engagement. A variety of methods were used to solicit participant feedback, including opening and closing rounds, generative discussions on what the primary supply of biomass in Canada could look like in 2050, and a scenario-building exercise where smaller discussion groups explored how to increase the availability of biomass energy from specific feedstocks. A final round was used to solicit participant feedback on the process of the dialogue and the content of the final report.

Context Setting

Ralph Torrie, Managing Director of the Trottier Energy Futures Project welcomed the participants and gave some context on the organization and the bioenergy challenge.

The Trottier Energy Futures Project (TEFP) is a research and modeling effort to determine how Canada can dramatically reduce its greenhouse gas (GHG) emissions that contribute to global climate change. By the time it finishes its work at the end of December 2013, the Trottier Project will chart a course for Canada to cut its energy-related greenhouse gas (GHG) emissions by 80% below 1990 levels by 2050. To get anywhere near the target, fossil fuel consumption and related emissions will have to decline about as quickly as they've grown in the last 100 years.

The prospects for achieving a low-carbon future come down to whether Canada can:

- Become significantly more energy-efficient
- Rely much more on electricity for low- and medium-temperature heat, personal transportation, and some industrial processes
- Decarbonize the electricity supply
- Increase the use of biofuels, while ensuring that bioenergy feedstocks are produced sustainably
- Deal with the habits, practices, and policies across the economy that set the underlying demand for energy.

Canada can likely reduce its GHG emissions by half through aggressive application of efficiency and renewable energy technologies. However, to achieve an 80% reduction, it will be necessary to examine the whole cause and effect chain that leads to the demand for energy services.

Most of the biomass used for energy in Canada comes from forest waste, which represents about 25 to 30 million dry tonnes a year. In a low-carbon energy scenario, Canada could need as much as 100 to 200 million dry tonnes of primary feedstock per year.

Scenario analyses of low-carbon energy futures share a number of common conclusions. In the eight national scenarios the TEFP reviewed, deep GHG emission reductions depended on:

- Major improvements in energy efficiency
- Greater reliance on electricity for heating, personal transportation, and some industrial processes
- A transition to low- or zero-carbon electricity sources
- Wider use of bioenergy to supply liquid fuels and meet other demands that cannot be easily or affordably converted to electricity.

But most of the scenario studies paid scant attention to the volume of primary biomass feedstock that can be sustainably produced or the criteria for determining sustainability. This is the issue that dialogue participants were asked to address.

Opening the Dialogue

As part of an introductory exercise, participants were asked to introduce themselves and express one hope and one concern about the sustainable supply of bioenergy feedstocks in Canada.

Most of the participants' **hopes** centred on sustainability, and included:

- Breaking Canada's dependency on fossil fuels
- Fostering a sustainable relationship with our ecosystems
- Extracting biomass from the forest on a spatial and temporal scale that sustains our ecosystems; and
- Enabling rural Canadian communities to thrive sustainably, by continue to earn enough income while maintaining the quality of the soil.

Policy was also a major theme, with participants expressing hopes about paradigm shifts that would:

- Promote more decentralized, community-based power and transformed energy systems; and
- Be based more often on rational scientific knowledge or embrace more holistic approaches to the low-carbon economy.

Some participants highlighted Canada's world-class forest management policies. Participants also expressed the hope that Canada would play a leadership role in the development of sustainable bioenergy and use its cutting-edge forest management policies to pave the way for other countries and for sustainable bioenergy. The participants voiced their hope that forest management policies in Canada would stay ahead of industry interests.

Some participants cited technology as a source of hope for:

- Better diversification of the bioenergy product mix
- Development of cost-effective second-generation biofuels
- New ways to extract biomass sustainably (for example, nano-cellulose)

Concerns included:

- The sustainability of rural Canada and the need to ensure incomes for farm families
- Preservation of the soil and maintaining micronutrients as well as macronutrients, on both forest and agricultural lands, leading to the possibility that no additional forest or agricultural biomass can be harvested for energy without jeopardizing micronutrient cycles
- The biodiversity and ecology of Canadian forests
- Unsustainable harvesting
- The volatility of the fuel market
- The cost and efficiency of new energy sources
- Pressure on the price of bioenergy feedstock and the need to ensure a level playing field for the bioenergy industry
- A concern on the part of several participants that domestic forest management policies are inadequate, and that international policies are having an adverse effect
- The realities and uncertainties of climate change
- The unsustainable growth of developing economies, including a concern that a "one car, one person" is an unreasonable model for global development

Historical Timeline

What events, policies, people and initiatives have shaped our use of bioenergy over time in Canada? Dialogue participants collaborated on a timeline of these events; the results of that exercise are presented below. The following timeline was developed by participants and was not intended to be comprehensive, nor necessarily an accurate reflection of dates. For a more detailed, interactive version of this timeline, please visit the Carbon Talks website.

1826	Samuel Morey discovers an internal combustion chemical mixture of ethanol and turpentine can be used as a fuel
1870	Energy consumption is mostly wood
1896	Henry Ford's first car design, the Quadricycle, runs on pure ethanol
1900	Energy consumption is mostly coal
1900	Advent of cheap oil
1907	Mass production of the automobile begins
1912	Harvest of timber from west coast forests begins
1920	Western Canada built on wheat and horsepower
1941	World War II petrochemical industry development
1941	Oil shortages during World War II lead to the development of European biofuel technologies
1950	Allocation of public forest resources to large industrial forestry companies
1960	Decline in use of horse for forestry
1960	Energy consumption is mostly oil and gas
1960	Green revolution leads to increased agricultural productivity; shifts to synthetic pesticides and fertilizer
1960	Consumption of fuel growing faster than the economy
1962	Beginning of environmental movement, publication of Silent Spring by Rachel Carson
1972	Limits to Growth commissioned by the Club of Rome, published; warns of economic and population growth on a planet with finite resources
1972	Modern genomics begins and spurs growth in biotech sector
1973	1973 Oil Crisis; shortages and high prices caused by constrained US production
1975	National Alcohol Program in Brazil; nation-wide program to phase out fossil fuels and replace them with ethanol from sugar cane
1975	Canadian R&D investments in bioenergy
1979	1979 Oil Crisis; shortages and high prices caused by Iranian Revolution
1980	National Energy Program (NEP) created under the Liberal government of Prime Minister Pierre Trudeau
1980	Increased use of forestry waste
1980	Increased use of landfill methane
1980	Between 30 and 40 fine paper mills in Canada in the 1980s
1980	Subsidies for US ethanol begin to reduce US dependence on imported petroleum
1981	1980s oil glut

