Economic Viability and Environmental Security for Rural Areas from Increasing Renewable Energy-Use Based on Biomass Resources

Ragnhildur Sigurðardóttir[1,2], Kristiina A. Vogt[2,3], Daniel J. Vogt[2,3], Toral Patel-Weynand[2], Michael Andreu[2,3], Robert Edmonds[3], Kevin Hodgson[3]

[1]*Umhverfisrannsóknir ehf, Selfoss, Iceland,* [2]*CAPE International, Mukilteo, WA, USA,* [3]*College of Forest Resources, University of Washington, Seattle, WA, USA*

Abstract

Integration of renewable biomass resources with energy production has the potential to reduce greenhouse gas emissions, while contributing to economic stability and environmental security for rural areas. In Iceland developing decentralized energy production systems, where biomass is converted to methanol for use as a fuel source for hydrogen fuel cells, could increase the energy security in remote areas and provide new economic opportunities for the rural communities at large. These systems could be especially beneficial in situations where there are active farm forestry programs, substantial conversions of agricultural fields for energy crops (e.g. willow plantations), and where there is a surplus production of agricultural wastes.

Rationales for Renewable Resource Uses

Considerable attention is being paid to developing technology platforms using bioenergy systems to solve many global environmental problems. Bioenergy systems also have the potential to develop new economic options to produce sustainable rural communities when multiple outcomes are simultaneously desired from the same landscape (e.g., conservation vs. development, resource extractive based jobs vs. resource service jobs, etc) (Kurz et al. 2002, FAO 2001, FAO 2003, IPCC 2003, Najam 2003). The use of biomass to produce bioenergy is gaining stature in achieving sustainable development internationally. The Directorate General for Energy of the European Commission in 1999 produced a report that suggested that bioenergy from renewable resources has significant potential for creating new jobs, higher employment rates in the renewable energy sector at a lower investment cost (Domac 2002). The Commission has set the target of doubling the share of renewables in their energy supply quota from 6 to 12%, between 2000 and 2010 to meet their sustainability targets to fulfill the Kyoto Protocol (CEC 2000). Biomass transformation for energy production is an important component of the strategy as the Commission focuses on more environmentally friendly options (CEC 2000). As an added benefit, renewable energy production systems help in minimizing negative impacts on human/ecosystem health (see Table 1, Smil 2001, AMI 2003, Dynamotive 2003, Fenn et al. 2003, Methanex 2003).

Biomass as an Energy Resource

Bioenergy can be produced from a variety of biomass producing sources, including agricultural and forest residues, and energy crops (e.g. willow plantations). Biomass consists of the biodegradeable fraction of products, waste and residues from agriculture (including vegetative and animal substances) forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste.

In addition to being considered carbon neutral (zero emissions), because biomass conversions only emit the amount of CO_2 that is sequestered, the process does not increase net CO_2 levels in the atmosphere. Methanol produced from biomass has, furthermore, been found to emit between 40 - 80% less greenhouse gas (GHG) emissions than methanol produced from natural gas and emit less particulate matter, carbon monoxide and hydroxide (CEC 2000, see Table 1).

Table 1. Total GHG emissions of fuel cell vehicles using methanol produced from biomass and from natural gas for a family car (5 seats) (Ohlström et al. 2001)

Process	**g CO_2 (eq)/km**
Methanol produced from natural gas	117
Methanol produced from biomass	6
Reformulated gasoline including MTBE from biomass	185
Reformulated diesel from crude oil	111
Hybrid vehicles – 85% methanol from biomass blended with 15% gasoline	117
Hybrid vehicles – 85% methanol from natural gas blended with 15% gasoline	145

Conversion of Biomass Resources

Biomass can be used to generate energy in several ways: the traditional approach of direct combustion for heat as energy, as well as from new emerging techniques - production of biodiesels from crops rich in organic oils (such as sunflower), production of alcohols (from beetroot, wheat, shorgum, etc), and production of methanol from wood wastes and forest residues.

