Alternative Technologies to Transform Biomass into Energy

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Prepared for
Ontario Federation of Agriculture

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December, 2012

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Acknowledgements

The OFA would like to thank the following members of the evaluation team for assessing alternative technologies and providing their valuable input.

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Preface

In 2010, the Ontario Federation of Agriculture (OFA) received Agriculture and Agri Food Canada (AAFC) funding through the Canadian Agricultural Adaptation Council (CAAP) to conduct producer level research and value chain determination in support of commercializing agricultural biomass into energy and co-products.

In earlier studies, the OFA examined the opportunities to use biomass as a substitution for coal and natural gas, including a business case for purpose-grown biomass as a combustion fuel and the sustainable harvest of crop residues. These reports are available on the OFA website along with other biomass studies. Please visit www.ofa.on.ca/issues/overview/biomass to access these previous studies including this report.

In order to complete their due diligence on behalf of producers, the OFA placed a high priority on examining all existing technologies as well as promising emerging technologies that could be useful to convert agricultural biomass into electricity, fuel or other forms of energy. Hence, the scope of this study was broadened to look at all pathways leading to energy production. This study represents a significant deviation from previous studies where combustion technologies were examined to produce energy.

A worldwide search of emerging commercial technologies resulted in more than 20 different technologies being evaluated by a technical panel. The panel assembled the knowledge and skills from various sources including the research community, the commercial sector and government staff. The OFA wishes to thank those who diligently participated.

Based on the information presented, the Report provides useful guidance to the agricultural sector with respect to a greater understanding of the risks and opportunities of each technology. Recommendations on investment opportunities and scenarios will help producers with their individual investment decisions.

The report is also unique because a biomass producer, Scott Abercrombie of Gildale Farms, authored a chapter in the Report on harvesting, handling, storage and transportation of biomass materials. The OFA wishes to thank Scott for his important contribution to the study.

The OFA would like to thank the Western Sarnia-Lambton Research Park and its authors, Dr. Aung Oo and Dr. Katherine Albion for their thoroughness and dedication in preparing this report.

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Executive Summary

This study reviews alternative technologies to transform biomass into energy and co-products and also examines the applications of these technologies in the agricultural sector in Ontario. The consumption of different types of energy in Ontario agricultural sector is analyzed, and potential energy generation from agricultural biomass is estimated. The alternative technologies to transform biomass into energy and co-products are evaluated for their technical and commercial strengths and suitability for the agricultural sector in Ontario. Biomass harvesting, storage, transportation and handling activities for the bio-energy sector are also discussed. The financial spreadsheet models are developed to estimate the return on investment for the selected technologies. The status of research and development of emerging bio-energy technologies are presented. The segments of the bio-energy value chain are analysed to determine to what extent agricultural producers should participate in the bio-energy industry.

The agricultural sector in Ontario could not only be energy self-sufficient but could also provide biomass for energy use in other economic sectors. The agricultural sector in Ontario consumes a significant amount of gasoline, diesel, and propane, heating oil, electricity and natural gas for the livestock and farming activities. This annual energy consumption in the Ontario agricultural sector is equivalent to 3.35 million tonnes of biomass. Ontario farms produce over 50 million tonnes of grains, beans, and feeds and about 14 million tonnes of crop residues annually. Approximately 3 million tonnes, i.e. 20% of total crop residue produced, can be sustainably harvested annually. An additional 3 million tonne/yr of biomass can be produced by planting purpose-grown crops such as miscanthus and switchgrass on less than 5% of agricultural lands in Ontario. Approximately 30-35% of grain corn grown in Ontario is currently used to produce ethanol.

There are about 1.7 million cattle in Ontario (OMAFRA statistics) whose manure waste could be used to produce 1.55 TWh or over 60% of total electricity consumed in the agricultural sector. Approximately 5,500 TJ/yr of electricity could be theoretically generated from manure biogas if all of it were available for digestion facilities. Anaerobic digestion is a mature bio-energy technology at farm scale, ranging from 300 to 3,000 kW of electricity generation capacity. Ontario agricultural producers should participate in the complete value chain of AD bio-energy systems. Farm organization like OFA should lobby for better access to the electricity grid and for a better premium price of energy generated from the AD systems.

Anaerobic digestion, direct combustion, bio-ethanol and bio-diesel productions are the four integrated bio-energy systems with the greatest technical and commercial opportunities in Ontario. The direct combustion of biomass integrated with steam turbines is a mature technology which generates renewable heat and power. To be financially viable, the minimum electricity generating capacity of a direct combustion system should be 10 MW. For the direct combustion of bio-energy systems, Ontario producers could participate in feedstock supply and transportation of biomass. A partial participation in the form of taking minority stakes or joint venture with the energy producer could be possible in selected locations. Economies of scale would be an important factor for bio-ethanol industry, and availability of inexpensive feedstock is critical for bio-diesel industry. Participating in bio-ethanol and bio-diesel industries would provide a reasonable hedging for Ontario producers who consume considerable amounts of liquid fuels in transportation during farming activities. Taking minority stakes or forming joint ventures with financially performing bio-ethanol and bio-diesel manufactures are recommended.

Pyrolysis, gasification, torrefaction, micro turbines, and small scale energy storage are emerging technologies for agricultural bio-energy generation. More research and development is required, especially using agricultural biomass as feedstock for the commercialization of pyrolysis, gasification and torrefaction. It should be noted that the research and development of emerging bio-energy technologies is not an area of expertise for Ontario producers. If bio-energy systems with these emerging technologies were built in Ontario, agricultural producers should participate in the feedstock supply and biomass transportation of the value chain. Participating in energy production, marketing and selling of the energy and co-products would require further assessment for these technologies on a case-by-case basis. A similar approach could be employed for other emerging bio-energy technologies.

Economies of scale are important in bio-energy generation. The unit generation/production cost of a small facility could be 3 to 4 times higher than that of a large facility. Portable biomass processing and bio-energy production units have been developing in recent years. They range from portable biomass pelletizers to mobile pyrolysis units to small biomass gasification systems. These small units can process 1 to 3 tonnes/hr, (fewer than 30,000 tonnes/yr) of raw biomass. In many Ontario counties, approximately 150,000 tonne/yr of biomass can be gathered within 100 km radius. With smaller systems aimed at processing 20 to 30,000 tonnes of biomass annually could be supported locally with favourable economies of scale. Extreme care should be exercised in analyzing the financial feasibility of small scale bio-energy systems. Once the profitability of a small system is proven, there will likely be new larger entrants to the industry with favourable economies of scale.

The return on equity of most bio-energy systems ranges from 10 to 15%. Current prices for biomass and other energy sources as well as feed-in-tariff rates for electricity from biomass influence the actual return rate on equity for various projects. Generating heat and power from agricultural biomass at large scale would be relatively new for Ontario, and risks associated with bio-energy technologies must be carefully managed. The threat of other energy sources on the bio-energy sector in Ontario is significant. At the current low price of natural gas in Ontario, energy generation using natural gas as a feedstock is very attractive. Also, competition from other biomass resources from the forestry sector and municipal solid wastes should not be underestimated. The financial advantages of a bio-energy system using agricultural biomass should be identified at the feasibility study stage of each project.

Forming alliances with bio-energy industry organizations and R&D centres is recommended to monitor the development of emerging bio-energy technologies. For the large-scale use of biomass for energy generation, the best practices and industry standards need to be developed for biomass harvesting, storage, transportation and handling activities. Since most renewable energy receives regulatory supports, it is important to influence policy makers by highlighting the potential socio-economic benefits of responsible bio-energy production to the agricultural and rural sectors. The low price of natural gas and increasing electricity cost in Ontario could result in significant changes in energy consumption mix in the medium to long term timeframe. Further analysis is required to examine these effects on the bio-energy industry. The potential integration of bio-energy facilities with other bio-based industries should also be investigated.

Chapter 1 – Overview of Transforming Biomass into Energy

Biomass is considered a renewable energy source. Farms in Ontario traditionally produce grains, beans and meat for human consumption, feed for livestock, and feedstock for various industries. The agricultural sector can also offer purpose-grown biomass and crop residues to be utilized in generating electricity, heat and other by-products. As a significant consumer of energy products, the agricultural sector could potentially benefit from participating in bio-energy generation. In this chapter, the consumption of different types of fuels in the Ontario agricultural sector is presented. Energy from biomass is compared with other energy sources in the province. Preliminary assessment of alternative technologies to transform agricultural biomass into energy and by-products is discussed.

1.1 Ontario Agricultural Sector and Energy Use

Ontario is one of the most prominent agricultural provinces and home to approximately 50% of Canada's agricultural Class 1 land. Ontario is the largest producer of grain corn and soybeans, about 65% and 75% of Canadian total, respectively (Statistics Canada). The agricultural sector is one of the main economic pillars in Ontario, creating jobs in rural areas and in food processing industries. Farming activities consume significant amount of energy, representing about 2% of total energy consumption in Ontario. Table 1.1 lists the consumption of major energy types in the agricultural sector in Ontario.

Energy consumption is expressed as biomass equivalent in million tonnes. Ontario farms produce over 50 million tonnes of grains, beans, and feeds annually (OMAFRA crop statistics).

Table 1.1 Energy Consumption in Ontario Agricultural Sector

Energy Source	Consumption in Agri. Sector (TJ/yr)	% of Ontario Total	Biomass Equivalent (million tonne/yr)
Natural gas	12,655	1.54	0.68
Electricity	8,752	1.95	1.58
Diesel	8,238	3.41	0.45
Gasoline	7,315	1.29	0.40
Propane	3,245	8.43	0.18
Heating oil	1,339	3.93	0.07
Total	41,544	1.93	3.35

Source: Statistics Canada; Assumption: 30% electricity generation efficiency in estimating biomass equivalent

Approximately 14 million tonnes/yr of crop residues such as corn stover and wheat straw are also generated. Oo and Lalonde (2012) suggested that about 3.1 million tonne/yr of crop residues can be sustainably harvested. If 0.5 million acres, which is about 3.7% of total agricultural land in Ontario, were dedicated to purpose-grown biomass such as miscanthus or switchgrass, over 3 million tonne/yr of biomass could be produced. These estimates and energy consumption data shown in Table 1.1 suggest that Ontario agricultural sector could not only be energy self-sufficient but could also provide biomass for energy use in other economic sectors.

Electricity generated from biomass and other renewable sources can be sold to the grid at premium prices offered by the Feed-in-Tariff (FIT) program in Ontario. The majority of renewable electricity in Ontario comes from solar and wind sources. There has been no significant development in electricity generation from biomass except biogas electricity through anaerobic digestion of manure. There are about

20 biogas electricity plants in the Ontario agricultural sector based on personal communication with industry experts. There are about 1.7 million cattle in Ontario (OMAFRA statistics), and approximately 5,500 TJ/yr, i.e. 1.55 TWh of electricity could be theoretically generated from manure biogas. This potential manure-based electricity represents about 63% of total electricity consumed in Ontario agricultural sector (see Table 1.1).

The price of energy could fluctuate on a short to medium term time frame; however, prices will likely increase in the long term due to scarcity of energy resources, increasing population and economic activities. Therefore, participating in energy generation would provide a hedge for the Ontario agricultural sector against greater input cost of farming operations resulting from increased energy price. Approximately 30 to 35% of grain corn grown in Ontario is currently used to produce ethanol (Grier et. al, 2012). This allows Ontario agricultural sector participation in transportation liquid fuel energy markets to some extent. However, there is a potential for greater participation in energy markets due to the available biomass resources discussed above.

1.2 Biomass and Competing Energy Sources

When electricity generated from biomass is sold to the grid, it entitles the premium price as provided by the FIT program. However, for other forms of final energy such as space heating applications or onsite power generation of own use, biomass has to compete with different energy sources available in Ontario. The estimated cost of different types energy sources are compared with biomass pellets in Figure 1.1. The costs are at consumers' gate and compared in the unit cost per energy content ($/GJ).