1985 Eucalyptus pulp production and genetic work on this species increases dramatically

1987 Northwest Wildlife Preservation Society

1988 First international conference on climate change held in Toronto in June, 1988, titled *Our Changing Atmosphere: Implications for Global Security*

1990 1990s mountain pine beetle infestation starts

1990 1990s - significant regulatory period for pulp and paper industry

1990 Technology advances in combustion efficiency - 20-80%

1990 Recycling Council of British Columbia (RCBC) founded

1992 United Nations Conference on Environment and Development (UNCED), also known as the Rio Summit

1993 Forest Stewardship Council Founding Assembly was held in Toronto

1996 Forest industry cogeneration investments - Alberta oil sands adopt cogeneration to reduce emissions

1996 Increased commercialization of genetically modified crops

1997 Signing of Kyoto Protocol

1998 Toxic Free Canada / Labour Environmental Alliance Society (LEAS)

2000 Pacific Parklands Foundation

2000 Evolution in partnerships between government, academic and private sector

2001 Sustainable Development Technology Canada created

2001 September 11 attacks - followed by energy security discussions

2005 Renewable Fuel Standard - US Environmental Protection Agency

2006 Alberta Bioenergy Strategy

2006 Canadian dollar begins to rise and continues to do so over the next decade

2007 European Union 20-20-20 targets set

2008 2008 food crisis and economic downturn

2008 Collapse of US housing market and subsequent wood products industry decline

2008 Global recession

2008 Food price spike; concerns about biofuel crops

2008 Natural gas prices drop significantly; shale gas development reduces the economics of biomass

2009 US pulp and paper industry receives bioenergy subsidy

2010 Renewable Fuels Regulations mandate an average 5% renewable fuel content based on the gasoline volume

2011 BC raw log exports to China dramatically increase

2012 Less than 10 fine paper mills left in Canada

2012 $1 billion Pulp and Paper Green Transformation Fund (PPGTP)

2012 Federal government changes to water, clean air and Environmental Impact Assessment regulations

2012 Canada officially withdraws from the Kyoto Protocol agreement

How Big Could the Primary Supply of Biomass for Energy Be in 2050?

The first generative discussion focused on the table the Trottier Project had produced that showed the 7.6 exajoules of annual primary biomass production that might be available from Canadian forests, agriculture, and municipal waste. References for this table can be found in Appendix D of this report.

Feedstock	Total Tonnage	Heat of Combustion	Pathways
Food crops: wheat, corn, barley, canola, corn feed, flaxseed, oats, soybean, beans and peas, rye, mixed grains, other	108.8 million dried tonnes[1]	1,695.0 PJ[2]	First-generation biofuels production
Agricultural residues: Stover, husks, silage	70.0 million recoverable dried tonnes[3]	1,170.3 PJ[4]	Second-generation biofuels production
Energy crops: Switchgrass, cordgrass on marginal croplands	98.5 million dried tonnes[5]	1,585.1 PJ[6]	Second-generation biofuels production
Roundwood	132.2 million dried tonnes[7]	2,094.5 PJ[8]	First- and second-generation biofuels; gasification; fuelwood; wood pellets; combined heat and power (CHP); combustion or fossil fuel co-firing to produce electricity
Primary forestry residue[9]	27.8 million recoverable dried tonnes[10]	439.8 PJ[11]	First- and second-generation biofuels; gasification; fuelwood; wood pellets; combined heat and power (CHP); combustion or fossil fuel co-firing to produce electricity
Landfill gas	1.4 million tonnes[12]	96.9 PJ[13]	Direct combustion
Municipal solid waste: Combustible dis-posed waste	17.0 million dried tonnes[14]	249.9 PJ[15]	Direct combustion; thermochemical or biochemical conversion
Municipal solid waste: Combustible diverted waste	6.3 million dried tonnes[16]	114.9 PJ[17]	Thermochemical or biochemical conversion
Municipal biowaste	0.63 million dried tonnes[18]	9.1 PJ[19]	Direct combustion; anaerobic digestion to biogas for heat and electricity
Livestock waste	12.5 million recoverable dried tonnes[20]	187.2 PJ[21]	Direct combustion; anaerobic digestion to biogas for heat and electricity
TOTAL PRIMARY ENERGY POTENTIAL		7,642.7 PJ	

Table 1 - Estimated Annual Primary Biomass Production Potential, Canada

TEFP Managing Director Ralph Torrie stressed that the table was an estimate of total supply, not the net supply that might be available for energy after other needs and demands have been met.

Participants said the table should be more complex, with more comprehensive analysis of each feedstock category and historical perspective, and more detail on current bioenergy products. The life cycle carbon impact of harvesting each of the products is not presented in sufficient detail, and there could be an issue with displacing any of the items on the table. The participants also stressed that the supply figures are conditional because they are all subject to assumptions which could be reshaped by the development of new technologies and products. For example, TEFP used a three-year average for wheat yields, but one participant stressed that yields can fluctuate due to climate change or introduction of new technologies or practices.

In a low-carbon energy future, a major risk is that the primary supply of bioenergy will be determined by market forces, not by sustainability principles, with the resulting risk of an eventual market failure. Pertaining to the above, there is also a major risk that regulations to protect our biomass would not be in place in a timely manner.

DRIVERS

Participants defined the following factors affecting the demand for bioenergy:

- Climate change
- Increase in the price of fossil fuels
- Decrease in the availability of fossil fuels
- Regulations
- Global economics
- Perceived availability of biomass in Canada
- Rural sustainability and community resiliency.

Principles

Participants defined a number of principles for a sustainable development of bioenergy:

As a working principle, one participant said food, feed, and fibre would have higher priority as biomass products than energy. Another participant disagreed, noting that agricultural productivity is rising, food demand is levelling off, and solving world hunger is not just a matter of exporting our surplus: Canada did that for 25 years, he said, and sold product so cheaply that “we killed Third World farms.” The solution is for developing countries to increase their own output without damaging grasslands or other agricultural systems, and some countries are making good progress in that direction.

A participant cited agricultural residues as another promising source of feedstock. When corn yields increased, he said, residue supplies grew by a factor of three.