Much of the research emphasis in renewable energy resource production has focused on using agricultural crops or wastes to produce liquid fuels by fermentation processes (e.g., ethanol). This approach has been further expanded to include the production of heating materials and even cloth (Cargill-Dow 2000, Hettenhaus et al. 2000, Brown 2003, Kopetz 2003; many others). Conversion of agricultural products (e.g., sugar cane, corn) to ethanol for mixing with gasoline has been practiced for some time, and this practice has even been institutionalised in countries like Brazil (Mancini 1998). The use of agricultural biomass and organic wastes to produce ethanol is a well-established and commercialised industry in many countries. Similarly, wood is now being considered as the initial raw material for ethanol production. In the US, the feasibility of using wood to produce ethanol is also being considered to replace methyl-tert butyl ether (MTBE) as a gasoline oxygenate additive for gasoline. Biodiesel can replace fossil diesel fuel in engines without substantial modifications. The alcohol derivative can be mixed with up to 15% of gasoline without technical engine modifications (QLG 1997, Nyström and Cornland 2003). The conversion of biomass feed stocks (using wastes from pulp mills) is being considered to produce methanol as an automotive fuel in a “CO_2 neutral” process (Ohlström et al. 2001). This is driven in part because road transport contributes 85% of the CO_2 emissions generated by the EU transportation sector (Ekbom et al. 2003).

Methodologies for conversion of biomass to energy need to be further developed to maximize efficiency and environmental quality. We suggest that the contribution of wood to energy production has the potential to increase significantly if wood were to be transformed using green or sustainable practices. At present, wood is mainly being used as the sole fuel source in cogeneration plants (e.g., electricity, low-pressure steam production) and for heat/power generation by co-firing with coal or other fossil fuel sources. Conversion to sustainable options such as linking biomass generation of methanol to H has the potential to reduce GHG emissions by 80-90% over current practices (Mäkinen and Sipilä 2003).

Emerging Opportunities in Linking Biomass Conversions to Hydrogen Fuel Cell Systems

The practice of using biomass to produce methanol has only recently been suggested as a fuel source for hydrogen fuel cells (Sigurdardottir et. al. 2003, Vogt et al. 2004). Sigurdardottir et. al. (2003) and Vogt et. al. (2004) proposed a system which potentially can increase the use of biomass as a renewable resource in decentralized energy production systems that generate electricity using H fuels cells (see figure 1).

Methanol is the key liquid fuel driving rapid developments in fuel cell technology (Methanex 2003, IdaTech 2003, The Economist 23/10/97 & 22/04/99). While traditionally methanol is mostly produced from natural gas, a non-renewable resource (Kheshgi et al. 2000), wood based processes being developed today are becoming more sophisticated and efficient, for example, flash pyrolysis and hydrothermal liquefaction (Bridgewater 1999, TNO 2003). As recent as the 1990s, methanol production from wood was considered economically not viable since it was less expensive to produce it from natural gas (Sedjo 1997, Ohlström et al. 2001). Several factors are changing the economic accounting scenarios of the past: inclusion of environment sustainability and security factors as part of cost/benefit analyses, tax incentives/carbon tax on energy production (implemented in Sweden, Austria, others), regulations mandating the increase in the proportion of energy consumed from renewable resources to mitigate GHG emissions (CEC 1997, FAO 2002).

Using forests or agricultural resources and wastes to generate alternative energy is optimal, as renewable resources are being used, and biomass conversions can be made using environmentally sound chemical practices. These practices can also provide environmental services such as maintaining forest nutrient status by reapplying the residues from biomass conversion processes on the site (Andersson and Emilsson 2003). Mäkinen and Sipilä (2003) suggested ethanol and biodiesel are short-term solutions for acquiring biofuels and that the most significant GHG emission reductions will likely come from using methanol and hydrogen fuel cell systems.

Wood has a more consistent chemical composition, it a more efficient and reliable starting material to produce methanol (Brown 2003). Wood can be used as a starting material to produce methanol using one of two main processes: 1) *gasification,* and 2) *pyrolysis*. In the past 10 years, much engineering research and development are allowing the commercialization of biomass conversion systems. In particular, European countries, such as The Netherlands, Finland, Sweden, and Germany, have been very active in this area. While not yet perfected, gasification or pyrolysis of biomass efficiently produces a liquid fuel such as methanol.

