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Biomass Energy in Central British Columbia: Framing the Issues

By
Steve Helle, Art Fredeen, Mike Rutherford,
Greg Halseth, Mike Gillingham, Ken Parker,
Hugues Massicotte

Dr. Helle is an Assistant Professor with the Environmental Engineering Program, University of Northern British Columbia, 3333 University Way, Prince George, B.C., V2N 4Z9 Canada. Dr. Fredeen is an Associate Professor with the Ecosystem Science and Management Program, University of Northern British Columbia, 3333 University Way, Prince George, B.C., V2N 4Z9 Canada. Dr. Rutherford is an Associate Professor with the Environmental Engineering Program, University of Northern British Columbia, 3333 University Way, Prince George, B.C., V2N 4Z9 Canada. Dr. Halseth is a Professor with the Geography Program, University of Northern British Columbia, 3333 University Way, Prince George, B.C., V2N 4Z9 Canada. Dr. Gillingham is a Professor with the Ecosystem Science and Management Program, University of Northern British Columbia, 3333 University Way, Prince George, B.C., V2N 4Z9 Canada. Dr. Parker is a consulting biologist with Bird/Land Ecosystem Management, #113 3885 - Richet Rd., Prince George, B.C., V2K 2J2 Canada. Dr. Massicotte is an Associate Professor with the Ecosystem Science and Management Program, University of Northern British Columbia, 3333 University Way, Prince George, B.C., V2N 4Z9 Canada.

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For more information about NRESI contact:

Natural Resources and Environmental Studies Institute
University of Northern British Columbia
3333 University Way
Prince George, BC Canada
V2N 4Z9

Phone: 250-960-5288
Email: nresi@unbc.ca
URL: www.unbc.ca/nres

CONTENTS

Abstract

Bioenergy, or energy derived from biomass, was the predominant energy source for humans from prehistory to the mid-19th century. With on-going energy security issues, rising greenhouse-gas (GHG) levels driven by fossil fuel energy consumption and volatile natural resource prices, the biomass energy of yesterday is now being re-evaluated as the energy source for tomorrow. The technology of bioenergy production has evolved considerably in recent years, such that heat, electricity and liquid fuels for transportation can all be derived from a wide variety of biomass starting materials. Though the transformation of sunlight energy into chemical biomass energy in plants is in theory an endlessly renewable process, the way in which we manage our lands to generate this biomass energy can be degradative and unsustainable when all of the land-use values are taken into account. This paper evaluates bioenergy through the prism of sustainability, highlighting issues relating to the physical and temporal scales of the resource and impacts of its use, technological opportunities and limitations, net environmental impacts, and community concerns and needs. The geographic focus is the central interior of British Columbia, however, the issues raised in this paper will be relevant to all locations considering bioenergy.

Introduction

Biomass energy production has become a major political and environmental topic because of the potential to address global problems related to climate change and energy security (Karp and Shield 2008). Biomass energy, also called bioenergy, is defined here as the production of energy from biological sources. Bioenergy may hold promise for central British Columbia because it has the potential to substitute for a portion of our fossil fuel demand. This could improve energy self-sufficiency, increase economic and social viability and diversification of forest-based communities, and increase use of forest industry wood waste. The full range of environmental, social, cultural, and economic considerations, however, need to be scrutinized if biomass energy is to be a truly sustainable enterprise.

Here, we define sustainability in broad accordance with The Brundtland Commission report (WCED 1987), which defined sustainable development as that which "… meets the needs of the present generation without compromising the ability of future generations to meet their own needs." This generalized concept of sustainability is useful in conceptualizing the sustainability of biomass production. In this light, we propose the following criteria for determining the sustainability of biomass production for energy: 1) a full greenhouse gas (GHG)[1] accounting and reduction in greenhouse-gas emissions (e.g., decreases from both combustion of fossil fuel and landscape disturbance); 2) harmony with local to regional food production where land-use conflict arises; 3) maintenance of environmental and human health, biological diversity and ecosystem services; 4) proper consideration given to cultural and social values; and 5) net regional economic benefits are realized. The potential for conflicts among these criteria are obvious and perhaps unavoidable. Nevertheless, attempts to exploit biomass energy should not favour short-term gains, particularly economic ones, over the needs or health of future generations.

The objective of this paper, therefore, is to identify and explore the issues and questions surrounding sustainable bioenergy development and use in central B.C. Towards this objective, an overview of technologies for electricity and fuel production from biomass is provided in order to give context to bioenergy potential in the overall energy supply mix. This is followed by an analysis of BC biomass supply and sustainability for bioenergy, air quality issues surrounding biomass combustion, the use of combustion residuals as soil amendments, the impact of land use changes on greenhouse-gas emissions, and finally the economic, social, and cultural aspects of bioenergy use. The primary focus will be on the utilization of forest-generated biomass for energy production; other forms and sources of biomass and energy will also be considered for comparative purposes. This paper is not intended to be a guide on how to choose bioenergy applications; detailed reviews of modern biomass conversion technologies are available (e.g., Bridgwater 2006, Faaij 2006, BIOCAP 2008).

Biomass to Energy Conversion Technology and Processes

Bioenergy is a broad term that covers a range of technologies and applications, from

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[1] Greenhouse gases (GHG) include CO_2 and CH_4

traditional heating and cooking to electricity generation to the production of transportation fuels (referred to as biofuels hereafter). Feedstocks for these processes range from waste products (e.g., crop residues, forestry residues, livestock residues, industrial and municipal wastes) to dedicated bioenergy crops and forestry operations. Traditional cooking and heating applications accounted for approximately 30 exajoules[2] (EJ) of the annual 500 EJ global primary energy consumption in 2006. Modern applications of bioenergy provided about 20 EJ of primary energy supply, or 4% of total global energy use (IEA 2008b). This is primarily from modern heat and electricity applications, which are well established with mature, although continually evolving, technology. Biofuel production (primarily ethanol and biodiesel) has been increasing rapidly in recent years and supplied 1 EJ of global energy demand in 2006, or 1% of road transport fuel consumption (IEA 2008b). More advanced biofuel processes with greater biofuel yields per ha and potentially lower environmental impacts are in development.

Heat and electricity

Biomass heat applications include residential fireplaces and stoves, district heating systems, and industrial processes. Biomass combustion may also be used to drive engines/turbines to produce electricity. The appropriate technology for a given source of biomass depends on the biomass characteristics and on the location and size of the operation. Different bioenergy systems may be compared based on efficiencies, measured as the percentage of energy in the biomass that is converted into useful heat or electricity. Efficiencies for bioenergy applications range from 10 to 90% and depend on many factors, including the feedstock and the process used.

Biomass combustion systems can have very low efficiencies. For example, traditional and residential biomass combustion systems for heating typically have efficiencies of 10-20% or less and produce considerable dust and soot (Faaij 2006). Low efficiencies are due in part to poor heat recovery from the hot flue gases and to incomplete combustion. Incomplete combustion may result from low combustion temperatures, suboptimal fuel-air ratios, and the loss of volatile components as the temperature of the fuel rises. Compared to fossil fuels, a greater percentage of the energy content of biomass is present in the volatile components. In poorly designed furnaces or fireplaces these volatile compounds will exit with the flue gases resulting in incomplete combustion and considerable air pollution. Efficiencies can be improved by modifications to the boilers to keep the flue gases at high temperatures for sufficient time to allow for complete combustion of the volatile compounds. For stoves and fireplaces this can be achieved by exposure of the flue gases to the heat of the fire or by the addition of catalysts to allow combustion in the flue gas at lower temperatures. For large-scale combustion, efficiency may be improved by the use of fluidized bed boilers where the burning biomass is thoroughly mixed with air and the combustion gases to provide a uniform high temperature and optimal fuel-air mixtures. In addition, a portion of the energy contained in the water vapour exiting with the flue gas may be recovered by condensing this water.

Another strategy to improve combustion efficiency is to use a 2-stage combustion process, with the first stage at high temperature (400 – 1,000 °C) and oxygen-limiting conditions to convert the biomass

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[2] Exajoules (EJ) = 1 x 10^{18} joules; a joule (J) is a unit of energy where 1 Watt (W) is 1 Joule per second. An EJ is a large amount of energy; 1 EJ is equivalent to 170 million barrels of oil.

into gaseous, liquid and energy dense solid products. The proportion of gas, liquid, and solid produced depends on the oxygen supply, temperature and reaction time. Gasification processes, optimized to produce mainly gas, involve heating the biomass with limited oxygen to release the volatile components, which then react with steam, oxygen, and residual solids to produce a gas (syngas). Syngas contains carbon monoxide, hydrogen, water, carbon dioxide, methane, higher hydrocarbons and condensable tars. Gasification products can be used in internal combustion engines or gas turbines (tars, metals, and dust must be removed first). To obtain a liquid product (e.g., bio-oil), biomass is heated to high temperatures in the absence of oxygen for a few seconds (pyrolysis). The resulting bio-oil is a mixture of oils, acids, alcohols, aldehydes, ketones, esters, and water. Although bio-oil is difficult to work with (i.e., high viscosity that increases over time, polymerizes on heating, complex chemistry, phase separation, low pH, high water content), it can be used for heating and power generation (e.g., in an engine, boiler, or co-fired with coal). Long pyrolysis times at lower temperatures (300 to 500 °C) in the near absence of oxygen, drives off the volatiles and thermally decomposes the organic matter leaving almost pure carbon (biochar). These pyrolysis products (gas, liquid or solid) can often be used more efficiently than the original biomass, offsetting the energy requirements for conversion (~10% of the biomass energy content) (Metzger and Hüttermann 2008). For example, small-scale gasification systems for heat generation have efficiencies ranging from 80 to 90% (Faaij 2006). An additional advantage for bio-oil and biochar production is the increase in energy density, making these products more suitable for transportation over long distances compared to biomass. Both bio-oil and biochar have been proposed for carbon sequestration applications. Biochar can also be used as activated carbon or as a soil amendment.