A participant said the market would determine the highest value use for each feedstock. There was some disagreement on this point. Another participant offered that biomass should be examined in a segmented fashion because different feedstocks would yield different value end products. Revenues from forestry feedstocks are not homogeneous.

Most participants agreed that feedstocks from forest and from agriculture would have to be addressed differently.

One participant suggested that bioenergy development should be based on a principle of maintaining or increasing the carbon stock in the biosphere in order to address the carbon deficit over a period of time. There is an inverse relationship between the speed at which a forest grows and wood density, such that faster-growing stands deliver less energy for combustion or lower wood quality for other purposes. Canada's slow-growing but dense forest products have been a competitive advantage in the past. A participant said the limit on sustainable biomass and biofuels production may be the pace at which carbon accrues in a forest relative to the "disturbance regime" to which that forest is subjected. Violating this ecological rotation would lead to a net loss of carbon. This last principle generated some disagreement amongst the participants.

The group suggested a practical limitation on the convention that treats bioenergy as a source of biogenic, rather anthropogenic, greenhouse gas (GHG) emissions. If forest biomass is burned for energy when it would otherwise have decayed over a 10- to 20-year period, the change in pathway creates a carbon debt that must be repaid within five to 15 years. "Canada's carbon stock has to be maintained in the longer term in order for this to be sustainable," a participant said. The same principle would apply if bioenergy producers harvested whole stands that had been destroyed by mountain pine beetle infestations—a fire would only take 10% of that stock, and the remainder would decay more gradually.

Maximizing Sustainable Biomass Yields

Participants identified a series of factors that will determine the maximum sustainable yield of biomass from forest and agriculture ecosystems. There were a range of ideas and concerns on this topic, including:

- A concern that if forest yields rise, the rate of organic matter decomposition will have to increase to match. Otherwise, "you're drawing nutrient capital at a higher rate."
- Caution against generalizing about the different types of forest residue, suggesting that the group differentiate roundwood and non-productive forest from the types of residue that are typically left behind on the forest floor.
- Canada could capture carbon through the carbon cycle and sequester it in soils, in a way that also enhances their productivity. Soils are believed to store twice as much carbon as the atmosphere and all biomass combined.
- The sustainability of forest nutrients should be determined on a scale of at least 1,000 years.
- Canada must optimize productivity on each hectare of land, conduct a true life cycle analysis to determine the greenhouse gas impacts of different uses, then "use that land for the best end use" that it can sustainably support. Although

it may not be realistic to “analyse every hectare,” it should be possible to review different classes of land based on their productivity.

- A participant described an integrated, global model produced in The Netherlands, the IMAGE model (http://themasites.pbl.nl/tridion/en/themasites/image/) that calculates biological potential of the Earth’s entire land surface on a 0.5 x 0.5° grid. The model factors in soil characteristics, climate data, local labour costs, international trade, and aspects of population and diet that drive demand for food, fibre, and biofuels. “What we need is a high-resolution model of the productivity of the Canadian landscape that takes into account soils, climate and how it might change, and labour costs,” then overlays that with the biophysical potential.
- A participant said it would be a mistake to model bioenergy production on full usage of all the available resources. A forest is a complex, diversified ecosystem, where you have to walk the ground to know what happened there 45 years ago. In this broader view, it will only be possible to determine the volume of available bioenergy feedstock or the pathway to revitalizing the forestry sector by defining the breaking point beyond which the forest ecosystem is degraded.

As with many generative dialogues, this session did not lead to any consensus, but enabled the group to explore a range of issues and concerns.

During the session, participants expressed their interest in:

- Extracting biomass from the forest on a sustainable basis, while still maintaining the ecosystem goods and services on which we all depend
- Addressing sustainable extraction limits, markets, and market access at a time when climate change presents “substantial challenges”
- Supporting the evolution of a sustainable biorefinery for pulp and paper, in which wood fibre is converted to a variety of advanced products
- World-class forest management policies and practices that enable the entire bioeconomy.

Constraints

The second generative discussion examined the constraints that could affect Canada's biomass feedstock production, in particular:

- Emerging technologies
- Changes in cultivation practices or industrial processes
- Land use decisions and constraints
- Increased public concern on climate change
- Concerns over other environmental impacts

The ensuing discussion clustered around three key areas of concern.

Inventory of Biomass Feedstocks
The group discussed the need for a more comprehensive assessment of Canada's current and potential biomass feedstocks. Participants said resource inventories in British Columbia and Alberta are out of date, and any inventory should reflect the different types of biomass available, technical and economic constraints on harvesting in specific locations, and the potential to double forest productivity through improved silviculture. One participant stressed the need to plant trees that are adapted to the climatic changes that will occur over the next 80 years, rather than the regimes that were prevalent over the last 200.

Economic Constraints
Some participants identified market prices and competing products as a key constraint on the future availability of bioenergy feedstocks: a forest producer will always make more money producing 2 x 4s than by converting feedstocks to ethanol, since "energy is pretty much the lowest-value thing you can produce" from a tree. Prices will be calculated on a dry-tonne basis, and one participant said the feedstock price will have to be at least $100 per dry-tonne for the industry to sustain itself.

A participant said forest residues are not homogeneous, so that it's distracting and could detract from their bioenergy potential when all forms are lumped together. There are also important differences between forestry and agriculture—and between forestry in Canada and Europe—in the methods and expertise in place to improve management and boost productivity. That means the forest reserve available in Canada by 2050 will be a function of future improvements in forest protection and management of forest impacts, adaptation to climate change, applications of technology, diversification of uses, and integration of the various markets for forest products.

Technological Constraints

Participants expressed a range of views on the available technology for bioenergy development, particularly for producing second-generation lignocellulosic biofuels.

One participant stated that "cellulose may be the shale gas of the biofuels industry," noting that abundant shale gas resources have been known since the 1970s but are only going into production now. Cellulosic ethanol, he said, "is waiting for the technology that's going to unlock it." A more immediate option might be to produce synthetic gas and convert it into a hydrocarbon-like liquid fuel, possibly for a premium market like aviation biofuels.

Another participant countered that lignocellulosic biofuel development is far enough ahead that the limiting factor is feedstock supply chain and infrastructure, not technology. He added that "Big Oil does not produce ethanol. It produces gasoline," so without a regulated environment, there will only be limited demand for biofuels.

A participant said ethanol development also enables other technologies, noting that the engine for a 2012 flex fuel vehicle is 25-30 per cent more thermally efficient than its conventional counterpart.