A system for transforming forest biomass to methanol on a small scale has not been commercialized to date, but is a logical goal since wood is a higher quality, starting material with a more consistent chemical composition than many other types of biomass. These qualities make wood a more reliable material to transform to methanol. The efficiency of chemical conversion and the resulting products will vary

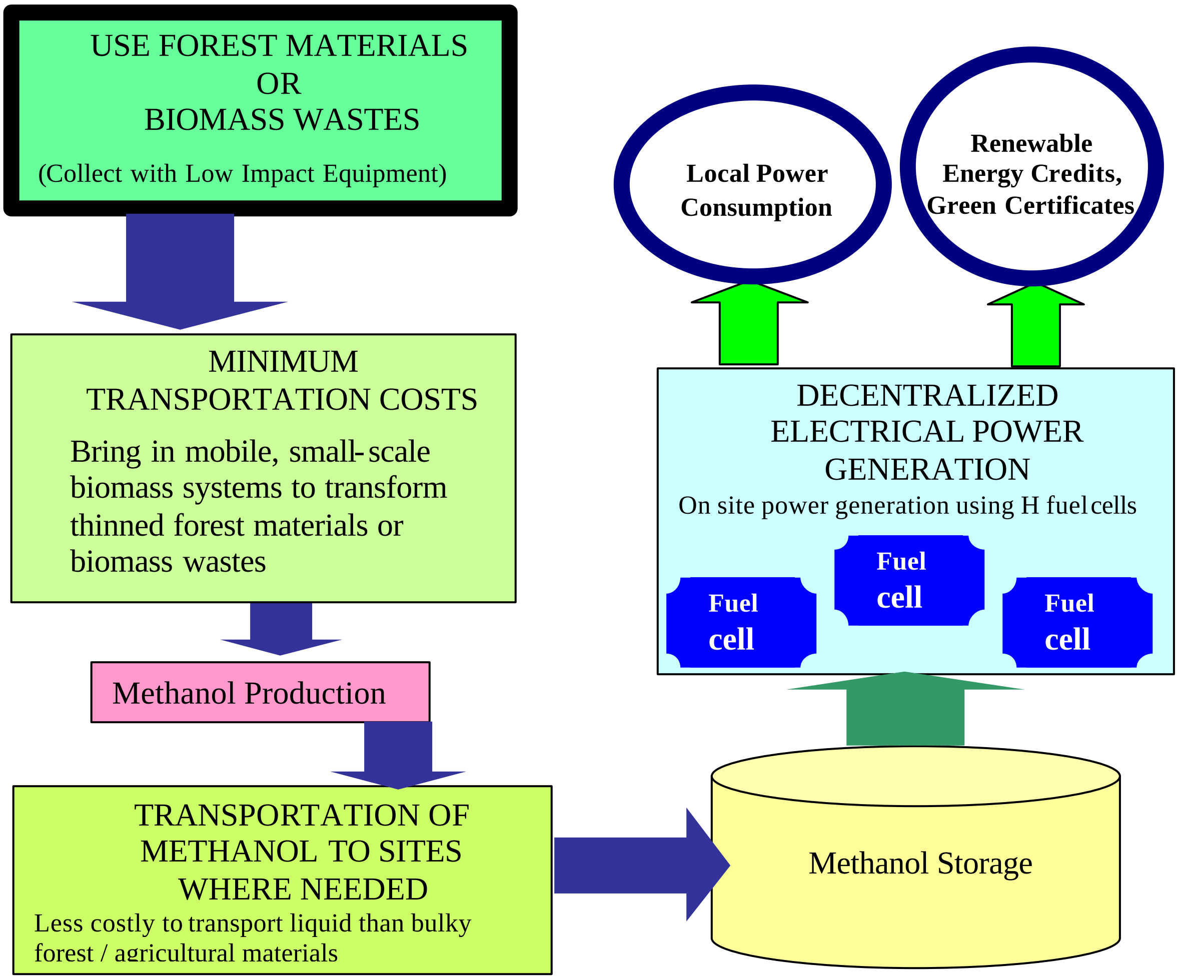

Figure 1. Flow diagram of biomass transformations to energy via production of methanol fuel for hydrogen fuel cells

based on the process (e.g., gasification, pyrolysis), the mix of tree species used, and what is included in the raw material (bark, needles, cones, etc.). Forest residue conversion efficiencies as high as 45-55% have been recorded for forest residue conversion to methanol and 65-75% for liquid bio-fuels (see below).