Biomass power plants for electricity generation come in a range of sizes, from 0.1 to hundreds of megawatts[3] (MW). Due to the distributed sources and low energy density of biomass, 100 MW is considered to be a large power plant, compared to 1,000 MW for a large fossil fuel power plant (a 100 MW power plant would provide enough electricity for 60,000 homes – assuming an 80% capacity factor). Biomass power plants larger than 20 MW typically use steam turbines to drive the generator, and have efficiencies of 25 to 30% for installations 20 to 50 MW in size, and efficiencies of 30 to 40% for installations from 50 to 80 MW. For smaller installations below 20 MW, steam-driven power plants are not usually economical. One option for small power plants is to use gasification and burn the resulting gas in internal combustion engines, with efficiencies ranging from 15 to 25% for electricity and much higher for heat generation (see below). Currently, small gasification power plants are available in 0.1 to 0.2 MW capacities. One of the most economical and efficient processes to produce electricity from biomass is to co-fire the biomass with coal in large coal-fired power plants, displacing up to 10% of the coal, with efficiencies of 40% (Faaij 2006). Future large biomass power plants employing biomass gasification (biomass integrated gasification combined cycle or BIGCC) are projected to achieve efficiencies of 50%. In this process the biomass is gasified, combusted, the hot combustion gases are used to drive a gas turbine and then to generate steam. The steam is used to run a steam turbine (Bridgwater 2006).

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[3] Megawatt (MW) is 1 x 10^6 W. Power plant size is typically given in units of MW. Typical large coal power plants produce ~1,000 MW.

With thermal electricity generation, the fuel energy that is not converted to electricity is discarded to the environment as waste heat. For biomass, this results in 50 to 80% of the original energy content of the biomass being lost to the environment as waste heat. Cogeneration systems (and combined heat and power plants) combine the production of electricity with the production of useful heat. The waste heat from electricity generation can be used for industrial purposes, heating greenhouses, or district (municipal) heating systems, provided the power plant is located nearby. Cogeneration saves 10 to 30% of fuel compared to separate generation of heat and electricity (Smil 2008). Cogeneration installations have overall efficiencies between 60 and 90%. Sizes are similar for installations that just generate electricity (1 to 60 MW electricity), and approximately 2 to 3 times as much heat as electricity is produced (IEA 2008a). For comparison, the average heating demand of a Canadian household is about twice the electricity demand, although the heating demand has much greater variation throughout the year. An advantage of industrial over district heating cogeneration systems is the more constant demand for heat throughout the year in industrial systems. Distributed electricity generation (e.g., a combined heat and power plant in every community) helps to increase the reliability of the electrical system compared to large centralized power plants.

Transport fuels

Globally, the transport sector accounts for 28% of energy consumption, primarily supplied by oil. Conversion of biomass to biofuels may result in several benefits. These include the possible reduction of greenhouse-gas emissions from oil and a decrease in the reliance on increasingly constrained oil supplies (IEA 2008b). In BC there are 2.25 million light vehicles (less than 4.5 tonnes) driving an average distance of 15,000 km every year with an average fuel economy of 11.5 L per 100 km (or 20.5 miles per gallon). These numbers may be used to compare the fuel consumption of an average car in BC (1,700 L of fuel per year) to the biofuel yields per ha presented in the following section. Note that the most cost effective way to reduce greenhouse-gas emissions from the transport sector come from improving the fuel economy of vehicles (Enkvist et al. 2007).

1st generation biofuels

Ethanol, made from sugar cane and starches, accounted for 83% of all biofuels produced in 2006 (IEA 2008b). Ethanol-blended gasoline (e.g., 10% ethanol) can be used in most current vehicles; flex-fuel vehicles can use an 85% ethanol, 15% gasoline blend. Ethanol has a lower energy density compared to gasoline, resulting in a slightly reduced range on a tank of fuel. In addition, ethanol is not compatible with current pipeline infrastructure and is transported mainly by rail and truck. Biodiesel (defined below) can be used as a diesel substitute or blended with diesel. Biodiesel has a slightly lower energy density than oil derived diesel, but burns more efficiently.

Ethanol can be made from sugar cane, grains, or cellulosic biomass. Ethanol production from sugar cane is the most efficient and cost effective process, yielding approximately 6,000 L per ha with an 8 to 10-fold return on energy investment. Ethanol from corn grain or other starches is produced by separating the starch from the other components of the grain, enzymatic hydrolysis of the starch to sugar, fermentation of the sugar to ethanol, and distillation of the fermentation broth. When made from corn, the ethanol yield is approximately 1,900 L per ha. The energy in the ethanol produced is slightly greater than the energy input (farming and processing) into the process (Groom et al. 2004, Field et al. 2007, Tilman et al. 2006). The variations in biofuel yield per ha are due to a number of factors, including the differences in yields between different climates, the fraction of plant biomass harvested, the usable fraction of the harvest and differences in the biomass properties and energy intensity required for conversion to fuel.

Biodiesel can be made from used cooking oil or from oilseed crops (e.g., canola, palm, soybean) through a simple chemical transformation once the oil is extracted from the plant. Biodiesel produced from canola returns approximately 3 times as much energy as that put into the process (e.g., the energy content of the produced biodiesel is approximately 3 times greater than the energy used for planting, fertilization, harvesting, transportation and processing). Biodiesel from canola yields approximately 2,700 L per ha. Biodiesel from palm oil has an energy return of 9, and yields 4,700 L per ha (Groom et al. 2008).

2nd generation biofuels

Next-generation biofuels, currently in the demonstration phase, will likely be made from a wide variety of cellulosic biomass sources (e.g., grasses, trees, agricultural and forestry residues, and some municipal and industrial wastes). These technologies hold the promise of high energy production ratios, while at the same time reducing the current concerns of competition between food and fuel. There are 2 broad approaches to converting cellulosic biomass into fuels. The first approach is via separation of the lignin, hemicellulose, and cellulose components of the biomass using acid or alkaline digestion, followed by enzymatic or acid hydrolysis of the cellulose to sugar. Ethanol is made via fermentation of the sugars followed by distillation. It is estimated that the energy return in ethanol and by-products will be 4 to 10 times more than the energy inputs, and ethanol yields will range from 3,000 to 10,000 L per ha using dedicated bioenergy crops (Groom et al. 2008).

The second approach to producing biofuels from lignocellulosic biomass uses thermochemical methods. For example, gasification can be used to convert the biomass into a syngas (e.g., CO and H_2). Syngas can then be used to make a variety of products, including methanol, hydrogen, or synthetic gasoline via the Fischer-Tropsch process. These processes may have energy returns as high as 60 and yield up to 50,000 L per ha, depending on climate (Groom et al. 2008). A comparison of various biofuels found fuels made from gasification processes were superior to biodiesel and ethanol (from grains and cellulosic biomass) for greenhouse-gas reductions, land use, efficiency and potential production (Volvo 2008).

The technology with the highest potential is biodiesel from algae. Algae with high oil content (up to 50% by weight when grown under the right conditions) can be grown under a wide range of conditions with minimal inputs. Biodiesel yields are an order of magnitude greater than conventional oilseed crops (50,000 to 100,000 L per ha.) (Groom et al. 2008).

All of these 2nd-generation biofuel processes may be used for the production of a wide variety of chemical feedstocks in addition to fuels, heat and electricity production (heat and electricity are produced from the biomass not converted to fuel or chemicals). These processes can be integrated into pulp mills or refineries and used to produce a variety of synthetic compounds for the chemical industry, displacing a portion of fossil fuel feedstock.

Anaerobic digestion

Wastes high in organic matter and moisture (e.g., municipal waste, manure, sewage sludge) may be digested anaerobically. Anaerobic digestion is a complex biochemical process during which a mixture of naturally occurring bacteria are used to digest the organic matter into sugars and organic acids and then into biogas. Biogas, a mixture of carbon dioxide, methane and to a lesser extent hydrogen sulfide, can be used for heat and/or electricity generation in engines or turbines or as a gaseous fuel for transportation (after processing and cleaning such as removing sulfides). Anaerobic digestion occurs naturally via methanogenic microorganisms in landfills and in manure collection lagoons, producing significant amounts of methane. As methane is a more potent greenhouse-gas than carbon dioxide, the methane produced from waste decomposition should be collected and flared to carbon dioxide, or collected and used for heat and/or electricity generation potentially displacing a portion of fossil fuel use. Many wastewater treatment facilities (e.g., anaerobic digesters to treat sewage sludge) and sanitary landfills (e.g., for municipal waste) currently capture methane for on-site energy generation. Although collecting landfill gas from landfills reduces greenhouse-gas emissions, these collection systems are not currently 100% efficient at capturing all of the methane; often less than 50% is collected over the lifetime of the landfill. For this reason, organic matter should be diverted from landfills to anaerobic digestion (with 100% capture of the generated methane) or to composting facilities (organic carbon converted to carbon dioxide under aerobic conditions) (Pelley 2008). Both aerobic and anaerobic digestion produce residuals containing some of the original nutrients (e.g., nitrogen).