Scenario Building

Each group was tasked with outlining a scenario for increasing biomass energy yields from their feedstocks (food crops, agricultural residues, and energy crops for one group, forest biomass for the other two), while addressing the following question:

Canada currently uses annual volumes of 30 million oven-dried tonnes (Odt) of wood-based energy and five million tonnes of corn and other grain feedstock for biofuel energy, in addition to relatively small amounts of energy from municipal solid waste, animal fats, and agricultural waste. Some scenarios for achieving a low-carbon energy future would require as much as 100 million Odt each of forest-based and agricultural biomass. To assess whether these targets are attainable and sustainable, your scenario should address these questions:

- *Is it plausible to expand production to this extent?*
- *What technologies will you use?*
- *What will be the environmental impact of your increased production?*
- *What impact will increased production have on GHG emissions?*
- *What are the foreseeable benefits and pitfalls of the increased production?*
- *How will the increased production in your biomass feedstock shift production priorities and affect local communities?*
- *Can you develop increase production and enhance the ecosystem, in harmony with other established production chains?*

Group #1 - Food Crops, Agricultural Residues, and Energy Crops

This group felt it was quite plausible to expand production. Agriculture has about 55 million hectares available. A yield of two tonnes per hectare would be required to reach output of 100 million tonnes. This production would be drawn largely from agriculture residues, with some crop production but no impact on production of food, feed, or fibre.

The group identified GMO crops and precision farming as two factors that would help farmers achieve higher yields while reducing their GHG emissions, noting that higher-productivity crops will require less nitrogen fertilization and use less fuel per tonne of output. Precision farming will also improve the overall environmental performance of farm operations. The group stressed that future production plans must not sacrifice the continuing process of building soil carbon, even though that would mean limiting the residues that can be removed.

The group agreed that better agricultural practices and a shift to higher-yield feedstocks would also make life better for agricultural communities.

The group acknowledged the risks associated with monoculture, but concluded that Canada had addressed the problem through regular crop rotation.

Governments can support expanded production of bioenergy feedstocks by easing some of the regulatory barriers to their development. At the same time, participants noted that farm producers are currently 10 years ahead of government in their understanding and use of current crop management processes and technologies. For example, most large farms now use satellite technology to support precision farming.

Group #2 - Forest Biomass I

This group calculated that Canada's forests could likely produce 127 million tonnes of biomass feedstock a year, drawn from the following sources:

- 27 million tonnes in annual allowable cut (AAC)
- 30 million tonnes from forest residues
- 10 million tonnes from forest fires
- 10 million tonnes from wood salvaged from insect infestations like mountain pine beetle
- 30 million tonnes from mill residues
- 20 million tonnes from silviculture

The group considered its calculation conservative, since the 54 million tonnes currently produced from AAC yield an estimated 40 million tonnes of available harvest residues. To discount that figure, the group assumed 30 million tonnes of AAC per year, yielding 27 million tonnes of residue. The AAC is set by professional foresters in consultation with some of the best modellers and conservationists available, and is generally believed to represent a sustainable level of harvest, but the group arrived at a lower target to ensure a proper ecological balance for the forest.

This group determined that bioenergy production would rely primarily on combined heat and power (CHP) with wood pellets, as well as increased use of district energy systems. Biofuels would account for a smaller share of total demand, since most of the output would be directed to the primary processing industry, largely for economic reasons.

With the evolution of these and other technologies, increased bioenergy production would improve air quality and lead to fewer forest fires. The short-term carbon balance would be negative, but the carbon debt would be paid back over time, particularly if bioenergy offset coal or other carbon-intensive fuels. Several participants emphasized that this carbon debt would have to be repaid in 15 years or less.

Overall biodiversity was cited as a concern that could be addressed by adapting forest management regimes. Enhanced forest management on smaller scales can lead to enhanced ecosystems by increasing the yield and decreasing the harvesting area. Forest management could also help the forest adapt to climate change by introducing species of trees that will do better in the next 50 to 80 years. Species diversity will prevent the vulnerability of monoculture, a point also raised by the agriculture experts.

The group concluded that increased biomass feedstock production could lead to a net increase in jobs, and a positive economic impact on the wider forest industry, as long as the added production stream supported other parts of the bioeconomy and did not shift labour from higher-value products like furniture.

This group pointed to the competition for biomass as a potential challenge for bioenergy production. The attractiveness of bioenergy as a business proposition is shaped in part by the volatility of fossil fuel prices, and by an economic model that includes no recognition of the carbon benefits of bioenergy. A variety of policy measures could support increased production, including easier access to harvest residues. Supply agreements between primary processing and secondary bioenergy industries could be a key component of this model.

Group #3 - Forest Biomass II

The group was cautiously optimistic that Canada's forest sector could reach the 100 million tonne target by using about 28 million tonnes of available slash, taking up the underutilized portion of the current annual allowable cut, enhancing silviculture practices, making better use of afforested areas, and planting on marginal land. Their calculation also factored in an anticipated decrease in forest product demand from the pulp and paper industry.

Energy conversion from slash would be based largely on today's technologies, though emerging options could include mobile pyrolysis technology to produce oil or ethanol, torrefied pellets, and better practices for sorting the slash.

The group pointed to the importance of effective product allocation in optimizing the use of all available technologies.

Using slash as a bioenergy feedstock would improve air quality and life cycle GHG emissions, since slash piles are currently burned at the roadside. This scenario would also enable forest carbon accounting.

The group saw increased bioenergy production as a source of support for the bioeconomy and the traditional forest sector, enabling smaller-scale operations that wouldn't require much transport to produce bio-oil, solid biofuels, or pellets. There is an immediate demand for pellets and biofuels to replace diesel generators that produce tar or gas as byproducts, so this scenario would quickly become economically viable.