Table 2. Efficiencies of converting different materials to methanol

Starting Material	Efficiency/Conversion to Methanol	Reference
Pulp Mill Black liquor	**65**	Ekbom et al. 2003
Biomass feedstock	**1000 kg ~ 700 l of methanol**	NREL/SP-420-5570-Rev.2
Biomass	**60**	Specht and Bandi
Forest residues	**55**	Mäkinen and Sipilä 2003
Wood residues	**43.5 – 50.8**	DOE 1990
Forest residues	**65 - 75** (liquid bio-fuels)	Oasmaa et al. 2003
Soybean-cake	**43** (to bio-oil)	Pütün et al. 2002

Hydrogen Fuel Cells.

Fuel cells represent a means of generating electrical energy virtually free of environmental pollutants. In contrast, the burning of fossil fuel resources (oil, coal, natural gas) is accompanied by the release of substantial amounts of potentially harmful compounds: unburned hydrocarbons, carbon monoxide, oxides of nitrogen, sulfur dioxide, CO_2. In particular, CO_2 release has been linked to the "greenhouse effect" and an increase in the global average temperature, or *global warming*.

While there are several different designs, all fuel cells use hydrogen gas (H_2) as a starting material to produce an electric current. Fuel cells have been used for many years in spacecraft as a means of producing both electricity and as a source of water. Presently, the infrastructure for transporting, storing, and dispensing H_2 gas is not generally available. Recently, however, in just the last year (2003), fuel cells able to use methyl alcohol (methanol) as opposed to H_2 gas as a starting material have become *commercially* available. This development has created new opportunities for powering fuel cells which do not require a H_2 gas distribution system.

Opportunities for the Use of Biomass for Energy by the Agricultural Sector in Iceland

In contrast to most other industrial countries, Iceland does not have incentives for converting to bioenergy to fulfill the requirements of the Kyoto Protocol. According to the Ministry of the Environment in Iceland (2003), the estimated increase in annual GHG emissions will not exceed the limits of Iceland's obligations under the Kyoto Protocol. However, converting biomass into biofuel would potentially decrease Iceland's dependence on external supplies of fossil fuel. For example, biomass derived fuels could substitute for conventional fuels used by the transportation sector and the fishing fleet. For example, pursuing alternative energy strategies would help to decrease the 30% GHG emissions occurring from the transportation sector and the 26% being emitted by fishing vessels in Iceland (Ministry of the Environment, 2003). Currently, the Icelandic government does not include the use of biomass resources in its climate policy except to increase annual carbon sequestration in biomass.

The logical incentive for increasing the use of bioenergy in Iceland would come from the creation of jobs and economic opportunities in rural areas, and to provide agriculture with new economical outlets. Additional benefits would be the stimulation of land-use changes (e.g., planting trees) that provide economic incentives for forestry projects. The biomass-methanol-fuel cell systems discussed earlier are also ideally suited to transform wastes generated in larger agricultural communities. There is a substantial need to dispose of agricultural waste with minimum transportation costs. If that material could be used to generate electricity when combined with fuel cells, several goals could be satisfied in rural areas. Furthermore, decentralized energy production systems are ideal for more remote agricultural areas with less secure energy infrastructures and where winter conditions result in blackouts, sometimes for several days at the time.

Some Key scenarios discussed below are ideal for installing decentralized bioenergy systems (i.e., methanol H fuel-cell systems) in Iceland:

- Larger agricultural communities with a need to dispose of agricultural wastes especially where transportation costs are low,

- Remote agricultural areas with insufficient energy infrastructure, where powerline blackouts are not uncommon during adverse winter weather conditions,
- Areas with relatively intensive farm forestry operations or where low input energy crops (such as willow) are grown, and
- Soil reclamation endeavors.

Expanding bioenergy systems to landscape-scale forestry projects in Iceland could also be useful in meeting recent government initiatives to increase forest cover in Iceland. For these reforestation projects to be viable, they need to provide economic returns to farmers in the short-term. By linking the afforestation programs to electricity production, they have increased potential in becoming sources of income generation. Even though ~80% of homes in Iceland use geothermal resources for heating, the other ~20% of the homes are predominantly rural homes where central heating systems are expensive to maintain. So the development of farm forestry projects that would provide energy at a lower cost to rural communities and the added incentive of early economic return from forests could stimulate the adoption of forestry projects, making forest ownership a desirable option. Furthermore, the deregulation of the energy market in Europe (including Iceland) will result in the development of new agriculture practices and potentially offer farmers the option of becoming ‘energy’ farmers (someone who sells surplus energy to the grid) in addition to growing food crops.