Transporting biomass

One drawback to most forms of bioenergy use is the low energy density of biomass, both spatially over the harvest area and also on a weight basis of the biomass and the produced biofuel. This low energy density increases collection and transportation costs, lowers the overall efficiency of bioenergy applications, and limits the economically feasible collection area for bioenergy plants. Dry wood has an energy density of 16 to 18 gigajoule[4] (GJ) per tonne (Huber et al. 2006, Ralevic and Layzell 2006), compared with an energy density of 25 to 30 GJ per tonne for coal. Green (undried) wood at 50 to 60% water content, however, has an energy density that is much lower at 6 to 9 GJ per tonne. To address this issue, biomass may be processed into pellets by drying and compaction, which increases the energy density to ~18.5 GJ per tonne. Energy used to produce pellets may be offset by transportation energy savings (e.g., pelletization is used prior to shipping biomass to Europe) and also by the greater combustion efficiency of pellets compared to unprocessed biomass (due to the dryness and pellet uniformity which allows for optimal air/fuel combustion conditions). Other densification processes include pyrolysis for conversion to bio-oil (17 GJ per tonne) and biochar (up to 30 GJ per tonne). Once biomass is converted to electricity, the energy content can be transported the distance of the electrical grid (Metzger and Hüttermann 2008).

Comparison of bioenergy use for biofuels, heat & electricity

Bioenergy is a versatile energy resource that can be used to complement British

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[4] Gigajoules (GJ) = 1x10^9 Joules; 1/1000,000,000th of an EJ. Average household energy use in Canada is 110 GJ/year, of which ~40 GJ/year is in the form of electricity.

Columbia's abundant renewable energy resources, which include hydroelectric, wind, solar, wave, tidal, and geothermal (Table 1). Given that there is a finite annual supply of biomass available for bioenergy uses, consideration should be given to determine the applications that result in the maximum benefit to society. The choice of applications will depend in part on the objectives (e.g., to maximize added value and employment, to minimize fossil fuel use and greenhouse-gas emissions, or others).

A unique application for bioenergy is the production of liquid fuels compatible with our current transportation infrastructure. A review of various energy sources for transportation use found that biofuel vehicles, in particular ethanol from corn or perennial crops, however, had greater greenhouse-gas emissions, air pollution, health impacts, water consumption, biodiversity impacts, and water pollution than battery powered electric vehicles charged by wind, solar, hydro, geothermal, tidal, wave, nuclear and coal (with carbon capture and storage) (Jacobsen 2009). Note, however, that the non-biofuel options require much greater changes to our existing infrastructure. Biofuels fared poorly due to greenhouse-gas emissions from direct and indirect land use changes and air pollutants from combustion. If land use changes are not accounted for, greenhouse-gas emissions from bioenergy are comparable with emissions from other non-fossil fuel energy sources (Table 1). There is a large range in the land requirements for bioenergy, with the largest land area for biomass from unmanaged temperate forests and the

Table 1. Annual technical and economical exploitable BC renewable energy resources, comparison of land requirements and CO_2 emissions.

Resource	BC Hydro estimates[a] (PJ)	Globe Foundation estimates[b] (PJ)	Energy per Area[c] (GJ per ha)	Greenhouse-gas emissions[d] (tonne CO_2 per GJ)
Large hydro[e]	54.0	21	20 - 120	0.0006 - 0.11
Small hydro	28.8	39	60 - 6,000	
Wind	57.6	114	30 - 3,000	0.003 - 0.02
Solar (PV)	1.4	20	80 - 600	0.008 - 0.04
Biomass	7.2	165	1.5 - 40	0.01 - 0.05
Geothermal	7.9	32		
Wave	2.3	28		
Tide	5.4	9		
Coal			150 - 1,500	0.27 - 0.36
Coal, advanced				0.22 - 0.24
Oil				0.19 - 0.24
Natural gas			1,500 - 5,000	0.13 - 0.34
Nuclear			7,000	0.003 - 0.03
Total	164.6	428		

[a] Current and future prospects (BC Hydro 2004, BC Hydro 2007)
[b] Globe Foundation 2007
[c] Gagnon et al. 2002, Smil 2003, smaller numbers indicate greater land requirements
[d] Holdren and Smith 2000, emissions for electricity production
[e] Large scale hydroelectric projects is in addition to the 200 PJ currently installed.

smallest land area for biomass from intensively managed forests (Smil 2003). Climate (mainly annual temperature and precipitation) will have a large influence on land requirements. Using forestry and agricultural residues for cellulosic biofuel production would greatly reduce the issues surrounding land use.

Bioenergy can generate stable, predictable base-load electricity, similar to large-scale hydro, geothermal, fossil fuels and nuclear power. Run-of-river hydroelectric, wind, solar, wave, and tidal power are considered intermittent or variable energy sources. In the absence of electricity storage technology, variable energy sources are limited to providing 10 to 20% of the total electricity fed into the grid (Turkenburb 2000). Variable energy sources, such as wind, and large scale hydro can be a good mix. Excess hydro capacity, if available, can be used when the wind is low. When the wind is strong, water can be stored in the reservoirs. Estimates of economically exploitable renewable energy resources for electricity generation in BC range from 160 to over 400 petajoules[5] (PJ), with wind power having the greatest potential (Table 1). For comparison, electricity use in BC in 2006 was 205 PJ (NRCAN 2006). Estimates of potential exploitable renewable resources are difficult to make and require many assumptions, including the time scale for renewal, level and accessibility of technology, resource access, and proximity to energy distribution infrastructure. For example, for bioenergy estimates, the BC Hydro estimate (Table 1) is limited to the utilization of existing waste wood, municipal waste and landfill gas while the Globe Foundation (2007) study estimate includes additional biomass sources, including logging residue, accessible beetle-killed trees, and agricultural residues. In addition, the BC Hydro estimate is based on existing commercially viable technology and the Globe study assumes near commercial technology will be viable.

Electricity production has several advantages over biofuel production. One is the technology is readily available. Another is the greater potential for reduction of greenhouse-gas emissions. For example, based on the amount of biomass that can be produced on a ha of agricultural land, 50% greater greenhouse-gas reductions can be obtained from using biomass pellets to displace coal in a coal-fired combined heat and power plant compared to using the biomass to produce cellulosic ethanol to displace gasoline (Hedegaard et al. 2008). These results are due to the large amount of energy required to produce cellulosic ethanol, and due to the fact that coal is more carbon dense than oil (more carbon per unit energy). Globally, in order to limit atmospheric CO_2 concentrations, emissions from coal need to be phased out in the near future, and should be a priority over emissions from natural gas and conventional oil (Kharecha 2008).

The largest current application of bioenergy is for heat. Between 20 and 40% of modern society’s useful energy requirement is for low temperature (<100 °C) heat (Smil 2003). If efforts are made to ensure complete combustion of the biomass, including the volatile components, and if there is good heat transfer from the combustion gases, heat production from biomass can be efficient., This, however, is not necessarily the optimal use of our biomass resources. The utility of our energy resources can be maximized by matching the temperature of the energy source to the required end use temperature. Energy intensive applications such as electricity generation or industrial processes require high temperature resources (e.g., biomass and fossil fuel combustion). Low

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[5] PetaJoule (PJ) = 1 x 10^{15} Joules; 1/1000th of an EJ; 1,000,000 GJ

temperature heat (for residential and commercial space heating) can be provided from the waste heat from high temperature processes (e.g., combined heat and power) or from low temperature energy sources such as geoexchange (heat from the ground), heat pumps (heat from the air), and/or solar heating where these resources are available. This is best illustrated by the following example for the utilization of a hypothetical 100 units of bioenergy to provide low temperature space heating. If burnt directly to produce heat in furnaces with efficiencies of 80% then 80 units of useful energy are delivered. Alternatively the biomass may be used to make electricity in a combined heat and power plant, with the electricity used to run heat pumps. Assuming the efficiency of the power plant is 40% for electricity production and 45% for heat production, and the efficiency of the heat pumps are 300% (heat pumps have efficiencies greater than 100% due to the utilization of energy in the surrounding environment), then the useful energy delivered is 165 units. In summary, using combined heat and power and heat pumps, the same amount of biomass can be used to heat twice as many homes in comparison to heating from direct combustion in furnaces. Of course the most cost effective measures for reducing greenhouse-gas emissions associated with heating are measures that improve energy efficiency, including better insulation, programmable thermostats, and efficient furnaces and hot water heaters (Enkvist et al. 2007).

Sustainable Biomass Production

The vast majority of biomass production on earth results from plants and algae (i.e., photosynthesis) that utilize the sun's essentially inexhaustible supply of light energy to convert CO_2 and H_2O into carbohydrates and other carbon compounds that make up biomass. In the near-term and at steady state, identical amounts of plant biomass are both made from and decomposed back to CO_2 and H_2O on a yearly basis such that no net accumulation of biomass occurs. This natural biomass turnover ensures that nutrient cycling is maintained to support new growth. The conversion of the annual inputs of sunlight energy into plant biomass globally is truly enormous. In terrestrial environments alone, annual production of plant biomass carbon exceeds the carbon resulting from fossil fuel combustion by 5-fold (i.e., ~30 Gt of net annual plant biomass carbon production, or, total net ecosystem production, versus ~6 Gt of greenhouse-gas carbon equivalent emissions [Wigley and Schimel 2000]). It is worth mentioning that although oceanic production is high, it results primarily from microscopic phytoplankton that turn over rapidly that are largely restricted to localized regions of nutrient upwelling, thus not currently amenable to capture relative to terrestrial biomass.

Terrestrial biomass energy was the principal energy source for humans until the mid-19th century, and still accounts for between 7 and 14% of global primary energy needs. This is greater than the proportions derived from either nuclear or hydroelectric facilities (Sims et al. 2006, Field et al. 2007). Although the future of biomass energy is open to question, one estimate puts the global potential for biomass energy at between 200 and 400 EJ per year, 5 to 10 times the current level (Jurginger et al. 2006). In terms of net primary production on lands not currently in forest, cropland or parkland, model estimates suggest that this would yield little more than 27 EJ per year in additional biomass energy, just slightly more than a 5% boost in the total global energy consumption at 2005 levels (Field et al. 2007). Thus, to reach 5 to 10 times current levels of biomass energy production, the bulk of biomass resources would presumably have to come from existing forests and croplands. The extent to which this can be achieved without sacrificing essential ecosystem services, food and fibre production, as well as other competing uses would need to be examined carefully.