Recommendations

As the session drew to a close, participants used flipchart sheets to note their individual thoughts on the steps to be taken to determine the sustainable volume of bioenergy feedstocks and, within that constraint, to increase bioenergy production:

Governments

- Support research and development on commercial bioenergy technologies and other sustainable technologies
- Simplify and coordinate fiscal support for R&D
- Fund university and industry research on biofuels and biorefining
- Support commercialization of bioenergy, for example lignocellulosic feedstock
- Finance pilot projects
- Develop policies that support decentralized cogeneration
- Implement solid biofuel requirements in coal-fired power generation to achieve coal replacement by 2050 (10% biofuel in 2020, 25% by 2030)
- Mandate renewable fuel standards
- Develop policies that reduce dependence on personal transportation
- Internalize sustainability into economics
- Harmonize energy policies
- Establish aggressive GHG emissions targets through regulations and laws
- Incorporate regulatory measures that assist in achieving sustainability and a level playing field for bioenergy, such as a carbon tax – price should be $30 per tonne in 2020, $50 per tonne in 2030, and $100 per tonne in 2050
- Make a strong commitment to environmental protection
- Make a clear statement that climate change is real
- Provincial governments should implement ecosystem-based management
- Create incentives for more intensive forest management (privatization of some forests?)
- Update provincial inventories
- Anticipate and adhere to upcoming accounting rules for biogenic carbon

Businesses

- Form alliances across domains (pulp and paper with chemical processors, food and pharmaceutical industry…)
- Forestry sector should implement extraction and conversion
- Acknowledge climate change
- Take the long view of return on investment
- Make a commitment to develop needed technologies and stick it out until achieved
- Invest meaningful dollars in technology innovation
- Enhance research partnerships with universities on bioenergy and biorefining
- Accelerate research and deployment through partnerships with academia, governments, and civil society
- Take innovative risks in the financing and organization of bioenergy
- Support dialogues like this one, with in-kind participation and finances to build consensus on future development of forest and agro-ecosystems
- Show leadership

Academia

- Educate about long-term resource planning to create a bridge between the urban and the rural
- Provide the tools (such as models) to facilitate technology advancement
- Provide very targeted research and effective network
- Orient R&D in cooperation with stakeholders
- Partner with industry to find and develop sustainable solutions
- Provide research on harvest levels that can still maintain long-term sustainability
- Provide a robust and up-to-date inventory of forestry

Civil Society

- Give social license to price carbon
- Advocate for a low-carbon society and develop clear calls for action
- Create pressure groups
- Partner with DSF, TEFP, CAE, businesses, and others to educate and push for sustainable technologies

David Suzuki Foundation

- Public information and education
- Develop low-carbon scenarios
- Support continuing dialogues like this one to address potentially divisive issues related to biomass for energy
- Advocate for lowest-carbon, sustainable solutions that have greatest positive impact, not just least harm
- Advocate for low-carbon society
- Lobby, lobby, lobby!
- Be credible in statements about climate change. If you are not, you have no credibility in proposing solutions
- Do some work on sustainable residue yields
- Engage government, businesses, and NGOs in discussions on the merits and cons of developing a bioenergy industry
- Define what is sustainable forestry for energy and promote it to government
- Have a consistent messaging on bioenergy

Canadian Academy of Engineering

- Lobby, lobby, lobby!
- Support the David Suzuki Foundation with credible data
- Increase public education on sustainable solutions
- Support innovation
- Do life-cycle analysis of various energy system pathways
- Focus on systems-level support
- Develop potential low-carbon scenarios
- Develop activities in regional sections
- Reward and encourage innovative research projects, especially among young engineers
- Integrate ecological approach in engineering curriculum and training
- Consider role of bio-based options for energy and construction projects
- Focus on transport fuels and viable second-generation (cellulosic) technology
- Define what is sustainable forestry for energy and promote it to government
- Have a consistent messaging on bioenergy

Trottier Energy Futures Project

- Break down the residues stream on your table into mill waste, logging slash, oil and gas right-of-way and provide quantified numbers for different annual cut levels
- Continue programs to bring all of the players together in dialogue and come up with scenarios to achieve sustainability
- Stay the course in this profoundly difficult and complex endeavour
- Keep doing what you are doing to support a low-carbon economy, it is a critical issue that needs dialogue
- Articulate scenarios for bioenergy and the bioeconomy
- Develop potential low-carbon scenarios
- Bring together government, businesses, and academics to formulate practical approaches to developing the industry
- Define sustainability
- Utilize economics-based inventory of biomass (similar to what is done for oil resources)
- Make a balanced assessment of energy system choices (costs, benefits, and tradeoffs)
- Network with academia and industry
- Increase your visibility for society through talks, papers, and op-ed pieces
- Develop and communicate a vision

Takeaways from Participants

Participants went through a final round of comments and shared what they liked and didn't like about the session, as well as their final recommendations.

A number of participants recommended having separate discussions for forestry and agriculture, since the two streams come with their own unique challenges and opportunities and deserve more in-depth analysis. However, most participants also appreciated the opportunity to learn more about both streams.

Most of the group saw sustainability as the core component of the discussion, but called for a better definition of sustainability. Along the same lines, several participants stressed the need to look at the knowledge gaps and come up with the right research questions.

When looking at forest biomass, one participant highlighted that time and space are important factors to take into account. While there were some discussions around temporal scales in forestry, including appropriate time frames for correcting any carbon debts, spatial scales received less emphasis in the discussion. A participant added that forestry will face new challenges with the changing climate, and spatial scales will need to be examined in order to define sustainability more accurately.

Many of the participants agreed on the need for more accurate data and a better inventory of available biomass resources before moving forward with scenario planning. A participant said calculations must be based on economically recoverable biomass, using models similar to the ones used in the oil and gas industry, to avoid creating artificial goals and targets.

Most participants were impressed by the level of expertise in the room and stressed the importance of having all actors represented in these conversations, including woodlot owners, industry, academics, government representatives, and First Nations. In particular, several participants said it would have been useful to have wider industry representation at the table. Partnerships are the prerequisite for a meaningful assessment of biomass feedstocks, and for any eventual shift to bioenergy.

Participants also mentioned the importance of having a simple message that could be pitched to a variety of audiences. One participant said the best way to get governments onboard is to offer a simple path to implementation.

Conclusions

Ralph Torrie thanked participants for their involvement in the dialogue process. He said he particularly appreciated the timeline exercise for the tremendous perspective it gave to the conversation: the history showed how much had changed in a short time period. The Trottier Project's challenge is to imagine a low-carbon future that is grounded in science, evidence, and logic, but without the limitations built into most energy scenarios.