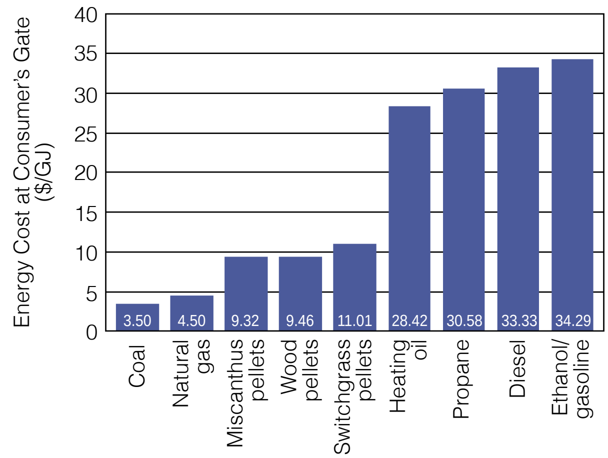


Figure 1.1 Comparisons of Biomass Pellets with Other Energy Sources in Ontario

As seen in Figure 1.1, coal and natural gas are the most cost-competitive fuels in Ontario. Liquid transportation fuels, diesel and gasoline are the highest cost energy sources. Production of bio-diesel and corn/cellulosic ethanol could be financially attractive for the Ontario agricultural sector. Additionally, the bio-fuels used for transportation are mandated by federal and provincial regulations. Biomass pellets, both forestry and agricultural, are relatively less inexpensive than heating oil and propane. Therefore, space heating applications, where heating oil and propane are heavily used due to lack of natural gas infrastructure, could offer potential markets for biomass pellets. The fuel cost of such space heating applications could be reduced by approximately 65% by switching to biomass pellets.

The consumption of heating oil and propane in selected sectors, mainly for space heating applications in Ontario, is given in Table 1.2. The biomass equivalent in million tonnes/yr is also estimated. The commercial and institutional sector is the largest consumer of heating oil and propane, representing over 50% of the provincial total. As shown in Table 1.2, the potential

Table 1.2 Potential Biomass Space Heating Markets in Ontario

Energy Source	Consumption (TJ/yr)	Biomass Equivalent (million tonne/yr)
Agricultural Sector		
Propane	3,245	0.18
Heating oil	1,339	0.07
Residential Sector		
Propane	8,446	0.46
Heating oil	12,765	0.69
Commercial and Institutional		
Propane	12,096	0.65
Heating Oil	17,573	0.95
Total	55,464	3.00

Source of consumption data: Statistics Canada

demand of biomass, replacing heating oil and propane, is approximately 3 million tonnes annually. This demand can be met by crop residues or purpose-grown biomass grown on less than 4% of agricultural land in Ontario.

Two noteworthy trends in energy markets in Ontario are the increasing price of electricity and the declining price of natural gas. In the Ontario Long-Term Energy Plan released in 2010, the provincial government stated that residential bills are expected to rise by 3.5 per cent per year, and industrial prices are expected to rise by 2.7 per cent per year over the next 20 years. In the meantime, the price of natural gas has decreased significantly from its peak in 2007-2008 and is expected to remain at current level due to abundant shale gas discovered in nearby regions. These trends could result in the improved economics of Combined Heat and Power (CHP) using natural gas as a fuel in medium to large industries where there are considerable heat demands. For example, the IGPC Ethanol Inc. is installing such a CHP unit at their plant in Aylmer, Ontario (personal communication with IGPC Ethanol Inc.).

1.3 Preliminary Assessments of Alternative Technologies

Energy contained in biomass can be transformed into heat and/or power through a number of primary conversion technologies and integrated conversion technologies. Primary conversion technologies include anaerobic digestion, direct conversion, gasification and pyrolysis. Integrated conversion technologies include gas-fired boiler, oil-fired boiler, Internal Combustion (IC) engine, indirect fired gas turbine, micro turbine, gas turbine, fuel cell, Stirling engine, heat exchanger, steam turbine and energy storage. Some of the technologies are commercial while some can be considered as emerging technologies. The preliminary assessments of selected alternative technologies to transform biomass into energy are summarized in Table 1.3.

Anaerobic Digestion (AD) is a proven commercial technology to convert wet biomass such as manure or municipal green wastes into combustible gases. Integrated conversion technologies listed in Table 1.3 further transform the combustible gases into heat and power. IC engines are the most common integrated conversion technology for the anaerobic digestion system to generate power. The typical electricity generation capacity of AD systems ranges from 250 to 500 kW, and up to 3,000 kW units are commercially available. Indirect fired gas turbines can be also used in the anaerobic digestion power systems; however, they are more costly than IC engines. Gas turbines, micro turbines (which are small gas turbines), and fuel cells require relatively clean gases to operate. Stirling engines have been proven at lab scales; however, extensive commercial use has yet to be confirmed.

Heat and power can also be produced by direct combustion of biomass in fixed bed or fluidized bed boilers as the primary conversion integrated with heat exchangers or steam turbines. This energy conversion system has been in commercial operation for decades. Direct combustion steam turbine biomass power generation systems are relatively larger ranging from 10 MW to over 300 MW of electrical power. Co-firing biomass with coal to generate heat and power could have some issues at higher biomass-to-coal ratio since the combustion temperature of coal-fired boilers is higher than the ash melting temperature of biomass causing fouling of boilers. However, the direct combustion systems dedicated to biomass are designed at lower combustion temperatures and operate with no major technical issues.

Biomass can be heated to 550-850 °C in the absence of air/oxygen to produce synthetic gases, mainly hydrogen and carbon monoxide. This primary conversion is called gasification and has been used commercially. The synthetic gases can then be converted into heat and power through the integrated conversion technologies shown in Table 1.3. The typical power generation capacity of biomass gasification systems ranges from 250 kW to 5 MW. Most commercial biomass gasification energy system use wood as feedstock; however, agricultural biomass gasification systems have not been used extensively in commercial applications. This is due to the relatively more corrosive nature of gases produced from agricultural biomass in comparison with forestry biomass. Advancements in cleaning of synthetic

Table 1.3 Preliminary Assessments of Selected Alternative Technologies

Primary Energy Conversion Technology	Final Form of Energy	Integrated Conversion Technology	Comments
Anaerobic digestion (Commercial)	Heat	Gas-fired boiler	Commercial, could feed steam to steam turbine
	Power	IC engine	Commercial and widely-used
		Indirect fired gas turbine	Commercial
		Micro turbine	Commercial, gas cleaning is essential
		Gas turbine	Commercial, gas cleaning is essential
		Fuel cell	Emerging
		Stirling engine	Emerging
Direct combustion of biomass in fixed bed and fluidized bed boilers (Commercial)	Heat	Heat exchanger	Commercial
	Power	Steam turbine	Commercial and widely-used
Gasification in fixed bed and fluidized bed gasifiers (Commercial with forestry biomass, demonstration-commercial with some agricultural biomass)	Heat	Gas-fired boiler	Commercial, could feed steam to steam turbine
	Power	I.C. engine	Commercial and widely-used
		Indirect fired gas turbine	Commercial
		Micro turbine	Commercial, gas cleaning is essential
		Gas turbine	Commercial, gas cleaning is essential
		Fuel cell	Emerging
		Stirling engine	Emerging
Pyrolysis (Emerging-demonstration)	Heat	Oil-fired boiler	Commercial, could feed steam to steam turbine
	Power	Indirect fired gas turbine	Commercial
		Stirling engine	Emerging

gases could improve the commercial viability of the gasification heat and power systems using agricultural biomass as feedstock.

Pyrolysis is an alternative primary conversion technology which can produce synthetic gases, bio-oil and bio-char by heating biomass at relative lower temperatures of 350 to 550 °C in the absence of air/oxygen. Producing speciality chemicals through pyrolysis has been in commercial operation, e.g. renewable chemicals for food and wood processing industries from Ensyn Corporation (www.ensyn.com). However, the production of energy through pyrolysis technology can be considered at the emerging to demonstration stage, especially for agricultural biomass feedstock. Pyrolysis has a great potential as an alternative technology due to the versatility of its products. Bio-oil could be theoretically further refined like crude oil to produce an array of fuels, chemicals and other products. Bio-char could be used in energy applications or as fertilizer, which is complementary to agricultural activities. Currently, a significant amount of research and development is attempting to resolve some technical issues such as higher acidity and instability of bio-oils.

In addition to the technologies shown in Table 1.3, torrefaction is another alternative technology of interest in recent years. Torrefaction is essentially the roasting of biomass at 200-300 °C, producing energy dense and hydrophobic biomass, especially suitable for outdoor storage and co-firing with coal at large power plants. The resulted coal-like biomass has a number of advantages over conventional biomass pellets, including lower transportation cost per unit energy content. This advantage would allow biomass exports to Europe, where solid biomass demand is expected to grow significantly over the next decade (Ginther, 2011). Torrefaction technologies are currently in laboratory to pilot scale productions and mostly use forestry biomass. Torrefaction of agricultural biomass is at the laboratory research and development stage at present. In southern Ontario, torrefaction of agricultural biomass could occur at the point of use for small to medium scale applications due to relatively short transportation distance.

Bio-based liquid fuels, mainly ethanol and bio-diesel, are currently produced in commercial operations. Production of ethanol from starch/sugar crops is a relatively mature technology. However, cellulosic ethanol technologies are at pilot to demonstration stage and have yet to be proven for commercial viability. In 2012, DuPont has started the construction of a commercial scale cellulosic ethanol plant in Iowa. This plant is expected to begin production in mid 2014 using corn crop residues as feedstock. Bio-diesel technologies are also commercially proven. At current mandatory blend rates in Ontario, bio-diesel plants seem to be financially attractive only if inexpensive feedstock such as used cooking oil or other industrial wastes are available. Both sugar/starch ethanol and bio-diesel technologies are expected to progress gradually in lowering the production costs. The development of cellulosic ethanol technologies should also be monitored since a large quantity of crop residues is available in Ontario.

Chapter 2 – Biomass Harvesting, Storage, Transportation and Handling

The initial activities relating to biomass conversion include harvesting, storage, and transportation to a processing or conversion facility and material handling to pre-process the biomass to the facility's specifications. Agricultural biomass is a low value commodity as compared to grain or forage commodities. Thus, it is important in these initial steps in the biomass supply chain that all efficiencies must be maximized to supply biomass such that both the supply and the conversion of the biomass are economically viable. The objective would be to minimize the number of steps, handling, labour and cost incurred to supply biomass to the conversion facility. At the present time, corn stover residual and purpose grown crops including switchgrass and miscanthus hold the most potential as agricultural biomass feedstock. Thus, these will be the focus of this chapter in the report.

2.1 Harvesting of Biomass

2.1.1 Conventional Equipment

Many farms have conventional forage equipment to harvest crops such as corn silage, hay and straw by either chopping using a forage harvester or by cutting and bailing. The same equipment can be used to harvest corn stover by raking and bailing or for purpose grown crops by swathing and bailing or by chopping with a forage harvester. Thus, harvesting corn stover or purpose grown crops can be done without additional capital costs in equipment. However, there are limitations to conventional equipment that must be considered. For example, balers who produce a round bale are very common. However, round bales are not as efficient for storage, transportation, and handling compared to large square bales, especially high density bales made by newer generation balers capable of chopping the material while baling. High density balers can produce bales with up to 25% greater density, which translates into improved efficiencies for handling, storage, and transport. Additionally, because of the greater density, the bales withstand stacking and handling better than the round bales. Because of the inefficiency of rounds bales, in many cases round bales will not be accepted or face a discriminatory price adjustment at the end conversion facility. Furthermore, round bales may require pre-processing at another location since the equipment to break up round bales is different from square bales and the operation produces considerable dust. Another limitation may be the capacity of smaller or older forage equipment.

Newer generation forage equipment such as high density balers or high capacity forage harvesters should require no modifications and only little adjustment to harvest biomass material. While this equipment might be cost prohibitive for producers with small acreage, many custom operators will provide these services cost effectively, especially as this equipment is not likely to be utilized during the timeframe of harvest of the biomass crops. Examples of new generation, high capacity conventional equipment are shown below in Figure 2.1 and Figure 2.2. Several equipment manufacturers offer similar equipment.