Globally, forests represent the earth's primary biomass energy reserves, containing over 60% of global biomass carbon (IPCC 2000, Prentice et al. 2001). This only reflects the principal, however, and not the annual rates of return. From an annual net forest biomass production perspective, the picture is less promising. Estimated biomass production from forests globally is only 3 Gt of carbon per year (Malhi et al. 1999), ~10% of the annual plant total. Among forest types, boreal forests are thought to contain a quarter of the global forest biomass reserves (Malhi et al. 1999), but have some of the lowest rates of net annual biomass production among forest types because of low annual light receipt, cool temperatures, cold winters, moisture limitations, and frequent and/or severe disturbances.

Specific disturbance agents such as the current mountain pine beetle epidemic in British Columbia, and the resulting volume of dead and dying lodgepole pine throughout the interior of the province, is serving to focus our attention, not only on this one-time and short-lived forest dead biomass resource, but also on the viability of bioenergy overall for helping us to meet energy needs in a more sustainable way. On one hand, the forest-rich interior of British Columbia would seem to represent a region with a strong case for sustainable development of biomass energy; a legacy of primary forest biomass fuel accumulated over centuries, a mountain pine beetle epidemic that has left large stands of dead pine trees, and a large per capita land base. On the other hand, this legacy of primary forest is home to a remarkable flora and fauna, the dead pine is distributed over a vast region that is often interspersed with other species making its capture economically, environmentally and/or ecologically untenable in many cases. A dispersed human population and resource can work counter to economies of scale. Although this 'dead' carbon may appear non-essential, it has many functions that will be discussed later in this section. Furthermore, in harvesting dead pine, collateral damage to other non-pine vegetation such as understory seedlings and young trees decreases the carbon sink of the forest due to loss of photosynthesis as well as increases in the rate of C loss due to disturbance of soil and with inputs of dead carbon. The compounding effects of superimposed natural and human disturbances are not well understood and require further study.

Decisions about the future of biomass energy need to consider the sourcing of biomass and the production systems used, and in particular, the sustainability of these systems. In this section, we consider a variety of biomass production systems, from municipal, agriculture and forest wastes. We will focus on the latter, including the common current use of forest residue with other systems of extensive (natural) to intensive (high input) biomass production systems.

The Scale of the Biomass Resource

Although a detailed evaluation of sustainable bioenergy resources in BC is not available, approximate estimates of available biomass resources for the province are summarized in Table 2 (Ralevic and Layzell 2006). The assumptions made in generating these numbers deserve critical examination. Before we set proportions of the biomass resource or residue/waste that can be exploited for bioenergy, we need to determine if these biomass consumption rates are sustainable in the bigger picture after considering the effects on greenhouse gases, wildlife and habitat, and long-term

Table 2. Estimated biomass resources in B.C. (after Ralevic and Layzell 2006).

Biomass resource	Total dry weight tonnes per year	Usable dry weight tonnes per year	Energy content (GJ dry per tonne)	Energy potential (PJ per year)
Municipal solid waste[a]	2,013,882	735,000	16	15.2
Crop residues[b]	1,423,600	143,900	16	2.3
Livestock manure[c]	1,379,739	388,000	13.5-17.8	6.1
Summerfallow land[d]		147,000	16	2.4
New or converted agricultural land[e]		2,600,000	16	41.4
Forestry residue[f]	39,800,000	11,900,000	16	191.0
Enhanced silviculture[g] (10% additional forest products)				19.1
Enhanced silviculture[h] (10% fast growing bioenergy plantations)		4,000,000	16	63.7
Mountain pine beetle wood - recoverable[i]	67,300,000	2,400,000	16	37.7
Mountain pine beetle wood - non-recoverable[j]	192,500,000	8,700,000	16	138.6
Total				517.4

Assumptions for Table 2: [a]Municipal solid waste was that collected from large communities (80% of total) while usable waste includes dry combustible waste that is not recycled. [b]Crop residues left on the field after harvest range from 50% (grains) to 5% (hay, fodder corn) of the harvest; it is assumed that half of all crop residues left on the field could be collected for bioenergy use. [c]Livestock manure was estimated from the total number of livestock in BC, predominately cattle, with an estimated recovery rate of 25%. [d]Summerfallow land: 50% of summerfallow land can be used for growth of bioenergy crops (large yields, low fertilizer requirements, e.g., switchgrass, *Miscanthus*). [e]New or converted agricultural land: 10% of agricultural land in BC may be converted to biomass crop production. [f]Forestry residue: 30% of total biomass in harvest is residue (branches, needles, leaves, roots), of which 70% may be harvested. [g,h]Enhanced silviculture such as stand establishment, site preparation, pre-commercial thinning, early tree removal, intermediate cuttings, stand and site rehabilitation, residue recovery, inferior tree removal, and replanting after harvest with high quality seed stock would result in a 20% increase in forest productivity, half of which could be used for bioenergy. [i]Mountain pine beetle wood – recoverable: residues from increased allowable cut of MPB trees, harvested over 20 years. [j]Mountain pine beetle wood - non-recoverable: 90% of MPB wood that is not recoverable for traditional forest products is harvested for bioenergy over 20 years.

site productivity, which necessarily includes soil productivity.

Forest residue biomass

We define forest residue broadly in this paper to include all harvested or damaged plant biomass materials that result from harvesting activities that do not end up in forest products. Current biomass energy production in British Columbia is almost exclusively derived from the combustion of forest residue, in this case resulting from forest wood and fibre products industries. Although this residue was initially stockpiled and/or later burned in bee-hive burners, it is now commonly used for the cogeneration of energy for wood products industries, and in some cases, local communities. Yet, 2,400,000 green tonnes of wood residue are still incinerated in Tier 2 burners and 550,000 dry tonnes of mill residues are not currently utilized, representing ~26 PJ per year using the same assumptions as in Ralevic and Layzell (2006) (i.e., 0.96 tonnes per m^3, 44% water content, 16 GJ per dry tonne energy content). This amount, however, is down from 1,800,000 tonnes in 2004 due in part to downturn in forest industry and increased bioenergy demand for residues. Any expansion of forest residue biomass energy production, beyond the currently under exploited resources just mentioned, will inevitably be tied to an increased rate of forest harvest for forest products, or an increase in harvest residue (i.e., woody debris) capture from cutblocks. We need to fully consider the implications of increasing the current rate of forest harvest or reducing the levels of residue retention in cutblocks as both activities can erode biodiversity or productivity of future forests.

Extensive biomass production systems

Extensive biomass production systems include natural ecosystems that rely on existing plant diversity and resource availability. These systems would require minimal or no intervention and inputs and therefore would have lower associated economic costs, but possibly lower yields than intensive systems. At their lowest level of input and disturbance, they would utilize naturally occurring communities of plants and species and be harvested on long rotations in ways that would sustain all aspects of the environment. Although the current methodology and assumptions used for calculating the annual allowable cut (AAC)[6] in BC have been subject to debate, certainly it represents the upper bounds to removal of biomass from forests while sustaining our current forest systems. Total timber volume harvest from all BC Timber Supply Area (TSA) and Tree Farm License (TFL) forests, representing the vast majority of timber harvested in the province, amounted to ~85 million m^3 in 2007 (Ministry of Forests and Range 2007). If all of this were used for bioenergy as opposed to forest products, assuming conversion factors of 2.44 m^3 per dry tonne (Stennes and McBeath 2006) and 16 GJ per dry tonne (Table 2), the entire AAC for BC would represent 557 PJ of biomass energy, or approximately half of BC's primary energy demand (1,140 PJ).

In the short-term, mountain-pine-beetle-killed pine, recently estimated to reach 435 million m^3 of timber by the end of the epidemic (Walton 2007), would appear to represent a windfall of biomass that could

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[6] The Annual Allowable Cut, commonly referred to as the AAC, is the amount of wood permitted to be harvested in the Province within a one year period to ensure the sustainability and productivity of our forests.

also be exploited for bioenergy. Although the majority of this is not readily recoverable (Table 2), it is driving interest in bioenergy at the current time. From the calculations in the previous paragraph, it holds a tremendous potential for biomass energy equaling 5 years of AAC.

The economic realities of using this mountain pine beetle biomass in central BC for bioenergy were recently explored by Stennes and McBeath (2006). In a local example, they showed that total costs to harvest, haul, chip, and deliver lodgepole pine in the Prince George region of BC ranged from 83 to 101 Cdn$ per dry tonne of wood, the lower cost reflecting whole-tree usage as opposed to log only. Natural gas prices would need to be above 14 Cdn$ per GJ, higher than current rates (2008), for it to be viable on a simple economic basis. Policy instruments such as the newly introduced provincial taxes on fossil fuels could make up this difference. For example, there are currently incentives from BC Hydro for electricity generated from biomass. Finally, total GHG emissions were found to be 20-fold lower for biomass as opposed to natural gas energy plants (>59 MW facilities) given the Prince George region scenario (Stennes and McBeath 2006). Thus, although the economics of using pine biomass for energy may be refutable, its savings with regard to extraction and use-related GHG emissions appear to be less so.