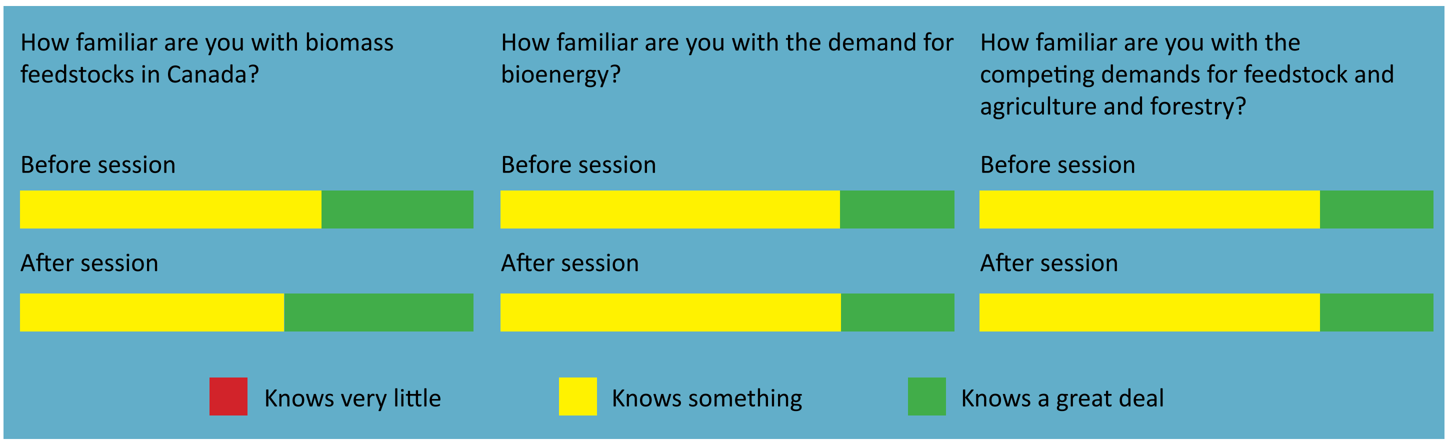
Torrie said the day's discussion had reassured him that a significant bioenergy future is not beyond the bounds of what might be achieved sustainably. It also reinforced the need to cut across silos. He said the dialogue was the first of its kind, and will inform the TEFP's work on low-carbon energy futures.

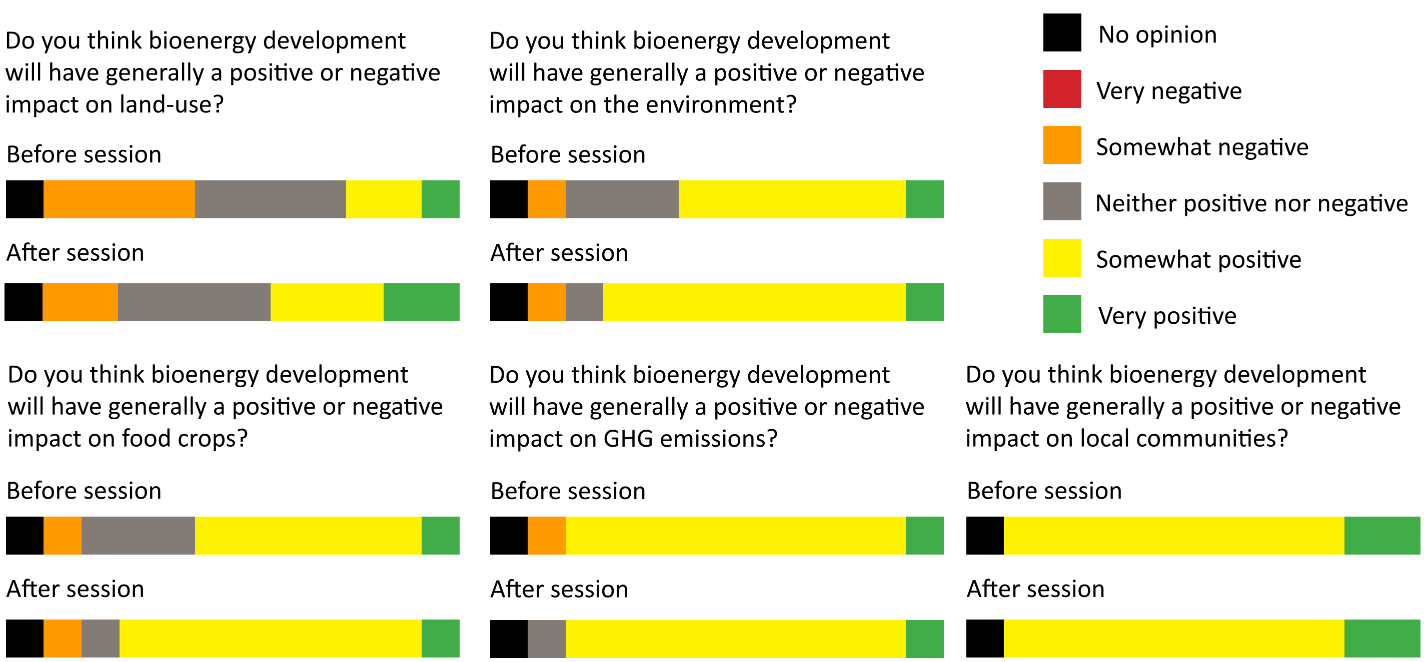
This report has been reviewed by the TEFP and all dialogue participants for accuracy.

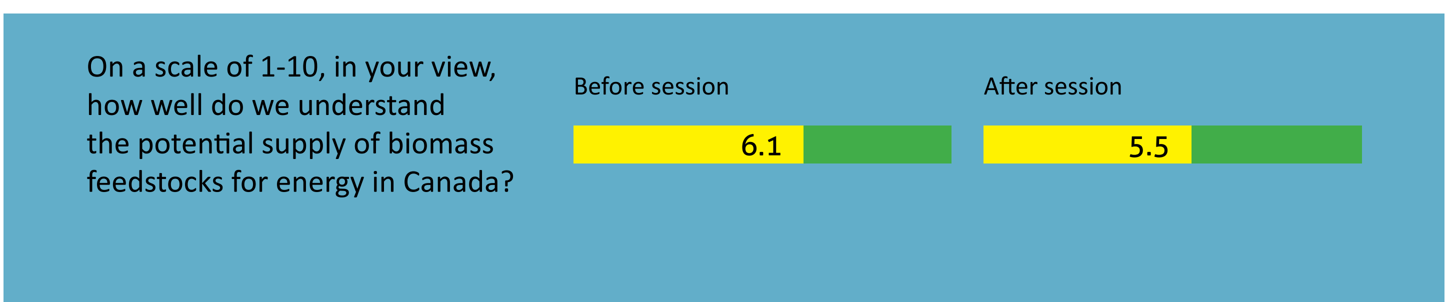
The discussion guide and this dialogue report are available through the Creative Commons on the Carbon Talks website. Participants are encouraged to continue to engage with Carbon Talks and TEFP through their websites.