Another tool that offers increased efficiency for harvest of biomass is a bale accumulator, an example of which is shown in Figure 2.3. A bale accumulator is drawn behind a tractor and uses hydraulics to pick up bales in the field by driving along side and grabbing the bale while still in motion. The bale is then positioned on the carrier which automatically aggregates the bales into a stack that can be tipped up and unloaded when full. This allows the farmer to quickly and efficiently collect and clear bales from the field with a single tractor and operator, compared to using a loader tractor and wagons which requires two tractors and operators. Using a bale accumulator creates neat stacks of bales facilitating subsequent loading onto a truck for transport.

Figure 2.1 High Density Baler (Krone)
(Source: www.krone-northamerica.com)

Figure 2.2 High Capacity Forage Harvester with Kemper Head
(Source: www.claas.com)

2.1.2 Developing Equipment Specific to Biomass

In response to the opportunity to harvest corn stover, especially for the ethanol market, several equipment manufacturers have modified combines to harvest both the grain corn and corn stover or corn cobs simultaneously in a one pass operation. Examples of specialized equipment are shown Figure 2.4.

Figure 2.3 Bale Accumulator Used to Aggregate Bales in the Field
(Source: www.fwi.co.uk)

Figure 2.4 Specialized Combines to Harvest Grain Corn and Stover
(Source: www.cngva.org)

2.1.3 Economic Cost of Harvesting Activities

The economic costs of harvesting biomass can be derived using rates for the required harvest activities for custom operators for traditional forage crops and adjusting for differences in yield. The rates used in calculating the harvest costs were taken from the OMFRA Survey of Custom Farm work Rates (http://www.omafra.gov.on.ca/english/busdev/facts/10-049a3.htm).

2.1.3.1 Switchgrass

Assuming an average yield of 10.0 DM t/ha, the costs to harvest a switchgrass crop by swathing, raking and bailing and removing the biomass from the field are shown in Table 2.1. Costs for raking are included as it is assumed that the switchgrass is swathed in the fall; thus in the spring prior to bailing raking would likely be required to turn the swaths to help facilitate drying of the biomass.

2.1.3.2 Miscanthus

Miscanthus is commonly harvested either in chopped form or in baled form. Assuming an average yield of 16.0 DMt/ha, the costs for both harvesting methods are shown in Table 2.2 and Table 2.3. The rate per hectare for swathing has been increased by 40% as a slower ground speed and increased fuel consumption would be required due to the large volume of biomass from a miscanthus crop. Due to the low density of chopped biomass, the cost in this harvest method is nearly equal between the cutting/chopping operation and removing material from the field.

2.1.3.3 Corn Stover

Corn stover collected after the primary grain corn is combined would be harvested by using a stalk chopper to shred the stover, raking into a window and then baling. Costs to harvest corn stover using this approach are shown in Table 2.4 and are based on a yield of 5.0 DMt/ha. This approach would maximize the yield as compared to allowing the combine to discharge the cobs and husks into a windrow and subsequently baling only this biomass. Recently, the University of Illinois has published a calculator to enable producers to calculate the value of their residue crops (http://miscanthus.ebi.berkeley.edu/Biofuel/CropSelection.aspx and Biomass Magazine, Nov., 2012).

Table 2.1 Harvest Costs for Switchgrass

Harvest Activity	Rate	Harvest Cost ($/DMt)
Cutting/Swathing (Fall)	$39.52/ha ($16/acre)	$3.95
Raking (Spring prior to baling)	$17.29/ha ($7/acre)	$1.72
Baling	$8/bale	$19.04
Field Removal	$2/bale	$4.76
Total		$29.47

Table 2.2 Harvest Costs for Miscanthus in Baled Form

Harvest Activity	Rate	Harvest Cost ($/DMt)
Cutting/Swathing (Spring)	$55.34/ha ($22.40/acre)	$3.46
Baling	$8/bale	$19.04
Field Removal	$2/bale	$4.76
Total		$27.26

Table 2.3 Harvest Costs for Miscanthus in Chopped Form

Harvest Activity	Rate	Harvest Cost ($/DMt)
Chopping (direct cut with Forage Harvester)	$177.84/ha ($72/acre)	$11.12
Field Removal	$172.90/ha ($70/acre)	$10.80
Total		$21.92

Table 2.4 Harvest Costs for Corn Stover

Harvest Activity	Rate	Harvest Cost ($/DMt)
Stalk Chopping	$37.05/ha ($15/acre)	$7.41
Raking	$17.29/ha ($7/acre)	$3.46
Baling	$8/bale	$19.04
Field Removal	$2/bale	$4.76
Total		$34.67

As discussed earlier, corn stover may also be harvested in a single pass operation using a specialized combine. At the present time, this method is uncommon in Ontario, but research suggests a theoretical harvest cost of $32/DMt (Shinners et. al, 2003).

2.1.4 Practical Considerations and Implications of Harvest Methods to Biomass Quality

Operators must understand the requirements and specifications of the specific supply opportunity for which biomass is to be harvested. For example, switchgrass may be cut and swathed in the fall and baled either several weeks later when dry or in the early spring. Baling in the fall will reduce the opportunity for nutrient leaching but will increase the yield potential as more of the leaf portion of the plant will be collected. When harvesting miscanthus, baling will pick up a lot of the leaves that have been shed from the stock and fallen to the ground in comparison to harvesting by chopping with a forage harvester, which will only harvest the standing stocks. Similarly, when harvesting corn stover, collecting the stover in a one pass operation will eliminate the pick up of any roots and dirt from the stocks. However, by harvesting with this method, the moisture content of the stover biomass must be addressed as it will be 30% or greater in a typical Ontario fall harvest. Collecting stover in the spring by raking and bailing will allow stover to be harvested at moisture contents under 10%; however, there is a much greater potential for increased contamination from dirt picked up the root mass of the stock, mud tramped into the stover from grain harvest equipment, or from dirt that has splashed onto the stover from heavy rainfall. These examples demonstrate the trade-offs and the quality implications of harvest methods and timing which must be considered.

2.2 On-Farm Storage

Once the biomass is harvested, it must be stored until needed. Conversion facilities will generally only have a working storage representing a small buffer as compared to the total annual processed tonnage. Thus, biomass will likely be stored on farm. This represents a challenge because of the high volume and low bulk density of the biomass. Also, each biomass crop is generally only an annual harvest. Additionally, biomass must be stored in a manner to preserve the quality of the biomass, thereby limiting deterioration.

2.2.1 Suitability of Current Storage Methods Used for Forage Crops

Forage crops such as corn silage and hay are commonly stored on many farms. Typical storage methods for baled material are storing the bales under the cover of a building or tarp or to wrap the bales in a plastic film to protect the crop from the environment to facilitate outdoor storage. Bales may be wrapped individually or as a stack or row to reduce costs. The same storage methods are suitable for biomass crops stored in baled form.

Forage crops harvested in chopped form are typically harvested wet at approximately 40 to 70% moisture content, and ensiled within a structure such as an upright silo, concrete bunker, or a plastic ag-bag. Using proper storage protocols and ensuring the material is within critical moisture content will cause the crop to ferment slightly to stabilize and prevent further degradation (http://www.omafra.gov.on.ca/english/crops/facts/07-047.htm). This method of storage is likely suitable for only biomass crops if they are going to be used as a feedstock in an anaerobic digestion conversion process. For other conversion processes, harvesting and storing biomass crops in this manner has major disadvantages in terms of biomass quality. Harvesting biomass while green eliminates any opportunity for nutrient leaching to occur in the field, thus creating higher nutrient replacement costs. Additionally, if the conversion facility requires dry biomass material, the biomass must be dried in a commercial dryer at a much higher cost than allowing biomass to dry naturally in the field before harvest.

The use of the same storage structures for the storage of dry chopped biomass is an option; however, the capacity is greatly reduced even on a dry matter basis. Dry biomass will not compact well within the storage structure and will remain 'spongy'. Further research relating to the use of vertical silos and bunkers for storage of dry biomass is warranted as there are many of these structures with significant storage capacity in rural Ontario which are sitting idle, thereby potentially creating low cost storage structures.

The addition of propionic acid to the biomass prior to storage is another opportunity for further research. Propionic acid is currently used on many forage crops to help inhibit mould growth and bacteria. Thus, this also may be beneficial to prevent degradation of biomass in storage especially when stored for longer periods. Based on current prices, the application would cost approximately $2.50 per large square bale.

2.2.2 Alternative storage methods

Another option for the storage of chopped biomass is to simply pile chopped or bulk biomass in large piles in the field. Generally, the biomass would be left uncovered and exposed to the environment. The top layer of the pile would form a crust and serve as a protective layer, preventing precipitation from reaching the remaining biomass. This storage method would have the most potential for quality degradation and spoilage, with potential negative implications to the conversion process.

Many other possibilities and opportunities for the storage of biomass crops exist. An innovative idea is to combine a biomass storage facility with a rooftop photovoltaic solar system to maximize the functionality and share capital costs of the structure.

2.2.3 Economics of storage

Shown in Table 2.5 are approximated costs for different storage options for biomass. These figures assume that biomass is being stored for one year and includes material, equipment and labour to transfer into and out of storage, and capital costs of equipment and buildings where applicable. For storage using a vertical silo or bunker, no capital costs for the structure are included as it is assumed to be idle otherwise. Cost associated with the actual harvest such as baling or chopping is not included.

Table 2.5 Cost Estimates of Different Storage Options

Storage Method	Annual storage cost ($/DMt)
Unwrapped bales under tarp	5 – 8
Unwrapped bales in coverall structure	22 – 24
Wrapped bales stored outside	16 – 20
Chopped biomass in coverall	32 – 38
Chopped biomass in vertical silo or bunker	14 – 16
Chopped biomass in field piles	10 – 12

Note: Cost estimates are for 300-500 tonne of storage capacity.

2.2.4 Risks due to unique biological and material properties of biomass

One must consider that biomass, even when dry, is still subject to potential deterioration and dry matter loss from biological processes. Increased moisture content, duration of storage, temperature fluctuations and the amount of biomass stored all negatively impact the potential for deterioration. As deterioration starts, there is significant risk of the formation of mould spores and ultimately the possibility of heating to the point of spontaneous combustion. It is important to routinely monitor biomass in storage for any signs of deterioration and take corrective action immediately if needed.

2.3 Transportation of Biomass to Conversion Facilities

Due to the low bulk density of biomass especially in chopped form, biomass must be sourced in a close radius to the conversion facility to minimize transportation costs. Bulk densities for chopped material can range from 70 kg/m^3 to 120 kg/m^3 while baled material can be 150 kg/m^3 to 200 kg/m^3.

2.3.1 Transportation Methods

Possible methods of transporting biomass to the conversion facility include farm tractor and wagons, transport truck and trailer or in extremely high volume or long distances, by rail or by marine freighter. In all methods of transportation, volume would be the limiting factor, given the density of either chopped or baled biomass.

Transportation by farm tractor and wagons would only be feasible if the distance from the farm gate to the conversion facility is 40 km or less. Beyond this distance, it is more economical for a farmer to hire a transport truck.

Transportation by transport truck and trailer is likely to be the most common method. For baled material, either a flat bed trailer, flat bed B-trains or a walking floor van body trailer would be used. Capacities are shown in Table 2.6 for different trailers for both a standard density 1.2x0.9x2.3m (4x3x7.5ft) square bale weighing 420 kg and a high density bale with the same dimensions weighing 525 kg.

Table 2.6 Capacity of Common Road Trailers

Trailer Combination	Standard Density Bale 1.2x0.9x2.3 m		High Density Bale 1.2x0.9x2.3 m	
	# Bales	Weight (Tonne)	# Bales	Weight (Tonne)
53ft Flatbed	42	17.64	42	22.05
B – Train	51	21.42	51	26.76
16.15 m (53 ft) Walking Floor Van Body	39	16.38	39	20.48

For chopped material, a walking floor, van body trailer is most efficient and easily facilitates unloading. A 16.15 m (53 ft) trailer has up to 120 m^3 in volume which translates into 8.4MT to 14.4 MT of biomass per load.

Rail or marine would likely to be applicable modes of transportation only if the biomass was pelleted prior to transport to increase the bulk density.