Creative systems of biomass sourcing need to be explored. Hydro, rail, seismic, road and other allowances and right-of-ways currently criss-cross the province, and often require frequent harvesting, mowing or brushing as normal maintenance. The quantity of this resource along with sustainable levels and ways to harvest it need to be more thoroughly examined. Estimates suggest that forest biomass resources that are cut and/or harvested, but not currently utilized include 750,000 to 1,500,000 m^3 from BC Hydro, 2,000,000 m^3 from the Oil and Gas Commission along with unknown amounts of biomass from the Ministry of Transportation (Larson 2008), representing 24 PJ per y (using the Ralevic and Layzell 2006 assumptions: see above) of additional energy.

Any increased amount of forest residue capture from forests would need to carefully consider ecological impacts on regenerating forest ecosystems. For example, coarse woody debris left on the soil surface provides a habitat for numerous plant, animal and microbial species. Increased removal of fallen coarse woody debris may negatively impact the chemical, physical and biological properties of the forest floor at some harvest sites, and may lead to more soil compaction. Impacts of intensive forest residue capture at harvest sites on nutrient cycling would also need to be evaluated. Furthermore, removal of surface residues can increase erosion and result in a greater sediment and nutrient loss to streams. In addition, reactivating decommissioned roads to allow for the salvage of unused forest residues may have significant impacts on increased recreational access to the land and related wildlife and other issues that are currently managed through access management. All of these issues affect the long-term sustainability of our forest ecosystems, and must be considered carefully before greater residue capture is considered.

Intensive biomass farming

Intensive biomass farming would require varying degrees of intervention and relatively high levels of inputs such as fertilizer, herbicide and/or pesticide, input costs that have risen with those of fossil fuels. Ignoring agriculture (see below), intervention could be seen to range from annual harvest of perennials such as in coppiced[7] shrub and tree systems to the longer rotations of fast-growing trees such as poplar. With intensive biomass farming, where maximal biomass yields are required, genetically modified species are considered and often in the context of reduced plant diversity systems such as monocultures. The debate about the relative merits of intensive versus extensive forestry is not a new one and continues in the conservation and forestry arenas.

Many factors may limit the applicability of intensive forestry systems for biomass production in central and northern British Columbia. First, the physical climate over much of the region does not provide the rapid growth and short harvest rotation intervals seen in many tropical and temperate regions. Hence, the return on investments would only be realized over long time-scales relative to financial investments and markets. Second, the land tenure system would likely need alteration if groups other than the crown were to invest in intensive forest systems. Third, 'extensive use' of intensive biomass systems would require considerable examination and study to ensure the conservation of our cultural, societal, ecological and environmental legacies and services. These legacies, once lost, would not easily be reclaimed, if at all, and any costs to society resulting from a loss of ecosystem services would need to be carefully examined.

Agricultural biomass sources

Agricultural systems of biomass production are a subset of intensive biomass farming systems. Bioenergy from crop seed or residue is largely in the form of 2 energy commodities, liquid fuel for transportation and electricity generation, respectively. A third form of agricultural bioenergy (biogas) is derived from the anaerobic digestion of manure collected from intensive livestock operations.

Sugar cane, palm oils, and crop seed sources, such as corn kernels or canola seed oil are the current crops of choice for biofuel production, but all have large environmental costs, including increased soil erosion, nitrate and phosphorus loss, declines in biodiversity, and impacts on air and water quality (Danielsen et al. 2008, Robertson et al. 2008). Although sugar cane and palm oils are not grown in BC, there is a growing international trade in biofuels and some potential biofuel options exist for central and northern Canada. Cellulosic biomass sources, including crop residues and perennial biomass crops that require lower levels of chemical inputs and tillage (e.g., *Miscanthus* and Switchgrass [*Panicum virgatum* L.]) hold the promise of reducing the environmental impacts of biomass generation (Robertson et al. 2008). Remaining concerns include direct and indirect land use changes. Examples include the converting of lands currently used for the production of food crops, grasslands or forests to land used for bioenergy crops, and at the same converting additional grasslands or forests to croplands due to food shortages caused in part by biofuel production. The degree to which we convert grasslands and forests to agricultural land affects the net greenhouse balance and carbon stocks of landscapes as well as the ecology and environment (Searchinger et al. 2008). These concerns would need proper study and consideration before sweeping changes in landscape use were implemented.

The use of agricultural residues (both plant and animal wastes) for bioenergy reduces direct and indirect land use changes compared to intensive farming. The regular incorporation of plant and animal residues

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[7] Coppiced: an area of woodland in which trees or shrubs are periodically cut back to ground level to stimulate growth and provide biomass.

into soil, however, is an important means of maintaining soil quality and soil productivity. Plant residues are often left on the land after harvest to reduce soil erosion or are incorporated into topsoil to maintain soil organic matter levels and to fuel the biological component of arable soils. Application of manures, rich in nitrogen and phosphorus, complete essential nutrient cycles and reduce the need for synthetic fertilizers. These practices also provide an important means of carbon sequestration. Reductions of soil organic matter have long been identified as a threat to soil fertility and to sustainable agriculture in Canada (Acton and Gregorich 1995).

Manure from intensive livestock operations does presents several challenges, including methane emissions from storage lagoons, unpleasant odours and poor air quality, water and groundwater contamination, and the possible presence of pathogens. Additionally the nutrient balance may not match crop requirements, and transportation to crop lands may be prohibitively expensive. These challenges can be addressed by composting the manure, or by anaerobic digestion to produce biogas and a residual solid and liquid that retains some of the fertilizer value of the initial manure. The biogas can be used for on-site heat and electricity production. A more thorough analysis of the trade-offs between various animal waste bioenergy applications could prove useful.

Bioenergy examples

Bioenergy is being considered to help BC reduce greenhouse-gas emissions in the residential, commercial and transportation sectors and also for electricity production. Bioenergy does supply a significant amount of the province's energy demand, approximately 190 PJ of the 1,140 PJ total primary energy demand in 2004 (or ~17% of total). This is primarily generated from forest industry residues used mainly in the forest industry (NRCAN 2006). Most of the bioenergy power plants in BC are associated with pulp mills. The exception is the power plant in Williams Lake, which has been operating for 15 years on sawmill residues.

Due to increasing electricity demand, BC Hydro is projecting a shortfall in generating capacity of ~50 PJ by 2016 (BC Hydro 2007), the year the province has set a goal for electricity self-sufficiency. Half of this shortfall is to be met with increased efficiency and conservation, the rest with new net-zero greenhouse-gas emission sources, including bioenergy (BC Energy Plan 2007). About 75 PJ of biomass resources would be required if the 25 PJ of electricity is to be entirely generated from biomass (using a biomass to electricity conversion efficiency of 30%). Towards this objective, 4 new biomass power plants powered by waste biomass were recently announced in BC, providing 2 PJ of electricity to BC Hydro[8]. This will be enough electricity for approximately 50,000 houses (average household annual electricity use in Canada is 40 GJ or 0.00004 PJ). Three of these power plants are associated with pulp mills and will not generate additional jobs, but may increase job security. The fourth power plant, to be built in Prince George, will be a stand alone power plant powered by forest residues currently left in the forest. This power plant will generate 65 to 75 jobs, primarily in trucking. To encourage these types of bioenergy plants, the stumpage on forest residues was reduced to $0.25 per m^3. Trials are underway with new tenure systems that charge stumpage on total fibre in the harvest area (as opposed to just charging stumpage on harvested fibre). This change will reduce

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[8] http://www.bchydro.com/news/articles/press_releases/2008/bc_hydro_announces_successful_proposals_in_phase_one_of_bioenergy_call_for_power.html

waste left in the forest and provide a constant supply of residual fibre for pellet and bioenergy industries.

In 2006, the transportation sector accounted for 39% of BC's greenhouse-gas emissions (NRCAN 2006). Towards reducing these emissions, there is a 5% renewable fuel mandate by 2010 (Federal and Provincial). In BC, this is equivalent to 400 million L or 15 PJ of renewable fuel. The provincial objective is to produce 50% of this in BC, requiring almost 20 PJ of biomass resources (assuming an efficiency of 40% for the conversion of biomass to biofuel).

Sweden, which has implemented policies to encourage bioenergy use from forestry residues, may be considered as an example for BC bioenergy use. Sweden has a somewhat similar climate to BC and strong forest industry, although the population is more than double and land area half has large as BC. In 2006, modern bioenergy applications accounted for 360 PJ, or 18% of total primary energy supply. Bioenergy applications are industry (50%, pulp and paper sector), district heat and electricity (40%), residential use (10%), and biofuels (2%). Of the 360 PJ, 93% was from woody biomass, 3.5% from municipal organic waste, 2.8% from agriculture-based biomass for liquid biofuels and 0.4% from biogas. To meet the growing demand, liquid biofuels and pellets are imported, including pellets from BC. The majority of the biomass used is from forest based residues, and future increases in supply are based on expansion of the forest industry and in extracting more of the branch and top residues from the forest by integrated harvesting rather than leaving them in the forest as at present. Bioenergy use is expected to increase by 30% by 2025 to 470 PJ (IEA 2008c).

In Sweden, district heating (including combined heat and power) and heat pumps are widely used. District heat supplies 180 PJ of heat (approximately half the heating demand) and 47 PJ of electricity, and is used in the urban centers of 232 out of 292 municipalities. Overall efficiencies for the combined heat and power plants are 88%. District heating plants can run on various fuels, depending on available supplies and costs. In 2006, 62% of district heating was from biomass. The share of municipal solid waste used for district heating is expected to increase to 27% as the disposal of organic combustible waste in landfills is no longer allowed. Some of the electricity produced is used to run heat pumps providing over 80 PJ of heat from 27 PJ of electricity. Heat pumps are used in areas without district heat and are installed in 80% of new family houses (IEA 2008c).