Small-scale bioenergy systems could be an economic tool to aid rural development in Iceland, especially since the Icelandic government has decided to pursue reforestation as evidenced by the passing of a law (1999 nr. 56 19. March) stipulating the planting of new forests to cover at least five percent of the land area below 400 m elevation within the next 40 years. This law will result in approximately 2 180 km^2 of land being planted into new forests. If the cost of stand establishment is estimated to be 120 thousand ÍKR/ha (Suðurlandsskógar 2003), the total cost of establishment is more than 26 billon Icelandic ÍKR of which 97% is provided by the Icelandic government. Furthermore, the State will provide additional funds for the first thinning of these forests at an estimated cost of ~15 billion ÍKR (assuming thinning costs to be 70 thousand ÍKR/ha [Suðurlandsskógar 2003]). The major incentive for enacting this new law was to stimulate planting of forests to provide stability and economic returns to rural communities.

Establishment of new forests for wood production under challenging growing conditions is an expensive endeavour. It is therefore economically strategic to maximize returns from farm forestry projects in Iceland. Early thinnings for bioenergy purposes would be an ideal solution to increase the value of these forests. Similarly, bioenergy uses of biomass could potentially subsidize the cost of land reclamation projects in the country.

A growing number of countries, including Iceland, have committed to accelerate the development of hydrogen energy technologies in order to improve their energy, environment and economic security. The commitment of the Icelandic government and others, such as the U.S., the EC, UK, Canada, Australia, Brazil, France, Germany, India, Italy, Japan, Korea, Norway and Russia, is an indication that the global community shares a common interest in advanced research and development supporting the commercial use of hydrogen and fuel-cell technologies. Moving towards opportunities for linking biomass or other wastes transformation to H fuel cells is thus an obvious path to pursue for Iceland.

References

AMI. 2003. Beyond The Internal Combustion Engine. The Promise of Methanol Fuel Cell Vehicles http://www.methanol.org.

Andersson L, S Emilsson. 2003. Regular recycling of wood ash to prevent waste production. Pp. 210-212. Intern. Nordic Bioenergy Conf. Proc. Paper. Pp 2. Jyväskylä, Finland (2-5/9/2003).
Bridgewater A. 1999. A Guide to Fast Pyrolysis of Biomass for Fuels and Chemicals. Pyne Newsletter No. 8. Aston University, Birmingham, UK. www.pyne.co.uk.

Brown RC. 2003. Biorenewable Resources. Engineering New Products from Agriculture. Iowa State Press. A Blackwell Publishing Company.

Cargill-Dow. 2000. www.findarticles.com/cf_sccfrm/m1204/7_98/62838069/p1/article.jhtml.

CEC 1997. Energy for the Future: Renewable Sources of Energy – White Paper for a Community Strategy and Action Plan COM(97) 599 Final. 26.11.1997.

CEC 2000. Green Paper on the Security of Energy Supplies COM(2000) 769.

DOE. 1990. Assessment of costs and benefits of flexible and alternative fuel use in the U.S. transportation sector. Technical report five. Costs of methanol production from biomass. Department of Energy. DOE/PE-0097P. Washington.DC.

Domac J. 2002. Bioenergy and job generation. Unasylva 211 Vol. 53: 18-19.

DynaMotive. 2003. http://www.dynamotive.com/flash.asp.

Ekbom T, N Berglin, M Lindblom. 2003. High efficiency emthanol/dme production from biomass via black liquor gasification as renewable motor fuels. Pp. 440-442. Intern Nordic Bioenergy Conf Proc Paper. Pp 2. Jyväskylä, Finland (2-5/9/2003).

FAO. 2001. How Forestry can reduce poverty. DFID – Depart of Intern Development.

FAO. 2003. State of the Worlds Forests. Part II. Pp. 61-73. Forests and poverty alleviation; Annex 2. Data Tables. Pp. 126-151.