2.3.2 Economic Evaluation of Transportation Modes

In previous studies, costs for the different transportation modes have been identified by considering both fixed and variable components. The fixed cost would include such things as loading and unloading cost, facility costs, etc. The variable component, which is a function of the distance travelled, represents fuel and operating costs. Transportation costs can be calculated as:

Transportation costs ($/DMt) = C1 + C2 x L

Where;

C1 = Fixed cost constant ($/DM t)

C2 = Variable cost constant ($/DM t/km)

L = Distance in km

Table 2.7 Fixed and Variable Cost Constants

Mode	C1	C2
Truck	5.7	0.1369
Rail	17.1	0.0277
Marine	19.6	0.0113

Constants assuming a bulk density of 120kg/m3 for various different transportation modes are found in Table 2.7.

As an example, the calculated cost from the model to transport 14.4 DM tonne a total distance of 150 km by truck would be $377.84. This is inline with industry rates of $120 per hour for a truck and walking floor trailer as it would take approximately 3 hours to complete the above example including loading, driving and unloading time for a total cost of $360.

Natural gas has been used in the transportation sector for many years; however, with the recent drop in natural gas rates compared to the equivalent energy costs of diesel fuel, many fleets are rapidly converting over to Natural Gas Vehicles (NGVs). NGVs offer significantly reduced fuel costs over diesel, with current market prices provided by Enbridge for compressed natural gas being $.70/L equivalent compared to diesel at $1.20/L (personal discussion with Enbridge sales rep). Thus, for trucks with high annual fuel consumption, significant savings are realized which quickly offset the higher capital costs of purchasing a NGV. Figure 2.5 illustrates the payback when buying a heavy or medium duty NGV over a diesel fuelled truck at various price differentials between natural gas equivalent and diesel. As an illustration, a NGV hauling 25 tonnes of biomass a distance of 150 km would expect a cost savings of $26.25, or $1.05 per tonne compared to a diesel fuelled truck. This is a significant cost savings given that biomass is a low value commodity. Additional environmental benefits result from reduced greenhouse gas emissions from NGVs.

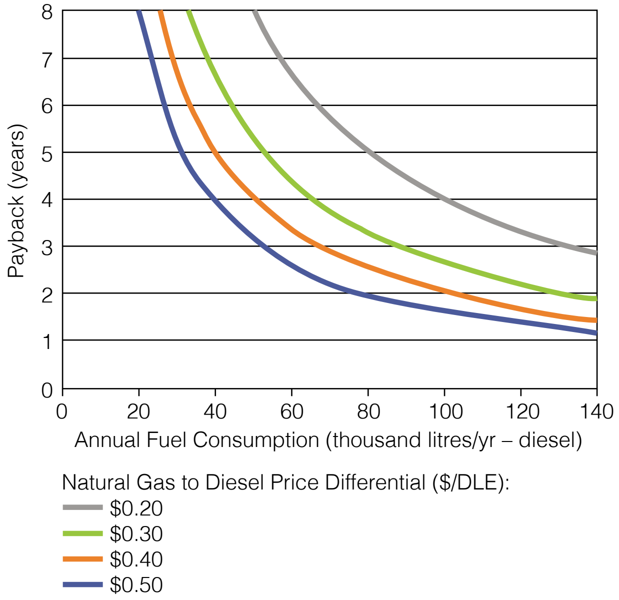


Figure 2.5 Heavy Duty Vehicle Payback Cost Curves

(Source: Canadian Natural Gas Vehicle Alliance, www.cngva.org)

NGVs require specific infrastructure to refuel either at a quick fill station which operates similar to a conventional fuel pump or a slow fill station where the truck would be refuelled over a period of several hours, for example, parked overnight in a truck yard. Because of this, NGVs are ideally suited for line haul or regional haul routes. An example of a line haul route is a truck running on the 401 corridor from Toronto to Montreal where there is access to quick fill stations. An example of a good regional NGV application is a predicable, return-to-base route, such as those of garbage trucks or city buses. Rural Ontario hasn't yet developed a good network of quick fill stations; thus NGVs in rural areas are limited to fleets with access to natural gas and trucks that are running predicable, return to base routes. With the current infrastructure, this may pose a challenge for the use of NGVs in the role of transporting biomass. Recently, a producer, Four Corners Poultry introduced a high-pressure, commercial-grade, TSSA/CSA Approved Natural Gas Compressor and Quick-Fill CNG Storage System to fuel its farm service vehicles, in parallel with Natural Gas warming the family's chicken barns, their home, and running approximately 100 essential appliances.

2.4 Handling and Process Infeed

Equipment used to receive and handle biomass at the conversion facility will be dependent on the nature of the specific conversion process and the capacity for which the facility is designed. As such, a conversion facility is likely to specify the form in which biomass will be accepted, either pre-shredded and delivered bulk or in baled form. Furthermore, round and square bales require different steps and equipment for shredding. Few facilities are likely to accept biomass in both forms as each receiving method requires dedicated handling and storage equipment with little potential for shared equipment utilization.

To minimize complications to the conversion process, it is critical that receiving, storage and infeed system be designed to handle the inherent properties of biomass, including but not limited to moisture content, particle size variability, possible contaminants, flowability issues, etc. One of the major inherent risks of handling biomass is potential for dust explosions as a dust cloud can easily form in an enclosed environment, creating the potential for a source of ignition to ignite the air and fuel mixture. If good management and housekeeping practices are neglected in the process environment, this initial explosion can lead to a similar chain reaction in the facility, igniting any dust that may have accumulated on equipment or in the structure. Thus, equipment must be designed to minimize the release or build up of dust into the process environment, and material handling equipment should have appropriate safety features such as explosion venting and spark suppression. These considerations will ensure that the biomass indeed is safe, reliable and consistent for the conversion process to operate efficiently.

2.4.1 Pre-shredded (Bulk) Biomass Handling

Biomass pre-shredded or ground on farm would be delivered to the conversion facility and unloaded from the truck either by means of a self powered, live bottom (walking) floor trailer or dumped off using a regular dump trailer or a trailer tipper. Examples of these are shown in Figure 2.6, Figure 2.7, and Figure 2.8.

After being unloaded, material could be transferred using a wheeled loader or mechanical conveyors into either storage piles, silos, or onto a live bottom floor to act as storage, and/or a buffer before being introduced to the conversion process.

When the biomass is delivered pre-shredded, consistency and quality of the biomass is more difficult to monitor and to manage. Additionally, when handled in bulk form, fugitive dust is released into the process environment and must be controlled to maintain safe operating conditions.

2.4.2 Baled Biomass Handling

Biomass that is delivered in baled form can be unloaded and handled using a wheeled loader or a telehandler or an overhead crane system.

Figure 2.6 Unloading Biomass from a Walking Floor Trailer
(Source: www.keithdaycompany.com)

Figure 2.7 End Dump Trailer
(Source: hmitrailers.com)

Figure 2.8 Trailer Tipper Unloading Biomass
(Source: www.phelpsindustries.com)

Figure 2.9 displays the material handling systems at Drax Power in the UK, which is one of the largest biomass fired, power generation companies. Quality control checks can be performed on each bale, and further segregation or assimilation of the bales is possible to maintain consistency of the biomass feed into the process. Source identification and tracking is also more achievable when handling biomass in baled form.

Onsite storage of biomass would likely remain in baled form until introduced to the conversion process. To introduce the biomass into the conversion process, bales would be fed into a bale grinder or chipper such as shown in Figure 2.10. With proper consideration and design of an air take-away from the bale grinder, a negative pressure within the grinder minimizes any dust is generated and released into the process environment.

Figure 2.9 Material Handling Crane at Drax Power, UK

(Source: www.demagcranes.de)

Figure 2.10 Link-ka Bale Grinder

(Source: www.linka.dk)

Chapter 3 – Evaluation of Alternative Technologies

3.1 Introduction

Energy has a significant effect on Ontario producers because it is a major input to agricultural production systems. High energy prices have led producers to have an intense interest in generating energy on their farms and in their communities as a means to offset costs and generate revenue. To assist Ontario's producers, governments have supported the development of technologies that utilize non-traditional energy sources for the production of dispatchable energy and the sale of energy to the electrical grid. With the implementation of the Ontario Green Energy Act, Ontario producers are eager to participate in the energy market.

Advice for producers on the use and optimization of emerging energy technologies is not readily available to date. Producers engaging and investing in these new technologies face challenges managing technological and financial risks. Many of these new energy production technologies are being rapidly developed and commercialized around the world. However, some technologies are being promoted as ready for market without proven success.

3.2 Technologies Examined

Twenty emerging and available biomass-based technologies were evaluated for commercial readiness, for ease of implementation on farms and in communities; for assistance with the management of technological; and financial risks to producers. These technologies were also analysed to develop strategies to maximize energy efficiency through systems integration such as combining various conversion technologies. Technologies evaluated in this study include:

Biomass Conversion	• Anaerobic Digestion • Gasification • Pyrolysis • Torrefaction • Direct Combustion
Fuel Enhancement	• Biogas to Biomethane • Hydrogen Enriched Natural Gas
Energy Storage	• Compressed Air Energy Storage • Large-Scale Battery • Small-Scale Battery • Fuel Cell
Energy Production	• Gas-Fired Boiler • Gas Turbine • Indirect Gas Fired Turbine • Internal Combustion Engine • Microturbine • Steam Engine • Stirling Engine
Biofuels	• Biodiesel • Ethanol

3.3 ProGrid Evaluation Solutions

ProGrid Evaluation Solutions was used as a tool to assess the commercial and technical viabilities of the technologies and to recommend the most feasible technologies to monitor in the next 5 to 10 years. The ProGrid methodology and software were used as tools along with others to determine the final technology recommendations.

The ProGrid evaluation methodology allows for the assessment of the value of intangible assets to assist with the decision-making process (Bowman, 2005). The ProGrid methodology has been found to be useful to:

- Provide fair and objective procurement practices
- Identify innovative technologies and monitor development
- Assess the effectiveness of practices
- Establish and monitor long-range goals

ProGrid's flagship software program is GlobalEvaluator. Global Evaluator is a valuable tool that was used to assess each emerging alternative energy technology. The assessment results assisted with the identification of the most feasible technologies that are almost ready for implementation on farms and in rural communities and with technologies that are likely to be ready for large-scale implementation within 5 to 10 years.

3.4 The ProGrid Evaluation Process

The ProGrid methodology is comprised of 5 main steps (Bowman, 2005), shown in Figure 3.1.

Figure 3.1 The ProGrid Methodology

The methodology follows a sequence of evaluation steps. First, the main objectives must be identified. These objectives are called the "Overarching Objectives", the two factors involved in the decision, and required for success. Next, an Evaluation Matrix is created, which contains all the criteria for the evaluation of the technologies. The Language Ladders are developed using the Evaluation Matrix and are a series of progressive statements that represent levels of expectation. A team of evaluators assess each technology using the Language Ladders and the results of the assessment are graphically represented on a grid.

3.4.1 The Overarching Objectives

Many decisions involve two overarching factors or objectives, each of which may appear to be in conflict or opposition. A strength of ProGrid is the ability to consider the effect of two independent objectives on the final outcome (Bowman, 2005).

The Overarching Objectives represent the x and y axes of the final Evaluation Grid.

For the evaluation of the alternative energy technologies, the Overarching Objectives are:

1. Technical Strength
2. Commercial Strength

3.4.2 The Evaluation Matrix

The Evaluation Matrix is the backbone for evaluating intangible assets and contains the evaluation criteria. It is generally presented as a table with 3 columns. The Overarching Objectives are shown as the headings of the first and third columns. Criteria that support the Overarching Objectives are listed in the appropriate columns, with criteria influencing both Overarching Objectives listed in the second column. The criteria which affect both Overarching Objectives are called Enablers (Bowman, 2005).

The Evaluation Matrix for the alternative energy technologies is presented in Table 3.1. All these criteria are important for the adoption of alternative technologies on farms and in rural communities.

Table 3.1 The Alternative Energy Technologies Evaluation Matrix

Technical Strength	Enablers	Commercial Strength
Agricultural Fit	Financing	Energy Production
Technology Maturity	Skilled Labour	Co-Product Production
Complete System	Infrastructure	Value Chain

The Overarching Objective of Technical Strength is supported by 3 criteria that include:

- Agricultural Fit: the suitability of the technology for the agricultural setting.
- Technology Maturity: the development stage of the technology.
- Complete System: the existence of a full process of operations to support the technology from biomass harvest to energy use.