Environmental Concerns

Some of the environmental concerns associated with biomass energy production have already been raised in previous sections. Here we will consolidate these concerns and highlight their dependence on the types of bioenergy technologies being used (e.g., combustion and chemical conversion processes) and on the types of biomass systems being exploited (e.g., forestry and agricultural products and waste). Potential impacts include environmental quality deterioration (e.g., air, water and land), waste production and handling, land-use changes, and net GHG accumulations. Of particular interest to central B.C. are issues related to impacts associated with the removal, collection and transportation of biomass from forests to bioenergy-generating facilities, as well as the impacts of combustion on air quality and net GHG additions to the atmosphere.

Biodiversity Considerations

In the longer term, biomass-based fuel sources are likely to come from a combination of industrial wood waste, afforested[9] biomass, intensive biomass farming, and agricultural biomass sources. Many wildlife and biodiversity issues associated with intensive biomass production are more generally problems with agriculture such as a decline in forested areas and in biodiversity often leading to pest management issues. According to Robertson et al. (2008), a switch to perennial biofuel crops, such as grasses, shrubs and trees, could mitigate some of these problems and prevent competition with food production. The same authors suggest that in order to meet global biofuel needs, an area equivalent to the current area in world-wide row-crop agriculture may be needed – land-use changes on such a scale will likely further threaten biodiversity and native habitat for vertebrate species. Alternatively, afforestation of 2.5 billion ha of degraded land would supply enough biomass to meet the entire global energy demand, although the timescale required for afforestation precludes this option being a short-term solution (Metzger and Hüttermann 2008).

In the short-term there is both an abundant supply of standing dead pine as well as an abundance of road-side slash and debris piles in the BC central interior. Current harvest practices usually involve hauling whole trees to near-road processing sites resulting in debris piles that are either left on site, burned, or less commonly chipped. The amount of biomass removal to these slash piles is governed by provincial guidelines and their utilization as a biomass source should have no further impacts on wildlife species or biodiversity than the effects of the original forest harvest. Landscape-level planning of harvest (whether for timber, fibre, or biomass) and issues associated with biodiversity and wildlife retention will likely garner less importance than the economics of removing dead-standing, beetle-killed timber. Careful consideration will have to be given to access issues, however, should previously decommissioned roads be reopened to allow the removal of road-side slash piles for biomass fuels.

To be economical in the longer term, however, forest biomass harvesting likely needs to be conducted in association with timber harvesting and could include the removal of non-merchantable live and dead trees, down and dead woody material and brush. Almost by definition, biomass harvests will remove more woody material from a site than would be removed by traditional harvest. The retention of fine and coarse woody debris in forests, both standing and on the ground, however, has long been known to be essential for sustaining wildlife populations and biodiversity (e.g., Bowman et al. 2000, Bull 2002, Psyllakis and Gillingham 2009). A recent paradigm shift of forest management practices in interior BC forests has been to mimic natural disturbance regimes (see DeLong 2007) – natural disturbances normally create and retain considerably more coarse woody debris than commercial timber harvest and this difference will likely be greatly increased by removal of woody biomass for biofuel production. Further, recent attempts to recognize broad-scale conservation of biodiversity outside of protected areas across a ‘matrix’ of harvest lands (Lindenmayer and Franklin 2002) will also require careful re-evaluation if retained woody debris are greatly depleted on harvested lands that have also been subjected to residual biomass removal. Rather than viewing residual forest biomass as surplus or waste, specific retention

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[9] afforestation is the conversion of non-forested land to forest

guidelines for coarse woody debris retention will need to accompany implementation of wide-scale biomass harvest. In some European countries with high bioenergy use, the amount of residues that can be harvested depends on the local conditions, including soil properties (Thiffault 2008).

Air Quality

A deterioration of air quality associated with any fuel use is becoming less acceptable as the potential human health and environmental consequences are becoming increasingly understood. Deterioration of air quality can result from the net gaseous and particulate emissions that enter the local and regional airsheds from the production, processing, and combustion of the fuel. These emissions may be worsened and amplified by local geography and meteorological conditions which accentuate the concentrations of these airborne pollutants around communities where these emissions are occurring.

Biomass combustion results in CO_2, SOx (from the sulfur present in the biomass), NOx (from the nitrogen in the biomass and in the air), chloride, minerals and many incomplete combustion products, including volatile organic compounds. Some pollutant emissions depend on the biomass source. For example, burning treated or varnished waste wood can produce significant amounts of dioxins. Some of these compounds remain in the ash, some are gaseous, and some form aerosols and particulate matter (PM). Canada-wide, bioenergy is a major contributor to PM emissions: residential biomass combustion is responsible for 29% of PM2.5 emissions (particles less than 2.5 µm in diameter), and the wood and pulp and paper industries contribute 17% of PM2.5 emissions. Transportation is responsible for 30% of PM2.5 emissions (Environment Canada 2007). The use of biofuels can change pollutants associated with transportation. Ethanol blended gasoline (10% ethanol) results in a decrease in carbon monoxide emissions, but increases emissions of hydrocarbons, acetaldehyde, 1,3-butadiene, and benzene. Higher ethanol blends (85% ethanol, for use in flex fuel vehicles) results in a decrease in NOx, hydrocarbons, 1,3-butadiene, and benzene, and large increases in formaldehyde and acetaldehyde emissions (Graham et al. 2008). Biodiesel use reduces carbon monoxide, volatile organic matter, PM, and SOx emissions compared to regular diesel (Hill et al. 2006). In comparison to fossil fuels, biomass combustion generally produces less SOx, PM, carbon monoxide and organic compounds compared to coal combustion, less SOx but more PM and NOx compared to oil combustion, and more of most pollutants compared to natural gas combustion.

Both indoor and outdoor air pollution from biomass-burning contributes to cardiopulmonary health effects owing to the production of particulate matter (Heart and Stroke Foundation 2008). The majority of particles emitted from combustion, as both solid particles and liquid droplets, are less than 10 µm in diameter – PM10 refers to particles up to 10 µm in diameter. Those below 2.5 µm (PM2.5) and 0.1 µm (PM0.1) in diameter are more deleterious to human health because they penetrate more deeply into the cardiovascular tissue. Sustained exposure to particulate matter leads to a wide range of respiratory ailments (decreased lung function, pneumonia, bronchitis and chronic obstructive pulmonary disease), asthma, cardiovascular disease (heart disease and strokes), cancer (chiefly lung), brain damage (Alzheimer disease), premature births and infant mortality, and higher mortality in general among populations with chronic exposure to elevated PM10 levels.

Pollutants from bioenergy use can be reduced by modifications to infrastructure that achieves more complete combustion. Many of these are the same modifications discussed earlier to improve combustion efficiency, including fluidized beds or gasification. Standardised fuels (e.g., wood pellets) also improve combustion efficiency. Efficiencies of 70 to 90% are achievable, with 70% less particulates produced compared to inefficient systems (Faaij 2006). In addition, pollution control devices may be employed on stationary sources to remove pollutants from the flue gases after combustion. Typical pollution control devices include electrostatic precipitators, which use electricity to ionize dust particles and trap them on positively charged electrodes, and baghouses, which send the flue gas through fabric filters. Both devices are effective at removing PM (e.g., baghouses can remove greater than 99% of PM1.0).

For individual households, replacement of older wood stoves with certified wood or pellet stoves would effectively reduce both indoor and outdoor air pollution in towns and cities where they are currently in use. Old wood stoves produce up to 50 g of PM per hour compared to 6 g per hour for CSA/EPA-certified fireplace inserts and woodstoves. Thus, for a city like Prince George with a population of 77,000 people, PM10 emissions from residential stoves and fireplaces might be in the range of 160 to 200 tonnes per year if one house in 50 was equipped with a wood stove or fireplace that was used 50% of the time for 200 colder days of the year. A complete exchange of these older stoves with newer ones would reduce these particulate emissions to 19 to 24 tonnes per year.

An $8 million community biomass energy plant for the city of Prince George has been proposed, which includes a high efficiency electrostatic precipitator to reduce PM10 emissions to about 1 tonne per year. Clearly, the foregoing wood stove change out program alone more than offsets the emissions from this additional bioenergy installation, as would a variety of other measures to reduce road dust and open wood burning. A proposal from Canfor Ltd. to supply electricity from a combustion plant that utilizes wood residues associated with the pulp mills and other processing operations, and perhaps some beetle-killed wood, is in the development stages. The University of Northern B.C. is considering a gasification facility to reduce operational heating costs of their campus buildings. Conceivably, a proposal by Canfor Ltd. to build a large facility for production of electricity might integrate pulp mill operations with other process streams as an encompassing plan to reduce particulate emissions over the neighboring community. One of the 3 pulp mills east of Prince George (Intercon, Canfor Ltd.) has seen a reduction of particulate emissions from 1,482 (1985) to 104 tonnes per year (1999). Hence there appears to be potential methods, albeit expensive, to reduce particulate emissions, yet 2 other pulp mills (Northwood and PG Pulp mills, Canfor Ltd.) east of the city together produce close to 2,000 tonnes of PM per year. Efforts to upgrade these mills to the same standard as the Intercon mill would improve the air quality of Prince George considerably and increase the potential for further development of the bioenergy industry.

Residual Solids: Waste or Resource?

Combustion and thermo-chemical processes produce residual solids including ash, black carbon (biochar), and GHG emissions (all considered below). There is potential to use some of these by-products as soil amendments, but the benefits of these amendments on plant growth and the environment are in some ways poorly understood.