Pre and Post Questionnaire Results

Each unit represents the response of a single dialogue participant and are presented here to indicate thought shifts. Responses to questions asking for a response on a scale of 1-10 are averaged among all participants.







Glossary of Terms

Biorefinery
A biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass. The biorefinery concept is analogous to today's petroleum refineries, which produce multiple fuels and products from petroleum. Industrial biorefineries have been identified as the most promising route to the creation of a new domestic bio-based industry.

By producing multiple products, a biorefinery can take advantage of the differences in biomass components and intermediates and maximize the value derived from the biomass feedstock. A biorefinery might, for example, produce one or several low-volume, but high-value, chemical products and a low-value, but high-volume liquid transportation fuel, while generating electricity and process heat for its own use and perhaps enough for sale of electricity. The high-value products enhance profitability, the high-volume fuel helps meet national energy needs, and the power production reduces costs and avoids greenhouse-gas emissions.

NREL. (2009). Biomass research. Available: http://www.nrel.gov/biomass/biorefinery.html. Last accessed 7th February 2013.

Lignocellulosic Biomass
Organic material derived from biological origin which has a relatively high content of lignin, hemicellulose, cellulose, and pectin combined into a molecular matrix with a relatively low content of monosaccharides, starch, protein, or oils. Typically refers to plant structural material with high cell wall content.

Wu, A.; McLaren, J.; Madl, R.; Wang, D. . (2010). Biofuels from Lignocellulosic Biomass. Sustainable Biotechnology. 1 (1), p19-41
.

Mobile or Fast Pyrolysis
Wood pyrolysis has been used for centuries to create charcoal or tar used to caulk boats, embalm the deceased, and improve soil productivity *(Mohan et al. 2006; Winsley 2007)*.

Using a "slash and char" practice, approximately 50 per cent of the initial carbon in the biomass is sequestered and contrasts to only three per cent carbon sequestration from "slash and burn" forest practices *(Lehman et al. 2006)*. "Fast" pyrolysis gets its name because it uses a faster heating rate as compared to conventional pyrolysis methods *(Mohan et al. 2006).*

Either method (fast or conventional) involves the process of heating a biomass feedstock in the absence of oxygen *(Huber et al. 2006)* and condensing the resultant vapours. Fast pyrolysis produces high yields (up to 80 per cent of the dry weight) of bio-oils suitable for transportation fuels or for refinement for other uses *(Huber et al. 2006).*

Fast pyrolysis requires that uniform-sized biomass is used as feedstock to ensure even heating. The specific characteristics of these products are dependent on the species or tree component used and pyrolysis temperatures *(Mohan et al. 2006).*

Portable in-woods pyrolysis: Using forest biomass to reduce forest fuels, increase soil productivity, and sequester carbon.

Page-Dumroese, Deborah; Coleman, Mark; Jones, Greg; Venn, Tyron; Dumroese, R. Kasten; Anderson, Nathanial; Chung, Woodam; Loeffler, Dan; Archuleta, Jim; Kimsey, Mark; Badger, Phil; Shaw, Terry; 9 McElligott, Kristin. 2009. Paper presented at the North American biochar conference; August 9-12; Boulder, CO. Center for Energy and Environmental Security. 13 p.

Precision Farming
Precision farming, sometimes called site-specific farming, is an emerging technology that allows farmers to adjust for within-field variability in characteristics like soil fertility and weed populations. Precision farming uses the global positioning system (GPS), consisting of 24 satellites that transmit signals picked up by user receivers to define the receiver's location. With this information and on-board sensors, farm equipment can monitor crop yields and guide applications of crop inputs like fertilizers and herbicides.

Len Kryzanowski. (2012). About Precision Farming. Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag1950. Last accessed 7th February 2013.

Slash
Slash is the leftover tree limbs, tops and other residue left by logging activities. Slash is disposed of, by burning, in two ways:

- In piles: slash is piled together and burned during safe conditions, usually during the winter after it has been left to season (dry); and

- Through broadcast burning: the limbs and tops, and other residue are burned as they lie on the ground after cutting. The slash must be distributed continuously throughout the burn area to be burned effectively. Burning is generally done during very wet periods or with light snow cover in late fall or early spring.

BC Air Quality. (2012). Slash and Wood-Residue Burning. Available: http://www.bcairquality.ca/topics/slash-burning.html. Last accessed 7th February 2013.

Torrefaction

The torrefaction of biomass materials is considered to be a very promising technology for the promotion of the large-scale implementation of bioenergy. Torrefaction involves heating biomass in the absence of oxygen to a temperature of 250-320 °C. At these temperatures, a dry, torrefied product is obtained, which is stable, brittle and water resistant. This makes it much easier to grind than the parent biomass material and reduces biological degradation in storage. By combining torrefaction with pelletisation or briquetting, biomass materials can be converted into a high-energy-density commodity solid fuel or bioenergy carrier with improved behaviour in (long-distance) transport, handling and storage, and also with superior properties in many major end-use applications.

Provided that the torrefaction process is conducted in an energy-efficient manner, i.e. with heat recovery and integration, overall biomass-to-torrefied-pellets energy efficiencies in excess of 90 per cent (based on lower heating value) can be reached. In this way the overall energy efficiency of torrefaction-based biomass supply chains is increased, simultaneously reducing the CO_2 footprint and costs. In addition to the possible reduction of CO_2 emissions, torrefaction can help to exploit the large potential of residues. An increased use of residues might be one possibility to ease challenges for a sustainable bioenergy supply such as food vs. fuel issues or direct and indirect land use changes.

SECTOR. (2012). Torrefaction. Available: http://www.sector-project.eu/torrefaction.32.0.htmlning.html. Last accessed 7th February 2013.