Fenn ME et al. 2003. Nitrogen emissions, deposition, and monitoring in the western United States. BioSci. 53: 391-403.

Hirschler B. 2002. FEATURE – Hydrogen puts Iceland on road to oil-free future. Reuters 31/5/2002.

IdaTech 2003. Claude Duss, David Edlund. www.idatech.com.

IPCC (IPCC Working Group I Technical Support Unit). 2003. IPCC Meeting on Current Scientific Understanding of the Processes Affecting Terrestrial Carbon Stocks and Human Influences on Them. Expert Mtg Rep. Geneva, Switzerland, July 21-23, 2003.

Kheshgi HS, RC Prince, G Marland. 2000. The potential of biomass fuels in the context of global climate change: Focus on transportation fuels. Annu.Rev. Energy Environ. 25: 199-244.

Kopetz H. 2003. Bioenergy in Europe. Pp. 21-24. Intern Nordic Bioenergy Conf Proc Paper.. Jyväskylä, Finland (2-5/9/2003).

Kurz WA, M Apps, E Banfield, G Stinson. 2002. Forest carbon accounting at the operational scale. The Forestry Chronicle 78: 672-679.

Mäkinen T., K. Sipilä. 2003. Utilisation and production costs in Scandinavia. Pp. 376-382. Intern Nordic Bioenergy Conf Proc Paper. Jyväskylä, Finland (2-5/9/2003).

Mancini E.M. 1998. A questão do Álcool Combustivel. Departamento Nacional de Desenvolvimento Energetico, Brasília. www.mme.gov.br/sen/dnde/Pgalcool/NT06.htm

Methanex. 2003. www.methanex.com/fuelcells/environment/urbansmog.pdf.

Najam A. 2003. The human dimensions of environmental insecurity: some insights from South Asia. ECSP Report 9: 59-74.

NREL (National Renewable Energy Laboratory). 1995. Methanol from Biomass. US DOE. NREL/SP-420-5570-Rev.2, DE93010018. www.nrel.gov/docs/legosti/old/5570r2.pdf.

Nyström I, DW Cornland. 2003. Strategic choices: Swedish climate intervention policies and the forest industry's role in reducing CO_2 emissions. Energy Policy 31: 937-950.

Oasmaa A, E Kuoppala, S Gust, Y Solantausta. 2003. Fast pyrolysis of forestry residues. 1. Effect of extractives on phase separation of pyrolysis liquids. Energy & Fuels 17: 1-12.

Ohlström N, T Mäkinen, J Laurikko, R Pipatti. 2001. New concepts for biofuels in transportation. Biomass-based methanol production and reduced emissions in advanced vehicles. VTT Research Notes 2074.

Pütün AE, E Apaydin, E Pütün. 2002. Bio-oil production from pyrolysis and steam pyrolysis of soybean-cake: product yields and composition. Energy 27: 703-713.

QLG (Quincy Library Group). 1997. Northeastern California Ethanol Manufacturing Feasibility Study. Executive Summary. November 1997. pp. 49. www.qlg.org/pub/.

Sedjo RA. 1997. The economics of forest based biomass supply. Energy Policy 25(6): 559-566.

Sigurdardottir et al. 2003. Renewable added value to forests – shift from traditional uses: Bioenergy coupled with hydrogen fuel cells. Intern Nordic Bioenergy Conf Proc Paper. Jyväskylä, Finland (2-5/9/2003).

Smil V. 2001. Enriching the Earth: Fritz Haber, Carl Bosch, and the Transformation of World Food Production. MIT Press. Cambridge, MA.

Specht M, A Bandi. The Methanol-Cycle – Sustainable Supply of Liquid Fuels. Center of Solar Energy and Hydrogen Research (ZSW), Hessbruehlstr. 21C, 70565. Stuttgart.

Suðurlandsskógar 2003. Greinagerð um innri vexti skógræktar. www.sudskogur.is .

TNO (TNO Environment, Energy and Process Innovation). 2003. From water vapour to hydrogen. Biomass, the sustainable alternative for coal, oil and natural gas. www.mep.tno.nl.

Vogt KA, M Andreu, DJ Vogt, R Sigurdardotti, K Hodgson. 2004. Enhancing sustainability of old growth forests in human landscapes by adding non-traditional values to younger forests. J For. (review).