Ash

Complete combustion of biomass releases all of the reduced carbon leaving behind the inorganic ash composed of mineral elements. Ash content is typically expressed as a percent of total dry biomass. Values for ash content in wood are usually below 0.5%, while that for bark of softwoods and hardwoods are ~2 and 5%, respectively (Haygreen and Bowyer 1996). Ash contents for many agricultural plants are in the range of 1-5% (Karp and Shield 2008). In reality, complete combustion does not occur in many biomass combustion facilities (e.g., boilers), resulting in the inclusion of un-incinerated biomass with the inorganic ash content. Unburned carbon concentrations in ash generated via commercial boilers has been reported to range between 7 and 50 % (Pitman 2006).

The chemical and mineralogical composition of ash is variable and depends on type of biomass used, part of plant combusted (if plant biomass is used), type of waste (wood, pulp sludge or other residues), combination with other fuels, type of soil and climate used to produce biomass, and conditions of combustion, collection and storage (Demeyer et al. 2001, Pitman 2006). Wood ashes are often dominated with several important plant macronutrients such as calcium, potassium and magnesium, although aluminum and iron (a plant micronutrient) concentrations can also be significant. Nitrogen, one of the key plant nutrients, is generally oxidized and transformed into gaseous waste components upon combustion resulting in low residual concentrations in ash. Dominant minerals in wood ash include calcium carbonate and calcium oxide, which account for much of the alkalinity of ash. In general, combustion increases concentrations of environmentally sensitive elements (e.g., trace metals) in ash compared to the original biomass (Pitman 2006).

Although most of the ash produced from wood and pulp / paper industries is currently landfilled, there is an increasing interest in using ash as a fertilizer or soil liming agent (Vance 1996, Pitman 2006). Addition of ash can increase plant yields and stimulate soil microbial activity in many soils; however, the effects of ash addition are poorly understood and not always positive (Aronsson and Ekelund 2004, Jokinen et al. 2006). Lack of nitrogen may account for the poor response in some cases. Incomplete combustion can result in the formation of undesirable organic compounds such as polycyclic aromatic hydrocarbons (PAHs) and dioxins in ash, but concentrations and/or bioavailability are often negligible (Vance 1996, Demeyer et al. 2001, Pitman 2006, Augusto et al. 2008). Pitman (2006) recommends that only bottom ash be applied to soils, as fly ash can have relatively higher concentrations of contaminants. Some jurisdictions require testing of ash for organic contaminants and environmentally sensitive trace elements prior to application to agricultural soils; application rates or cumulative metal additions to land are often limited. There is potential for the application of ash materials to soils in central B.C. (e.g., forestry and/or agricultural soils), but further research is required to better understand plant responses and environmental impacts of ash additions. The economics of ash transportation to field sites will likely limit the extent of this practice. In many cases, landfilling may remain the most economical practice for ash management.

Biochar

The term biochar is commonly used for the black carbon produced from biomass burned in an oxygen-free or low oxygen environment (e.g., pyrolysis) (Fowles 2007, Lehmann 2007a). Although biochar can be used directly as a high energy solid fuel (and for other commercial applications), it also can be incorporated into soils as an amendment (Lehmann 2007a, 2007b, Laird 2008). Interest in biochar addition to soil has increased since it was hypothesized that the highly productive Amazonian "Terra Preta" soils were created by pre-Columbian populations 500-2500 BP through biochar addition (Lehmann et al. 2003). New research has confirmed that biochar additions to some soils can increase plant growth and can also produce a soil carbon fraction that is relatively resistant to microbial decay, making biochar an ideal way to provide long-term carbon sequestration in soils (Lehmann 2007a, Laird 2008). This recalcitrance, however, also makes biochar a poor energy source for the underground food web. Supplemental additions of readily biodegradable carbon sources may be required to maintain biological activity in biochar-treated soils. Although putative benefits of biochar amendments include enhanced cation exchange capacity, water retention, amelioration of soil acidity and reductions in methane and nitrous oxide release (Fowles 2007), further research is required to determine the biological, chemical and physical responses of biochar addition to a variety of soils under various management, vegetation and climatic conditions. Also, more research is required to determine how biochar properties vary with pyrolysis conditions and with various biomass feedstocks. The practicality of using biochar as a soil amendment in central B.C. soils will largely depend on the economics of competing uses for the material (i.e., as a fuel versus soil amendment) and with costs associated with its transport and incorporation into soils.

Net greenhouse-gas emissions

Finally, with climate change as a primary environmental threat, the net effect of utilizing biomass for energy on the GHG balance in the atmosphere relative to other renewable sources of energy should be explored. Although GHG accounting is still in its infancy, the tools are rapidly becoming available to provide an open and rigorous accounting of net effects of any process on GHGs. Carbon accounting is commonly performed as a surrogate for GHG accounting because carbon-based gases, CO_2 and CH_4, are the first and second-most important gases (next to water vapour) affecting climate, respectively. Such an accounting process with respect to biomass energy would not be trivial or without assumptions and approximations. All energy sources need to be compared with similar frame-works, with consideration of the GHGs associated with the energy resource procurement (exploration, extraction, transportation, processing, and distribution) and generation (construction, operation, and decommissioning). For bioenergy this includes the fossil fuels consumed in all aspects of the biomass harvest, processing, and handling. It would also need to consider the net effect of land-use modification and combustion efficiency as discussed earlier. Biomass combustion by-products also deserve consideration since these can have significant short-term cooling (sulfate aerosols) or heating (black carbon) effects (Jacobson 2004). In order to compare GHG emissions from all energy sources that might be considered, we will need to develop expedient, honest and transparent ways to assess actual net GHG emissions.

The use of forest biomass for bioenergy, as with other types of forest use, affects the carbon balance of the forest. Forests can be net sinks or sources for CO_2. If the total respiration for a forest exceeds the total photosynthesis, then the forest is a net source for carbon. Conversely, if photosynthesis exceeds respiration, the forest is a net sink. Source or sink status varies from year to year depending on climate (Piao et al. 2008), disturbances (Kurz et al. 2008b), including fire (Bond-Lamberty et al. 2007), insect infestation (Kurz et al. 2008a), as well as the seral stage of the forest. Humans, however, are increasingly influencing the carbon balance of forestlands. For example, forest harvesting causes sub-boreal forestlands to be net sources of CO_2 for a period of ~10 years after harvest (e.g., Fredeen et al. 2007) and by converting old carbon-rich forests to younger managed carbon-poor stands, carbon is also lost to the atmosphere (Fredeen 2006). Although young stands have greater sink strengths (rates of carbon uptake per unit area), they never recover the total amount of biomass carbon found in old forests (on time-scales relevant to human life-spans and immediate climate change). Also, contrary to popular belief, even the oldest forest stands can still be net sinks for carbon (Pregitzer and Euskirchen 2004, Fredeen 2006). Finally, a recent carbon accounting study suggests that we might sequester more carbon by conserving and restoring forests than by converting them to energy (Righelato and Spracklen 2007). For example, converting forests or grasslands to bioenergy crops for biofuel production results in significantly more GHG emissions than is saved by the displacement of gasoline/diesel by the biofuel (Danielsen et al. 2008, Fargione et al. 2008, Searchinger et al. 2008). Other studies show that using low input perennials (e.g., switchgrass) with large carbon storage in the roots grown on degraded land for biofuel production results in GHG reductions, both from the displacement of fossil fuels and from sequestration in the soil (Tilman et al. 2006, Field et al. 2007, Metzger and Hüttermann 2008,). We should give such reports greater scrutiny before making rapid and perhaps irreversible land-use changes if our goal is to avert GHG accumulation and associated environmental alternations.

Communities and Biomass Energy

People are interested in environmental change and its implications for intrinsic as well as practical reasons. Intrinsic attention arises from an almost altruistic interest and understanding that natural systems have stand-alone value to all life on the planet. More practical purposes focus upon the economic benefits that can be derived from natural resources. Increasingly, these 2 sets of reasons blend as new economic and community futures depend upon both practical and intrinsic valuations of the environment and environmental change.

This section will outline a suite of issues relating energy development to community development. Energy, and affordable access to energy, is crucial to both community and economic development. As northern BC communities consider different forms of energy opportunities and development options, this discussion seeks to enumerate a suite of issues that they may wish to consider. The text will cover 3 key loci of issues: economic, social and cultural.

In debating any form of resource development project, experience tells us to be mindful of ‘who benefits and who bears the costs’. The flooding of the various Columbia River basin valleys, for example, has brought considerable benefit to the province of BC as a whole, but only after imposing tremendous costs on those whose homes, farms, towns, and livelihoods were drowned behind the dams. The issues noted in the economic, social and cultural sections below can be employed as a community ‘lens’ for critiquing new energy developments. Although the discussion may relate generally to a number of forms of energy development, some specific comments will link to the unique circumstances of energy generation from biomass.

Economic Issues

The post WWII opening of northern BC to industrial resource development was founded upon the availability of energy. Using wood waste to support a new pulp mill industry in the province's interior required a host of policy and infrastructure investments. Looking just at the matter of energy, pulp mills are energy intensive. The provincial government had to make available ample and affordable hydro-electric power and bring oil and gas pipelines to places such as Prince George before industrial investments would be made. A similar story was found in northwestern BC where access to hydro-electric energy was a key element to the creation of Alcan's smelter facility in Kitimat and economic diversification across northwest BC region.

In considering questions of energy and economic development, it is first worth noting that power generation unto itself creates very few permanent jobs. Rather, it is what we do with the power that creates the economic and development opportunities for employment and regional growth.