Appendix A - Dialogue Evaluation

The phone calls and emails during recruitment and after agreeing to participate gave helpful information.	5.3/7
The registration process was efficient and friendly.	6.3/7
The dialogue handbook provided for the discussions was clear and contained relevant and useful information.	5.6/7
The facilitator provided clear explanations, guidance and support throughout the day.	6.1/7
The meals and refreshments were satisfactory.	6.7/7
There was adequate opportunity for me to learn and to participate in group discussions.	6.1/7
Overall, the dialogue was worthwhile to me.	6.1/7
Based on this experience, I am more likely to become involved with similar consultations.	5.7/7

Appendix B - Dialogue Agenda

8:30 AM	Registration, Refreshments and Pre-questionnaire
9:00 AM	Opening. Ralph Torrie, Managing Director, Trottier Energy Futures Project
	Overview of Agenda, Rules of Engagement. Shauna Sylvester, Executive Director, Carbon Talks
	Introductory Round - What is one hope and one concern you have about the sustainable supply of biofuels in Canada?
	Context setting - Is Biomass a Low-Carbon Alternative to Fossil Fuel?
	Timeline exercise - What events, policies, people and initiatives have shaped our use of bioenergy over time in Canada?
10:45 AM	Break
11:00 AM	**Roundtable #1** - Thinking about the future – to 2050
	Roundtable #2 - How might the limits on Canada's biomass feedstock production be affected by...
12:30 PM	Lunch
1:30 PM	Scenario Building
3:00 PM	Break
3:15 PM	**Roundtable #3** - What is the critical path to advance the sustainable use of biomass in a low-carbon Canada?
	Summary and Next Steps **Final Round** - Recommendations and Evaluation
4:30 PM	Close and Post-Questionnaire

Appendix C - Rules of Engagement

1. Chatham House Rule: "participants are free to use the information received, but neither the identity nor the affiliation of the speaker(s), nor that of any other participant, may be revealed."
2. The focus is on dialogue not debate.
3. Hats off: Each participant is here as an individual and is not speaking on behalf of their business or organization.
4. Step up or step back.
5. Cell phones off (or muted).
6. Open Source: The information will be recorded and presented in a report that participants will review. Following the review the report will be available publicly and registered under the Creative Commons.

Appendix D - References For Table 1

1 - Derived from a three-year average of harvest totals from Statistics Canada's "Field Crop Reporting Series" (2011).
2 - Assumes the same carbon content for Canadian crops as given by: Wood, S., and D. Layzell, "A Canadian Biomass Inventory: Feedstocks for a bio-based economy" BIOCAP (2003) p. 20. Assumes that direct combustion of one tonne of carbon produces 35.76 GJ (Wood and Layzell, 2003, p. 23, footnote 8).
3 - Derived from three-year average from Statistics Canada's "Field Crop Reporting Series" (2011). Assumes the same conservative straw-to-grain ration presented by Wood and Layzell (2003) p. 20. Assumes that 80% of residue can be sustainably recovered for all crops but soy (20%) (Wood and Layzell, 2003; Klass, D., Biomass for Renewable Energy, Fuels and Chemicals. (Academic Press, San Diego, California: 1998).
4 - Assumes carbon content of 45% and 35.76 GJ from direct combustion of one tonne of carbon (Wood and Layzell, 2003, p. 23, footnote 7).
5 - Milbrant, A., and R.P. Overend, "Assessment of Biomass Resources from Marginal Lands in APEC Economies", NREL (2009), p. 29.
6 - Assumes carbon content of 45% and 35.76 GJ from direct combustion of one tonne of carbon (Wood and Layzell, 2003).
7 - Total volume of annual allowable cut (AAC) in Canada (2009): 246,000,000 m^3 (National Forestry Database, "Wood Supply: Background" (2012) http://nfdp.ccfm.org/supply/background_e.php). Assumes 0.96 t /m^3 and 44% water content in wet wood (Ralevic and Layzell, 2006), thus 132.2 million dried tonnes.
8 - Assumes one tonne of carbon in 4.2 m^3 of wet wood and 35.76 GJ from direct combustion of one tonne of carbon (Wood and Layzell 2003).
9 - Primary forestry residue includes bark, branches, or unfit lumber that is typically left in the forest during harvest. Secondary forest residue refers to waste products from pulp mills and sawmills.
10 - Residue left in the forest equates to 30% of total roundwood of 132.2 MOdt (footnote 19, Ralevic and Layzell, 2006), 70% of which can be sustainably recovered (David Suzuki Foundation, "Smart Generation: Powering Ontario with Renewable Power").
11 - Assumes carbon content of 44% and 35.76 GJ from direct combustion of one tonne of carbon (Wood and Layzell 2003).
12 - In 2009, approximately one-quarter of methane gas was captured, totalling 349,000 tonnes. 100% capture would equate to approximately 1.4 million tonnes.
13 - Assumes a methane conversion rate of 14.4 tonnes/TJ.
14 - Total tonnage from Statistics Canada, "Human Activity and the Environment: Waste Management" (2012): 25.9 million tonnes. Assumes that 85% is combustible, and that combustible material has 22% average moisture content (Wood and Layzell 2003).
15 - Carbon content of 41% for dried combustible material, and 35.76 GJ from direct combustion of one tonne of carbon (Wood and Layzell 2003).
16 - Total tonnage from: Statistics Canada, "Human Activity and the Environment: Waste Management" (2012): 8.5 million tonnes, including 6.9 million tonnes of combustible material. Assumes 10% moisture content (Wood and Layzell 2003).
17 - Carbon content values taken from Wood and Layzell (2003, p. 29). Assumes 35.76 GJ from direct combustion of one tonne of carbon.
18 - Canadian population on sewers: 28,455,184 (Environment Canada, "Municipal Waste Water Indicator", http://www.ec.gc.ca/indicateurs-indicators/defaultasp?lang=en&n=2647AF7D-1). Assumes average 0.97 kg of wet waste per day, equal to 0.063 kg of dry waste (Klass, 1998).
19 - Assumes carbon content of 40% (Klass, 1998) and 35.76 GJ from direct combustion of one tonne of carbon (Wood and Layzell 2003).
20 - Number of head of cattle, poultry, pigs, and sheep from Statistics Canada's Agricultural Division (2012) Catalogue no. 23-012-X; 23-010-X; 23-015-X; 23-011-X. Dried kg/head/day from Klass (1998).
21 - Energy content of waste and percentage recoverable from Ralevic, P., and D. Layzell, "An Inventory of the Bioenergy Potential of British Columbia," BIOCAP (2006).

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