The Overarching Objective of Commercial Strength is supported by 3 criteria that include:

- Energy Production: the amount of energy generated the final useable form, as well as dispatchability and reliability.
- Co-Products Production: the production of additional products to energy or fuel.
- Value Chain: the degree of participation by producers in the production, marketing and sale of energy and products.

Three criteria that support both the Technical Strength and Commercial Strength Overarching Objectives are referred to as Enablers and include:

- Financing: the availability of funds to implement the technology.
- Skilled Labour: the availability of skilled individuals to operate the process.
- Infrastructure: the compatibility of the technology or process with existing farm and rural operations, and infrastructure.

3.4.3 Language Ladders

Language Ladders are a series of expectation statements, which serve as measurements for the evaluation. The 4-step “ladder” starts with a basic statement (“A”), and each “rung” is a statement of higher expectation, until all expectations are exceeded (“D”). There is a Language Ladder for each of the criteria of the Evaluation Matrix (Bowman, 2005).

The Language Ladders for the evaluation of the alternative technologies are provided in Tables 3.2a to 3.2i. The Language Ladders were developed following consultations with experts in the agriculture and energy fields. The ideal results of implementing the alternative energy technologies were determined, and the various stages of development and implementation were identified.

Table 3.2a Agricultural Fit

The alternative technology:	
A	Fits with the biomass feedstock available for use in the energy generation systems (the available feedstock can be sourced from the field or are a co-product from a process).
B	... AND will lead to more efficient harvesting and processing of the available agricultural biomass ...
C	... AND will result in new farming practices (such as increased nitrogen applications) ...
D	... AND will ensure sustainability of farm land by producing co-products that can be returned to the soil to maintain the threshold value of soil organic matter.

Table 3.2b Technology Maturity

The alternative technology is:	
A	An emerging technology at the research and development stage.
B	Proven at the demonstration-scale with the use of a variety of feedstock.
C	In commercial operation without serious reliability issues ...
D	... AND is modular and can be rapidly transferred/duplicated for implementation over a wide area.

Table 3.2c Complete System

When the alternative technology is implemented, it will be part of a system which:	
A	Requires supporting units and processes which have not yet been developed.
B	Produces co-products and has a positive overall energy balance ...
C	... AND which can be integrated with other agricultural activities ...
D	... AND allows for energy storage.

Table 3.2d Financing

To implement the alternative technology:	
A	Governments are willing to provide subsidies and support.
B	Financial institutions are willing to provide funding in the form of loans.
C	The risk-reward ratio is favourable ...
D	... AND there is affordability in every step of the value chain with minimal waste at any stage.

Table 3.2e Skilled Labour

For the operation of the alternative technology in rural communities:	
A	Workers must be brought in to operate the systems.
B	Workers are available and specialized training is required.
C	Skilled workers are available and some additional training is required ...
D	... AND these workers have agricultural experience.

Table 3.2f Infrastructure

The alternative technology:	
A	Installation competes with other land uses.
B	Requires specialized farm buildings or equipment (biomass handling), some of which are in place.
C	Infrastructure is in place throughout the value chain (transmission lines, pipelines) ...
D	... AND the technology generates products (energy and/or co-products) that can be used in Ontario and exported.

Table 3.2g Energy Production

The energy generated from the alternative technologies:	
A	Results in a neutral or small positive energy balance.
B	Can be used by the producer on-site or allows producers to participate periodically in the energy market ...
C	... AND will be a sustainable, reliable supply ...
D	... THAT can be stored or rapidly dispatched depending on the supply and demand.

Table 3.2h Co-Product Production

The alternative technologies produce:	
A	Co-products that do not yet have a use.
B	Useful co-products that can generate revenue if markets existed.
C	Co-products with established uses and markets ...
D	... AND that can be used as a soil amendment to improve crop production and contributes to sustainability.

Table 3.2i Value Chain

Use of the alternative technologies allow the producers to:	
A	Only supply the biomass as a feedstock ...
B	... AND participate in the operation of the system to generate energy and co-products ...
C	... AND participate in value-added processing of energy and co-products ...
D	... AND market and sell the value-added products.

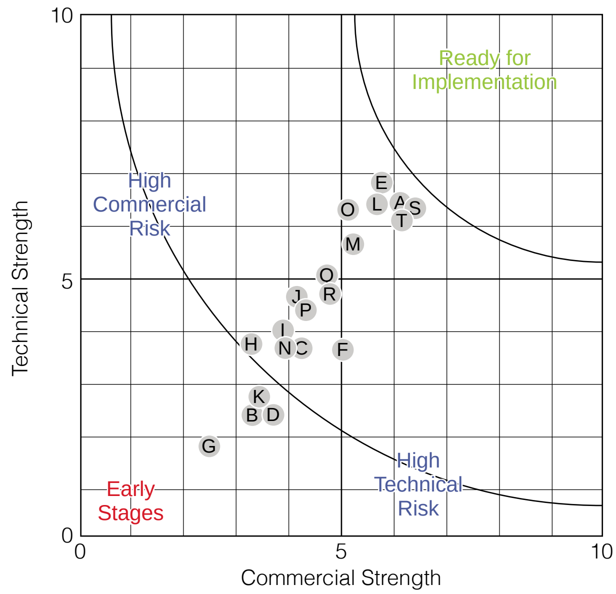
3.4.4 The Evaluation of Technologies

Experts in the energy and technology fields were invited to evaluate the technologies listed in section 3.2. The ProGrid software creates evaluation forms containing the Language Ladders. These evaluation forms are distributed to the evaluation team. An evaluation form is completed by each member of the evaluation team for each technology. The evaluation input is analysed by ProGrid and presented graphically.

3.4.5 Establishment of the Grid

The results of an evaluation can be shown in the form of an Evaluation Grid with the Overarching Objectives as the axes. The Evaluation Grid for the alternative technologies is shown in Figure 3.2. The x and y axes are the Overarching Objectives. The evaluation result of each alternative technology is represented by a grey circle on the chart.

A circle in the top right quadrant indicates that the technology has received high technical and commercial strength ratings and suggests that the technology is nearly ready for implementation.



A. Anaerobic Digestion
B. Gasification
C. Pyrolysis
D. Torrefaction
E. Direct Combustion
F. Biogas to Biomethane
G. Hydrogen Enriched Natural Gas
H. Compressed Air Energy Storage
I. Large-Scale Battery
J. Small-Scale Battery
K. Fuel Cell
L. Gas-Fired Boiler
M. Gas Turbine
N. Indirect Gas Fired Turbine
O. Internal Combustion Engine
P. Microturbine
Q. Steam Engine
R. Stirling Engine
S. Biodiesel
T. Ethanol

Figure 3.2 The Alternative Technologies Evaluation Grid

A circle in the bottom left quadrant indicates low technical and commercial strength rankings and suggests that the technology is in the early stages of development. A high technical strength and low commercial strength (upper left quadrant) result indicates that there is a high commercial risk associated with the technology. A high commercial strength and low technical strength (bottom right quadrant) result suggests that there is a high technical risk associated with the technology.

During the evaluation, the focus was on energy and fuel production. It is important to note that these technologies were evaluated based on the use of biomass as a feedstock to produce energy or fuels and not for the production of chemicals.

3.5 Interpretation of the Evaluation Results

The Evaluation Grid presents the results of the assessments. It shows that the technologies that are currently the most feasible for use on farms or in rural communities include Direct Combustion, Gas-Fired Boiler, Anaerobic Digestion, Biodiesel and Bioethanol production. These technologies are represented by grey circles in the top right quadrant, close to the “Ready for Implementation” arc. These technologies are expected to be ready for large-scale implementation for the production of energy from biomass on farms or in rural communities in the near-term.

In the longer-term (5 to 10 years), the alternative energy technologies that are expected to be ready for implementation on the farm or in rural communities include Pyrolysis, Gasification, Torrefaction, Microturbine and Small-Scale Energy Storage. These were identified as the most commercially viable in the future based on the evaluation results presented on the Evaluation Grid, the Opportunity Profiles of Appendix A, and the comments provided by the evaluators.

Pyrolysis has been used for many years to produce chemicals from biomass. The strengths of pyrolysis include the production of energy and co-products as well as the suitability of the technology to the agricultural setting. The main weakness is the maturity of the technology for energy and fuel production. Pyrolysis has many potential benefits for the agricultural community, and once the technology has been proven for energy and fuels production, markets are expected to grow rapidly.

Gasification is an established technology for the production of energy from fossil fuels. However, gasification is at the early stages of development for the use of biomass feedstock to produce energy. The greatest strength of gasification is the production of energy, whereas the main weakness of the technology is with regards to the acquisition of financing.

There is much interest in torrefaction technologies, and production facilities have been constructed in Europe. A major strength of the torrefaction technology is the production of fuel. Major weaknesses identified by the evaluators were the lack of maturity of the technology (process flow for variable particle sizes from agricultural biomass) and the ability to acquire financing. There are very few commercial torrefaction plants in operation; however, torrefaction provides for the inexpensive storage of biomass feedstock and produces a dispatchable fuel.

Microturbines are a mature technology with strengths in energy production and the potential for producers to participate in the value chain. Microturbines will likely require skilled labour for operation and may be unsuitable for all agricultural settings. Also, microturbines do not produce co-products for the generation of additional revenue.

Small-Scale Batteries were identified as a feasible technology due to the maturity of the technology, the production of energy, and the participation of producers in the value chain. Weaknesses identified were unsuitability to the agricultural setting, the acquisition of financing and the lack of co-product production.

Although there are challenges associated with these five technologies, many of these challenges can be overcome within the next 5 to 10 years. It is expected that with continued technology development, these technologies will progress through the commercialization process and become feasible for producers to implement on the farm and in rural communities.

Chapter 4 – Technical Detail of Emerging Technologies

There are a number of bio-energy technologies being developed around the world searching for greater efficiencies of energy conversion, increased ability to process diverse feedstock, lower production costs, improved reliability of operation, etc. Based on the current intensity of global research and development activities and the characteristics of energy sector in Ontario, the evaluation panel identify pyrolysis, gasification, torrefaction, small-scale energy storage and micro-turbine as emerging technologies. These technologies could be employed significantly once their technical and commercial strengths improve in the evolving energy sector in Ontario. However, it should be noted that it is not easy to predict the timeframe for the commercialization of these technologies. In this chapter, technical details of these selected emerging technologies are discussed.

4.1 Pyrolysis

Pyrolysis is the thermo-chemical decomposition of biomass. In the absent of oxygen, biomass is heated to approximately 500 °C to produce liquid bio-oil, a mixture of gases (syngas), and solid char (bio-char). Pyrolysis processes can be categorized into three speeds: fast, intermediate and slow. These are characterized by how long biomass is heated or residence time, in the pyrolysis reactor. The residence time of a fast pyrolysis process could be as short as 2 seconds, and that of a slow pyrolysis process could be 30 minutes. Varying residence time and process temperature could result in different proportions of liquid, gas and solid fractions. In general, more bio-oil is produced by shortening the residence time while more bio-char is obtained by increasing the residence time. A simple schematic of a pyrolysis process is shown in Figure 4.1.