When considering energy development matters, the key focus of concern is often with jobs and the opportunities (or disruptions) created by such employment changes. In terms of jobs, communities may wish to consider the different impacts that come at different stages of the development process:

- During the *building phase* of new energy production facilities, there are large numbers of construction jobs. In existing communities, these may present opportunities for new investment and growth. They may also exacerbate challenges around service provision and social problems. In discussing questions of employment growth during the construction phase, it is important to balance the risk of over-responding or under-responding to housing and services needs. It is also worth considering what local infrastructure is in need of addition or renovation to which the 'sunk costs' of construction camps can contribute.
- Next there is the question of jobs during the *production phase*. As presently described, biomass energy production may sustain large numbers of jobs in the hauling and preparing of raw materials. In this sense, there may be a direct increase in trucking industry employment. There are far fewer jobs in 'processing' power, however, relative to those found with other value added forest sector facilities such as pulp, paper, plywood, medium density fibreboard, chip board, oriented strand board mills, and the like. For example, one European study found pulp and paper contributed 8 times more added value and 13 times more employment relative to bioenergy production (CEPI 2007).
- Unlike the production of commodity goods, there are very few jobs in the *marketing, retail, or 'product transport' phase* within the electrical energy industry.

In considering new employment possibilities from biomass energy, several additional considerations revolve around both numbers and types of jobs. These include:

- How many new jobs will be created?
- How will new job creation fare relative to the potential employment if the forest resource had been put to other uses?
- What types (and level of pay) of jobs will be created, and will the existing workforce be able to transfer in, or will they be able to train for the new required job skills?

Historically, communities in northern BC have been advocating for not only good quality jobs, but also jobs that northern residents can fill.

A related economic issue, and one which speaks directly to the potential for energy generation to create economic opportunity, concerns the question of 'where will the energy be used?' Well known across northern BC is the challenge to economic diversification which a lack of steady, 3-phase, affordable power creates. Completion of the provincial electric power grid was a formal recommendation in the CDI study noted (see below) precisely because of its key role in supporting local business and industry development. Many economic development studies highlight opportunities for doing other things in communities and with regional resources only to be challenged by limited access to the electric power grid. Even the very massive investment (and large numbers of jobs) which metal and coal mines can bring to an area very much hinges on the simple availability of one critical input – electricity. Concern about 'where energy will be used' has been a central feature of development debates in Kitimat and northwestern BC over the past decade.

The availability of low cost power can create significant industrial investment and regional economic diversification opportunities. Will power generated locally be designated, or priced, for local use? What other supports (i.e., policy, infrastructure, investments, etc) may be made available in concert with an energy development to facilitate local and regional economic opportunities? These are critical questions because the opportunity to realize community and regional benefits from biomass power generation depends on the ultimate disposition of the power.

When UNBC's Community Development Institute (CDI) undertook its Northern BC Economic Vision and Strategy Project (see http://www.unbc.ca/cdi/research.html or http://web.unbc.ca/geography/faculty/greg/research/edvs/), community and industrial interests were united in identifying that to generate new economic wealth, more of the economic values presently being generated in northern BC need to 'stay in the north' and not be recycled through other government channels. If the purpose of energy generation is to sell new power to BC Hydro for ultimate potential sale to customers outside of BC with revenues flowing back into provincial government general revenues, the matter of realizing local benefit is more complicated. Bioenergy may not be competitive outside of BC, however, without carbon trading schemes or other incentives in place. A possible benefit of distributed bioenergy production to small communities near biomass sources could be the extension of the electrical grid to these communities. At present many small places in northern BC (including most of the Haida Gwaii) rely on diesel electric generators that consume tremendous amounts of fuel. Biomass may create real benefits in small and remote communities by providing reliable primary or back up local power sources to support community development, economic expansion, and diversification.

Questions of access to power, and the generation of new power, also can be linked to community development and community economic development planning. Questions to consider focus upon whether the community wishes to pursue traditional resource extraction type industries or diversify into new fields that also depend upon the physical or amenity values of the forested landscape. For discussion of any choices and options, access to affordable, reliable power is essential.

Social Issues

Transitions in economic activity have social as well as economic impacts. Some of these social impacts derive from the volume of employment being created, while others derive from the type of employment being created. Although job numbers were noted above, this part focuses on the impacts of changing job types.

Economic livelihoods become intimately linked to both individual and place identity. People may have more easy or more difficult times changing jobs between economic sectors depending upon how well new job types fit with their ideas of work and of the feelings of self worth that work supports. Over the past 20 years, efforts at buffering forestry dependent communities from the negative implications of plant downsizing or closure have encountered this challenge. Retooling workforces from one type of industrial activity to another may or may not have a significant impact upon identity, which in turn will have impacts on the social structure, social change, and potential social disruption at a local level. In addition to skills training, social services supports may also be needed as part of workforce transitions.

All resource industries in northern BC are experiencing change. As a result, the question of social change is a familiar one across northern communities. It will be important for communities to ask questions about how a transition into biomass energy production will affect the social makeup and social construction of the local population. Beyond questions of identity, there are also impacts on the quality of life for employees and communities as a whole. Different industries bring different levels of pay, different levels of work and shift organization, and different understandings of skills development. Changes in these quality of life issues need to be discussed as they can impact the resiliency of households and the contributions those households make to the community.

Cultural Issues

Often given less press than economic or social change, there are important cultural issues that need to be considered in economic transition. We already have challenges with how we engage with industrial economic activities in the woods, and with how we mitigate their impacts upon cultural issues. In the forest industry, for example, we know about the challenge of losing First Nations' cultural markers such as culturally modified trees. We also know about the challenges of impacts on cultural economic activities such as traplines and fishing areas.

To date, we have relied upon environmental and social impact assessment processes to identify and guide us through important cultural impacts. Although this has been extensively applied to the mining industry, will it be applied to more routine biomass growing and harvesting activities? If so, to what standards will environmental, cultural, and social impacts be evaluated? Similarly, what definitions, criteria, and benchmarks of 'green' will be used? Although there are consultation mechanisms now associated with resource industry activities in the woods, will cultural impacts be part of biomass power generation approvals and operations? The pace at which biomass may or may not need to be made available for power generation may impact the time available to conduct such social and cultural impact studies and negotiations.

There are many ways to approach any economic development opportunity. By identifying which issues are important in local circumstances, there is an opportunity to investigate alternate business models and costing arrangements. Maintaining such flexibility can ensure that new opportunities create a foundation for other sectors to develop production and employment, which can multiply local and regional benefits.

Conclusions

Bioenergy is a versatile resource that can be used to produce heat, electricity and biofuels for transportation. Bioenergy can contribute to meeting the energy challenges facing the globe: securing the supply of reliable and affordable energy, and effecting a rapid transformation to a low-carbon, efficient and environmentally benign system of energy supply (IEA 2008b). Potential advantages of bioenergy use include job creation, energy independence for off-grid communities, air pollution reduction, and fossil fuel displacement. The magnitude of these benefits will depend on the source and availability of biomass supply and on the choice of bioenergy applications.

Community considerations around the issue of bioenergy include biomass availability, job creation, availability of low cost power, the pace at which changes are occurring and adjustments need to be made, and the question of who benefits and who bears the costs of new bioenergy developments. Bioenergy use can contribute to the diversification of the forest industry, potentially helping resource communities during forestry downturns. Bioenergy applications, however, increase the competition for residual fibre that may otherwise be used for higher value applications. When evaluating costs it is important to include additional costs that rarely get accounted for in development proposals and evaluations, including impacts on social services, emergency services, educational facilities, day and child care services, waste and environmental monitoring, road and civic infrastructure, and a host of others. By identifying which issues are important in local circumstances, there is an opportunity to investigate alternate business models and costing arrangements. Maintaining such flexibility can ensure that new opportunities create a foundation for other sectors to develop production and employment, which can multiply local and regional benefits.

Air quality may be positively or negatively impacted by increased bioenergy usage. Replacement of inefficient technology with efficient processes has the double benefit of lower air pollution and increased useful energy obtained from a given biomass resource (or of using smaller amounts of biomass to deliver the same useful energy). Utilization of the biomass that is currently burnt in beehive burners and roadside slash piles will reduce air pollution and provide an energy source with minimal environmental impact. Bioenergy use, however, involves combustion and as such generates more air pollution than other alternative energy resources, such as wind, hydro, solar and geothermal. Biomass combustion typically produces more air pollutants than natural gas. Therefore, if bioenergy is used for heating applications and displaces natural gas use, air pollution may increase unless effective pollution control strategies are implemented. In addition, adding ethanol to gasoline may exacerbate air pollutant emissions from the transportation sector.

In determining how bioenergy can contribute to our energy supply, both the source of biomass and the relative merits and impacts of bioenergy in comparison to the displaced energy source should be carefully evaluated. With growing competition for and decreasing availability of low cost waste biomass sources, future bioenergy expansion may depend on new biomass sources. Utilization of extensive and intensive resources will result in increased impacts on forest carbon sequestration, water quality and biodiversity. One of the main drivers for bioenergy use is to lower greenhouse-gas emissions, which is best obtained using waste biomass that would be burnt regardless. The technology with the largest greenhouse-gas reduction potential is the displacement of coal for electricity production (e.g., co-firing the biomass in a coal power plant).

There are many unknowns and uncertainties surrounding expanded bioenergy use. Assuming bioenergy will have net benefits, there is a lost opportunity cost associated with delaying development while benefits and impacts are determined. Given the many unintended negative consequences of current biofuel mandates (e.g., deforestation, increases in greenhouse-gas emissions, water quality deterioration, rising food prices), however, caution is warranted in further development of extensive or intensive biomass collection. In the meantime, bioenergy applications that have mainly positive benefits (reduced air pollution and a decrease in greenhouse-gas emissions), such as using waste biomass currently burnt in slash piles for coal displacement, could be further developed. Biomass energy appears to have its place in meeting the energy demands of today, but it is no panacea, and tomorrow, our forests may well be valued more for their biodiversity, environmental services, recreation potential, cultural significance, carbon sequestration, or other values that we cannot envisage today.

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