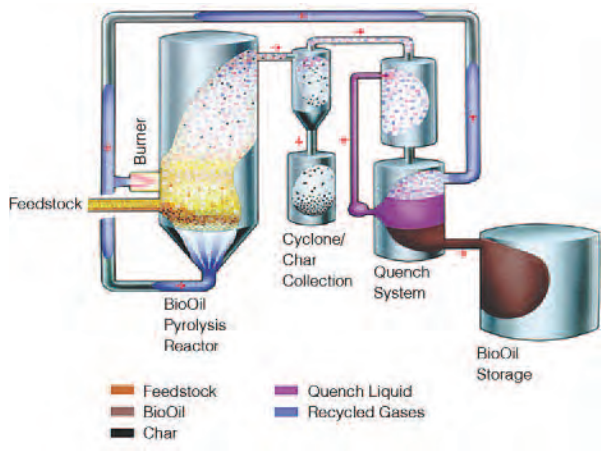
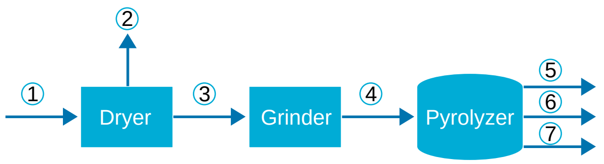


Figure 4.1 Schematic of Pyrolysis Process
(http://www.cleantechloops.com/biomass-pyrolysis/)

Pyrolysis technologies are often named based on the types of the reactor or how biomass feedstock is moved in the reactor. The pyrolysis technologies, therefore, include fixed bed, auger, ablative, rotating cone, fluidized bed, circulating fluidized bed and vacuum. A particular technology usually works well for some types of biomass at a range of particle size. A sample mass and energy balance of a pyrolysis process is shown in Figure 4.2 (adapted from Manganaro et al., 2011 and Mullen et al, 2010). Enthalpy is the measure of total energy, and enthalpy rate is the flow of energy at a given point in Figure 4.2. Approximately 30 – 35 % of energy contained in biomass feedstock is consumed in the entire pyrolysis process. Typical chemical compositions of pyrolysis products are shown in Figure 4.3 for corn stover. The Canadian companies actively developing pyrolysis technologies are Advanced Biorefinery Inc., Agri-Therm, Alterna, Dynamotive, Ensyn/Envergent, Pyrovac, RTI and Titan.



Stream No.	Stream	Mass Flow Rate (kg/h)	Enthalpy Rate (MJ/h)
1	Biomass (30 wt% moisture)	1,000	14,087
2	Water Vapour	189	512
3	Dry Biomass (~10 wt% moisture)	811	14,598
4	Ground Biomass	811	14,598
5	Syngas	162	973
6	Pyrolysis Oil	487	10,754
7	Biochar	162	3,406

Figure 4.2 Sample Mass and Energy Balance of Pyrolysis Process

(Adapted from Manganaro et al., 2011 and Mullen et al, 2010)

Bio-oil can be potentially upgraded to produce speciality chemicals or transportation liquid fuels. Chemicals found in bio-oil include levoglucosan, hydroxyacetaldehyde, acetic acid, acetol, furfural, furfuryl alcohol, phenol, cresol, dimethyl phenol, ethyl phenol, guaiacol, and isoeugonol. Successful commercialization of high value speciality chemicals from bio-oil could substantially improve the economics of pyrolysis technologies. The current research and development of pyrolysis technologies focuses on robustness of the reactors, consistency and stability of bio-oil, lowering the acidity of bio-oil, and development of bio-char products. Bio-char could be potentially used to improve the soil quality; therefore, pyrolyis is quite suitable for the agricultural sector once it is commercialized.

4.2 Gasification

Gasification is a thermo-chemical process in which biomass is mainly transformed into a mixture of combustible gases. In this process, biomass is heated to a high temperature of approximately 850 °C without combustion with a controlled amount of oxygen or steam. The resulting mixture of gases, called syngas, can be burned in gas engines or can be potentially refined to produce speciality chemicals or transportation liquid fuels. Gasification was developed over 150 years ago and was the prominent technology to generate energy from coal and forestry biomass. Stringent environmental regulations and competition from natural gas have made biomass gasification less attractive alternative at present. A schematic of biomass/coal gasification is shown in Figure 4.4.

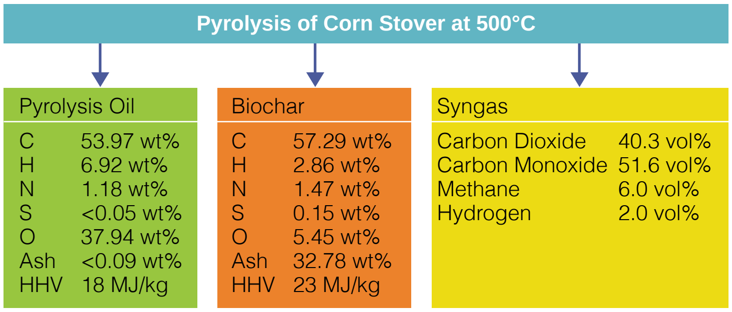


Figure 4.3 Chemical Compositions of Pyrolysis Products for Corn Stover

(Adapted from Mullen et al, 2010)

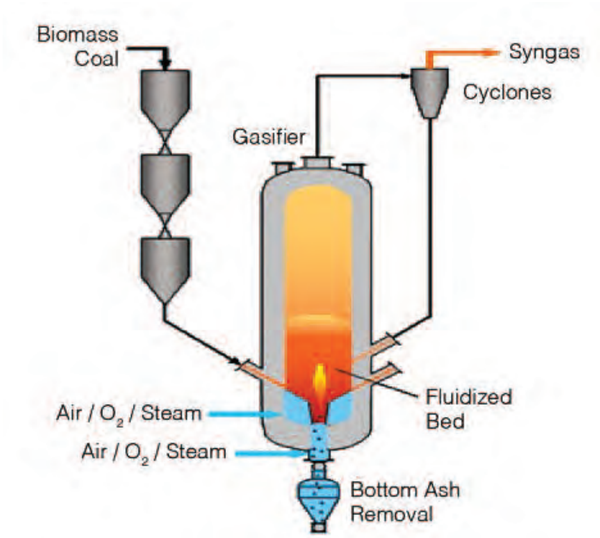
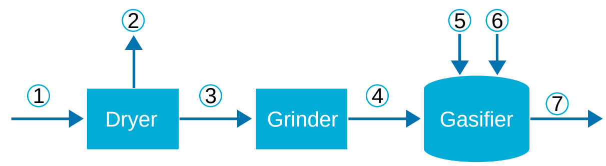


Figure 4.4 Simple Schematic of Gasification Process

(Source: www.newenergyandfuel.com)



Stream No.	Stream	Mass Flow Rate (kg/h)	Enthalpy Rate (MJ/h)
1	Biomass (30 wt% moisture)	1,000	14,087
2	Vapour	189	512
3	Dry Biomass (~10 wt% moisture)	811	14,598
4	Ground Biomass	811	14,598
5	Air	260	
6	Steam	173	43
7	Syngas	1,244	9,755

Figure 4.5 Sample Mass and Energy Balance of Biomass Gasification Process

(Adapted from Swanson et al., 2010)

Gasification technologies are also named based on the types of gasifier and how biomass feedstock is moved in the gasifier. The major gasification technologies are downdraft, updraft, cross-draft, bubbling bed, circulating fluidized bed, entrained bed, spouted bed and cyclone. The residence time and operating temperature of a biomass gasifier is usually optimized for a particular feedstock. A sample mass and energy balance of biomass gasification is given in Figure 4.5 (adapted from Swanson et al., 2010). Approximately 35 – 45% of energy contained in biomass feedstock is consumed in the entire gasification process. Typical chemical compositions of gasification products are shown in Figure 4.6 for corn stover. Major Canadian companies active in biomass gasification are Enerkem, Norampac, Nexterra and Plasco.

To generate heat and power, biomass gasification is usually integrated with gas engines for small to medium plants of < 10 MW or with steam turbines for larger plants. Hundreds of smaller size biomass gasifiers (10-500 kW) are also deployed mainly for intermittently operating thermal applications in China, India and South East Asia. However, reliability and maintenance of these units for continuous operation seems be an issue for the smaller gasification systems (Bauen et. al, 2009). The gasification of agricultural biomass has more issues than that for forestry biomass. Agricultural biomass contains some chemicals which could lead to melting of ash at lower operating temperatures, creating corrosive materials and forming deposits in the gasifier. Particulate emission from biomass gasification is also an issue in some jurisdictions where the environmental regulations are stringent.

Production of transportation liquid fuels and speciality chemicals from syngas through Fischer-Tropsch process is one of the major areas of research and development at present. They are mostly at demonstration stage for forestry biomass feedstock, and the economics is yet to be proven. Further R&D is needed for agricultural biomass feedstock. Co-producing

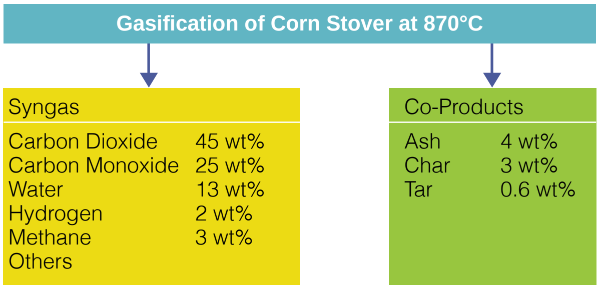


Figure 4.6 Chemical Compositions of Gasification Products for Corn Stover

(Adapted from Swanson et al., 2010)

fuels, chemicals and energy at a biomass processing plant, which is termed as bio-refinery, is the concept currently investigated in the lab and pilot plants around the world. Potential improvements in biomass gasification are environmental performance, conversion efficiency, multiple feedstock processing, superior reliability of smaller systems, syngas cleaning, and lower capital and operating costs.

4.3 Torrefaction

Torrefaction is essentially the roasting of biomass. In order to drive off moisture and volatiles, biomass is heated to 200 – 300 °C in this thermo-chemical process. The residence time of biomass in the torrefaction reactor could be as short as one minute in a fast process and could be as long as 60 minutes in a slow process. The ideal product from a torrefaction process is hydrophobic and energy dense coal-like materials. If torrefied , biomass is pelletized and could be transported over long distances at a lower cost per unit energy content in comparison with regular biomass pellets. The hydrophobic property of torrefied biomass has attracted interest from coal-fired power plant where coal is stored outdoor. If torrefied, biomass can be handled and burned like coal. The potential market size for torrefied biomass will be significant. Torrefaction technologies are currently at pilot to demonstration stages. A sample layout of a torrefaction process is shown in Figure 4.7.

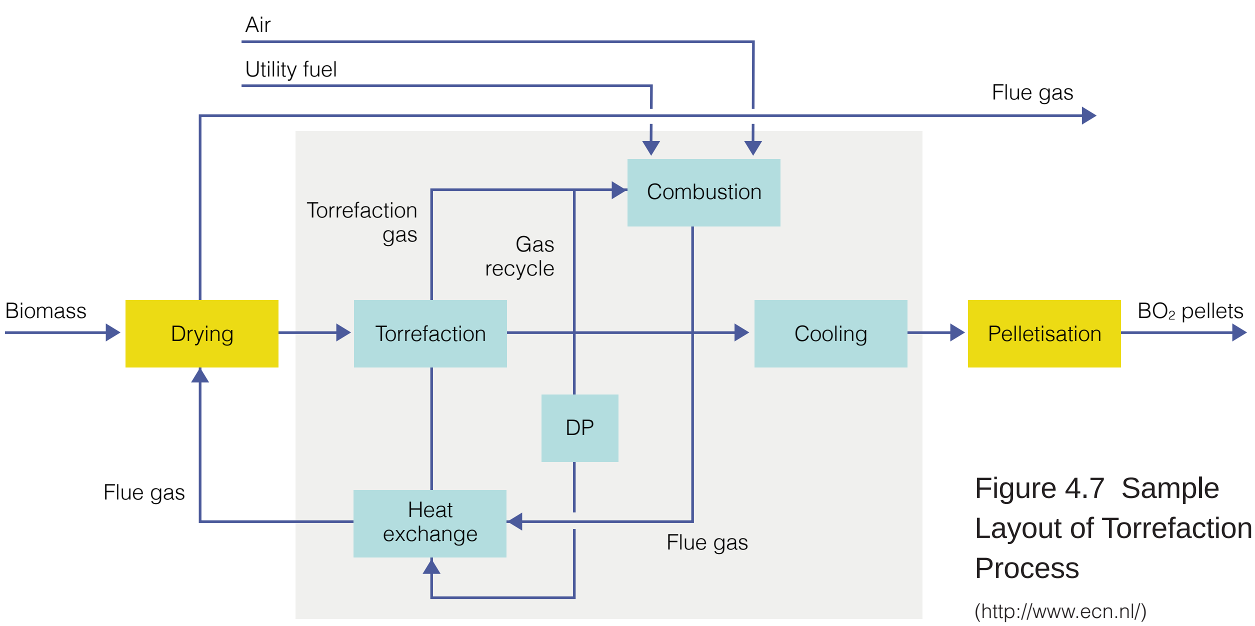


Figure 4.7 Sample Layout of Torrefaction Process

(http://www.ecn.nl/)

Torrefaction can be performed as a batch process or as a continuous process. The torrefaction process which has been in commercial operation for decades is the roasting of coffee beans. There are diverse designs of torrefaction reactors, mainly differing in how the biomass is moved in the reactor. In some torrefaction reactors, biomass is mechanically transported by means of conveyors, screws, moving beds, rotating drums, etc. Pneumatic transport mechanisms such as fluidized beds or centrifugal swirling are employed in some torrerafaction reactors. A combination of mechanical and pneumatic methods and steam explosion techniques are also being investigated. Torrefaction technologies can also be categorized as a slow reactor at low/high temperature or a fast reactor at low/high temperature. One of the technical challenges of torrefaction technologies is the consistency of the products. Unlike coffee beans, biomass in practical applications significantly varies in particle size as a result of shredding and in other characteristics. The effective separation of completely torrefied biomass from partially torrefied biomass from the reactor needs further development work.

Torrefaction is theoretically an auto-thermal process, i.e., torrefaction gas coming out from the process can provide sufficient energy to heat the biomass. Typical mass and energy balance of a torrefaction process is given in Figure 4.8. Approximately 20% of mass and 10% energy contained in biomass feedstock are converted to torrefaction gases and consumed in the process. These mass and energy losses could be higher for higher operating temperatures and longer residence times. The energy density, i.e., energy per unit mass, of torrefied biomass is 10-20% higher than that of raw biomass. Subsequent pelletization of torrefied biomass significantly increases mass and energy per unit volume of the products.

As mentioned earlier, coal-fired power plants have great interest in torrefied biomass as a potential alternative fuel. The major requirements of coal-fired power plants for torrefied biomass include hydrophobicity and grindability properties similar to coal. The current research and development of torrefaction technologies are explained in Figure 4.9. Four operating regimes of torrefaction are shown in Figure 4.9 based on the residence time and operating temperature, and the properties of torrefied biomass are qualitatively compared.

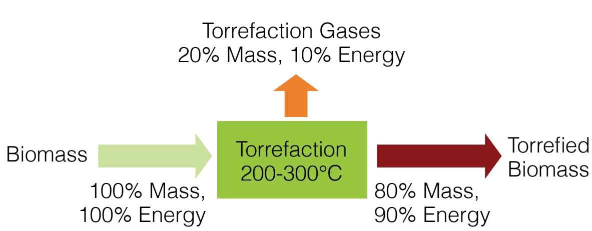


Figure 4.8 Typical Mass and Energy Balance of Torrefaction Process

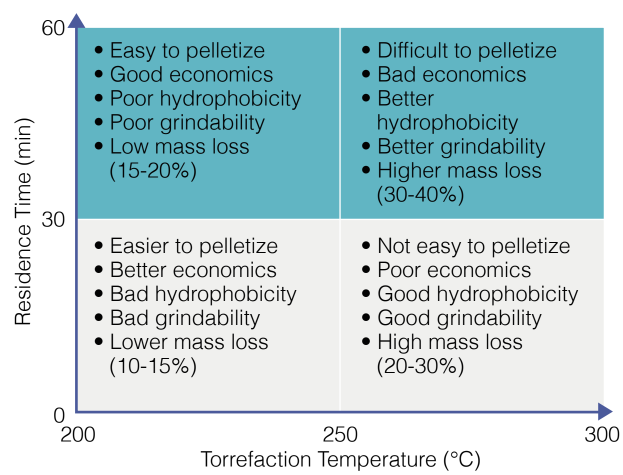


Figure 4.9 Torrefaction Process Regimes and Product Properties

Torrefied biomass producers prefer to operate at lower temperatures and shorter residence times, i.e., lower left regime in Figure 4.9. The economics of torrefaction in this regime is improved due to lower mass losses, and the torrefied biomass is easier to pelletize. However, the hydrophobicity and grindability properties of the product are poor in this operating regime. This implies that outdoor storage of torrefied biomass is probably unfeasible and the coal-fired power plants need new grinding equipment. The end users, mainly coal-fired power plants, prefer that biomass is torrefied at higher temperatures and longer residence times because current technologies would provide better quality products in this operating regime. The economics of torrefaction in that operating regime is unfavourable due to higher mass losses. Furthermore, the torrefied biomass is too crispy in this operating regime and too difficult to pelletize.

Torrefaction technologies are still under development. The optimum operating regime which would provide products customers need economically is yet to be identified. The largest torrefaction demonstration plant was built in the Netherlands by Topell Energy in 2010. The processing capacity of Topell demonstration plant is 8 tonne/hr of torrefied biomass. RWE, which is a large German energy firm, invested in the Topell torrefaction plant. It should be noted that RWE built a regular wood pellet plant with 750,000 tonne/yr capacity in the state of Georgia in USA in 2011. Diacarbon Energy Inc. is building a 1.3 tonne/hr torrefaction plant in British Columbia, Canada. The commercial large-scale production of torrefied biomass is yet to be seen, and this could potentially create an export market for Ontario agricultural biomass.

4.4 Small-Scale Energy Storage

Biomass is considered as dispatchable energy among the renewable sources. Heat and power can be generated from biomass on demand. This is a prominent advantage of biomass over wind or solar power which may or may not be available when the energy is needed. Small-scale energy storage systems are being developed especially to lower the capital and operating costs and mainly for wind and solar renewable energy generation. Small-scale energy storages may work with on-farm anaerobic digestion energy systems which produce biogas continuously. However, the small scale energy storage has to compete economically with biogas storage for the AD energy systems. The basic premise of integrating energy storage to bio-energy systems is to store the power generated during off-peak hours and sell it at a higher price during peak hours.

The major factors in the economics of small-scale energy storage systems are the price differential between off-peak electricity and peak electricity, the capital cost of the energy storage system, the length of peak hours, and the operating cost or the expected life of the energy storage. The FIT rates in Ontario for renewable energy do not offer a differential price for peak electricity at present. Installation of energy storage systems for large consumers is common in jurisdictions where the price of peak electricity is significantly higher than that of off-peak electricity. The current price differential Ontario consumers are currently paying for electricity during peak hours does not seem to be high enough to install energy storage systems.

The capital cost of small-scale energy storage systems is still relatively high, ranging $2,000 - $4,000 /kW of electricity production. For instance, the capital cost of a 1,000 kW on-farm AD energy system could be $4 million without energy storage. The installation of small-scale energy storage for this AD energy system could add $3 million to the capital cost. The energy storage systems will be used only 4-6 hours a day for peak electricity. The price of peak electricity should be substantially higher to justify the integration of energy storage. The potential closure of peaking coal-fired power plants and the gradual increase of renewable energy in Ontario could raise the price of peak electricity. The small-scale energy storage systems, which are under extensive research and development for wind and solar power, could play a role with the bio-energy systems in the future. Figure 4.10 exhibits the demonstration unit small-scale battery energy storage system.

The commercially available small-scale energy storage technologies which can be integrated with bio-energy systems include pumped-hydro storage, compressed air storage, thermal storage, lead acid and NiCd conventional batteries, and sodium sulphur and sodium nickel chloride high temperature batteries. Technologies under development include regenerative fuel cells, superconducting magnetic energy storage, flow batteries and hydrogen storage. Current research and development in the energy storage systems focus on extending the life especially batteries of the systems, lowering the capital cost, increasing the reliability and maintaining the performance over the life of the system.

Figure 4.10 Demonstration Unit of Small-Scale Battery Energy Storage

(Source: www.solarthermalmagazine.com)

Pumped-hydro storage is the mature and commercially available energy storage technology. Conventional pumped hydro facilities consist of two large reservoirs: one located at a low level and the other is situated at a higher elevation. During off-peak hours, water is pumped from the lower to the upper reservoir where it is stored. To generate electricity, the water is then released down to the lower reservoir, passing through hydraulic turbines and generating electrical power. The utility size pumped-hydro store could be as large as 1,000 MW and are in commercial operation around the world. Micro pumped-hydro storage systems could fit with bio-energy systems at selected locations.

Compressed air energy storage systems pressurize air into an underground reservoir during off-peak hours and release the compressed air to power a turbine/generator during peak hours. This mature technology is also commercially available. The size of the compressed air storage ranges up to 300 MW. Smaller compressed air storage systems could work well for bio-energy systems if the economics are favourable. Thermal storage systems have operated commercially around the world. Freezing ice or melting salt during off-peak hours for peak cooling and heating loads respectively, during peak hours is the basic operating principle of the thermal storage systems.

Lead acid and NiCd conventional batteries and sodium sulphur and sodium nickel chloride high temperature batteries are technically proven and commercially available energy storage technologies. The capacity of a battery storage system could range from < 10 kW to 10 MW. All batteries are electrochemical cells. They are composed of two electrodes separated by an electrolyte. During discharge, ions from the anode (first electrode) are released into the solution and deposit oxides on the cathode (second electrode). Reversing the electrical charge through the system recharges the battery. When the cell is being recharged, the chemical reactions are reversed, restoring the battery to its original condition.

4.5 Micro-Turbine

Gas turbines convert energy contained in gaseous fuels into heat and power. The major components of a gas turbine are compressor, combustor, turbine and generator. Air is pressurized in the compressor and combusted with fuel in the combustor. The high temperature and high pressure combustion gases then move across the turbine, providing rotational forces to turn the generator for power generation. The energy- contained exhaust from gas turbines could be recovered through a heat exchanger to provide heat. Gas turbines are technically mature and commercially available at 500 – 15,000 kW electricity generation capacity. Micro-turbines are small gas turbines, about the size of a household refrigerator, with capacities ranging from 30 – 200 kW of electricity generation.

If the cleaning of biogas and syngas improves technically and economically, micro-turbines could play a role in the energy use and generation in the agricultural sector. Furthermore, the relatively lower price of natural gas in comparison with other energy sources in Ontario could lead to the generation of heat and power using micro-turbines in small agricultural industries such as grain processing or biomass pellet production. Micro-turbines are considered as the system for distributed energy generation. Increasing price of electricity in Ontario would gradually make on-site energy generation financially attractive, and micro-turbines could be an important component of the evolving energy system in Ontario. Figure 4.11 shows the size of a micro-turbine and the internal components.

The commercial manufacturers of micro-turbines include Capstone, Honeywell, Northern Research& Engineering Corporation and Elliott Energy/GE Power Systems. Since the operation of micro-turbines is based on a mature gas turbine technology, there are potentially a number of manufacturers entering the market once the strong demand is created. The energy conversion efficiency of a micro-turbine is 15-25% for electricity generation only and 40-65% for combined heat and power generation. The unit capital cost ($/kW) of micro-turbines is significantly higher than that of larger gas turbines. The areas of improvements of the micro-turbines include reliability of operation, energy efficiency, recuperator technology, fuel flexibility and the capital cost. Additionally, the environmental performance of micro-turbines could be an issue if the fuel is biogas or syngas which contain more impurities in comparison with natural gas.

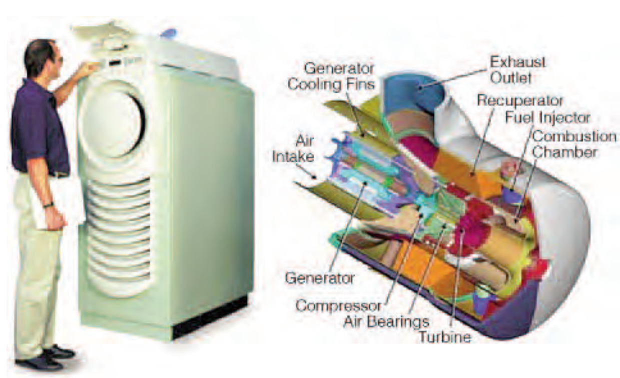


Figure 4.11 Micro-Turbine Set and Internal Components

(Sources: www. wppsef.org and Capstone)

Chapter 5 – Economics of Selected Bio-Energy Technologies

Generating electricity and heat from biomass has been financially proven in Europe because of regulatory supports and relatively higher energy prices in comparison with those in North America. In this chapter, the economics of selected bio-energy technologies are examined at the given prices of electricity, heat and other by-products in Ontario. Assumptions are made for some by-products such as bio-char since there are limited commercial markets at present. The selected bio-energy technologies include anaerobic digestion, direct combustion, bio-ethanol, bio-diesel, pyrolysis and gasification. The capital and operating costs of these selected technologies are based on literature and communication with industries. The return of investment of each selected technology is estimated at different production capacities.

5.1 Anaerobic Digestion

Electricity generation through the anaerobic digestion of manure has been slowly progressing in Ontario in recent years. There are currently about 20 AD power generation systems in Ontario connected to the electricity grid. Most AD systems use manure from cattle farms as primary feedstock, and the average size is about 300 kW of electricity generation. Livestock farming is an important and integral component of the agricultural sector in Ontario. Total market receipts of Ontario's farms are over $10 billion, and approximately 50% is from livestock farming (OMAFRA statistics). Dairy and beef farms are amongst the largest livestock operations in the province. Although the number of cattle has been declining in Ontario, there are approximately 1.75 million cattle and calves in the province (OMAFRA statistics). Theoretical energy generation from Ontario's cattle industry is 18,500 TJ/yr, which is 44.5% of total energy consumption in Ontario agricultural sector.

A financial spreadsheet model was developed to estimate the Return on Equity (ROE) of AD power generation system and is illustrated in Table 5.1. The AD system shown in Table 5.1 has the

Table 5.1 Financial Model for Anaerobic Digestion Energy System

General Parameters	Value
Capacity of the system (MWe)	0.4
Unit capacity cost (M$/MWe)	5.5
Debt to equity ratio	1.0
Interest rate (%)	5.0
Loan repayment period	15
Price of electricity ($/kWh)	0.13
Price of heat ($/GJ)	4.0
Number of diary cows equivalent	997
Cost of biomass ($/tonne)	0
Energy Generation and Revenue	**Value**
Electricity generation (MWh/yr)	3,264
Heat generation for sale (GJ/yr)	4,147
Sale of electricity (M $/yr)	0.42
Sale of heat (M $/yr)	0.02
Total revenue (M$/yr)	0.44
Cost Items	**Value**
Operating costs	
Biomass fuel (m3/yr)	44,843
Biomass fuel cost (M$/yr)	0.00
Labour (M $/yr)	0.05
Repairs and maintenance (M $/yr)	0.10
Handling and storage (M $/yr)	0.05
Sub-total operating costs (M $/yr)	0.20
Financing costs	
Total capital cost (M $)	2.19
Loan (M $)	1.10
Equity (M $)	1.10
Interest (M $/yr)	0.04
Loan repayment (M $/yr)	0.07
Sub-total financing costs (M $/yr)	0.11
Net income (M $/yr)	0.13
Income tax (M $/yr)	0.03
Return on equity (%)	9.42

electricity generation capacity of 400 kW, requiring about 1,000 dairy cows or equivalent. It should be noted that daily manure produced by a dairy cow is approximately 1.7 times higher than that of a beef cow (Beaulieu, 2004). The financial parameters such as debt-to-equity ratio and interest rate for the system are also shown in Table 5.1. Heat recovered from the I.C. engine is valued at $4/GJ, and the heat sale represents less than 5% total revenue. The manure is assumed at no cost for this on-farm AD system, and the value of by-product biomass fiber from the AD process is not considered in the financial model.

The capital cost of the AD energy system with 400 kW electricity generation capacities is estimated at $2.19 million, including the grid connection. The annual sub-total operating cost and sub-total financing cost of the system are $0.20 million and 0.11 million, respectively. The total revenue from energy sale is $0.44 million/yr. The FIT rate of $0.13/kWh for electricity from biomass is used to estimate the revenue from electricity sale to the grid. The estimated ROE of this manure-fed AD energy system is 9.42%. This level of ROE is un likely to attract significant investments from private investors; however, it is worth consideration for Ontario producers with sizable livestock operation for manure management and additional income perspectives.

Using the spreadsheet model, a sensitivity analysis was performed to estimate the ROE of different cattle farm sizes. Figure 5.1 provides the electricity generation capacity in kW and the ROE of four on-farm AD energy systems with different numbers of cattle. The minimum number of cattle for a positive ROE of an on-farm AD energy system is 500 as shown in Figure 5.1. The ROE would improve to 15% for a large livestock farm with 2,000 dairy cows. It should be noted that the average herd size of Ontario cattle industry is less than 100 cows (OMAFRA statistics), making on-farm AD energy systems uneconomic in most cases. This could be one of the reasons for the slow progress of the AD energy systems in Ontario. The ROE of AD energy systems would improve if off-farm manure and other wet biomass are available as low cost feedstock.

The ROE of on-farm AD energy systems would also improve with the increased price of electricity. Figure 5.2 shows the ROE of on-farm AD energy systems with 100 and 250 dairy cows. The economics of both systems become somewhat favourable at the electricity price of $0.25/kWh. The price of electricity at consumer gate in Ontario currently ranges $0.13/kWh-$0.16/kWh (http://www.ontarioenergy board.ca/OEB/Consumers/Electricity/Your+ Electricity+Utility), and is expected to increase. Therefore, integrating the AD energy systems with light agricultural industries in rural areas could be financially attractive with increasing prices of electricity in Ontario.

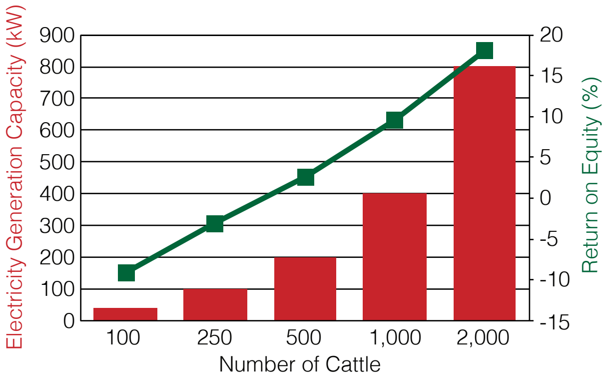


Figure 5.1 Electricity Generation Capacity and ROE of On-farm Anaerobic Digestion Energy Systems

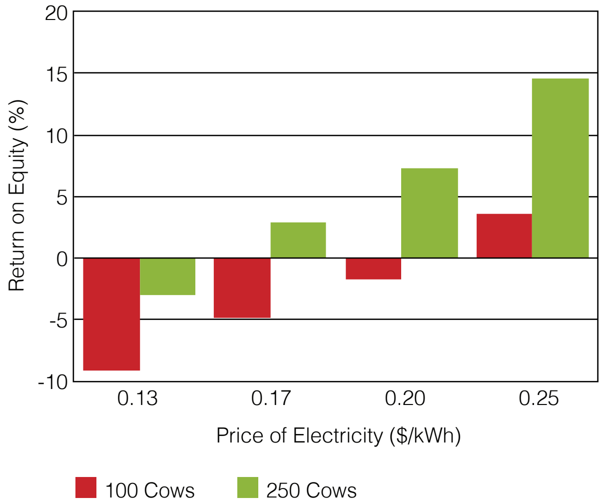


Figure 5.2 Return on Equity for On-Farm AD Energy Systems at Different Prices of Electricity

Another operating scenario considered for the AD energy system in this study is generating electricity only in peak hours, which presumably would get a higher electricity price with a gas storage system. Table 5.2 compares the ROE of AD energy systems for a regular 24 hour/day generation and peak hours only generation. For livestock farms with 1,000 dairy cows, a regular AD energy system would need 402 kW electricity generation equipments. However, for the same number of cattle, larger equipment of 1,041 kW

Table 5.2 Economics of AD Energy Systems for Regular and Peak Hours Electricity Generations

Parameter	AD System without Gas Storage	AD System with Gas Storage for Peak Hours Electricity Generation
Number of cattle	1,000	1,000
Electricity generation capacity (kW)	402	1,041
Capital cost (M $)	2.20	5.18
Operating cost (M$/yr)	0.20	0.19
Price of electricity ($/kWh)	0.13	0.19
Return on equity (%)	9.48	5.66

electrical capacities would be required for the peak hours only generation. A gas storage system, estimated at approximately $1 million for this capacity, would also be an additional capital cost. As shown in Table 5.2, the ROE of a peak hour only AD energy system is lower than that of a regular AD energy system. The ROE of peak hours only generation would improve if the peak hour electricity price is significantly higher than the current FIT rate for electricity from biogas.

5.2 Direct Combustion

Generation of energy from biomass through direct combustion is technically and commercially proven, especially in Europe. The direct combustion system can be designed at lower combustion temperatures to burn biomass to avoid the issues of ash melting and corrosion. Oo and Lalonde (2012) estimated that approximately 3.1 million tonnes of agricultural crop residues, mainly corn stover and cereal straw, could be sustainably harvested annually in Ontario. This amount of crop residues could power 500 MW base load power plant. However, a distributed system, smaller power plants of 10-50 MW capacity located across the province, would be preferable for agricultural biomass feedstock. The direct combustion of biomass for space heating also has a potential in some rural Ontario areas where propane and heating oil are currently used.

Table 5.3 gives the financial spreadsheet model for the generation of heat and power from direct combustion of biomass for a 50 MW electricity generation capacity. This base load power plant would consume approximately 300,000 tonne of biomass annually. Since this amount of biomass could be locally sourced in some Ontario counties, it is assumed that agricultural biomass bales can be chopped and fed into the boilers. There will be significant cost savings because of no pelletization of biomass and shorter transportation in comparison with the centralized utilization of biomass at a large power plant like Ontario Power Generation station. For this distributed energy generation scenario, the cost of biomass bales are assumed at $90/tonne, which could be an average cost of crop residues and purpose-grown biomass.

The capital cost of a 50 MW biomass power plant is estimated at $175 million. The annual operating cost of the plant is $32.77 million, which includes the cost of biomass fuel of $27.07 million. Assuming equal debt and equity for this investment, annual financing cost of this biomass power plant is $8.93 million. The power plant is assumed to have cogeneration capability, and heat generated is valued at $4/GJ. Total annual revenue from electricity and heat sales is $55.11 million, and the electricity sale represents over 96% of total revenue. The estimated ROE of a 50 MW biomass power plant is 12.28%. This level of ROE is unlikely high enough to attract significant capital from private investors. However, participation of Ontario producers in the investment could be seen as a risk-sharing measure by private equity investors.

Direct combustion biomass power plants typically use fluidized bed boilers and steam turbines to generate heat and power. Skilled workers such as stationary engineers would be required by the industry regulations to operate high pressure systems like steam turbines. The electricity generation capacity of less than 10 MW is most likely uneconomical for direct

Table 5.3 Financial Model for Direct Combustion Energy System

General Parameters	Value
Capacity of the system (MWe)	50
Unit capacity cost (M$/MWe)	3.5
Debt to equity ratio	1.0
Interest rate (%)	5.0
Loan repayment period	15
Price of electricity ($/kWh)	0.13
Price of heat ($/GJ)	4.0
Cost of biomass bales ($/tonne)	90

Energy Generation and Revenue	Value
Electricity generation (MWh/yr)	408,000
Heat generation for sale (GJ/yr)	518,400
Sale of electricity (M $/yr)	53.04
Sale of heat (M $/yr)	2.07
Total revenue (M$/yr)	55.11

Cost Items	Value
Operating costs	
Biomass fuel (tonne/yr)	300,737
Biomass fuel cost (M$/yr)	27.07
Labour (M $/yr)	3.80
Repairs and maintenance (M $/yr)	1.20
Handling and storage (M $/yr)	0.70
Sub-total operating costs (M $/yr)	32.77
Financing costs	
Total capital cost (M $)	174.85
Loan (M $)	87.42
Equity (M $)	87.42
Interest (M $/yr)	3.10
Loan repayment (M $/yr)	5.83
Sub-total financing costs (M $/yr)	8.93
Net income (M $/yr)	13.42
Income tax (M $/yr)	2.68
Return on equity (%)	12.28

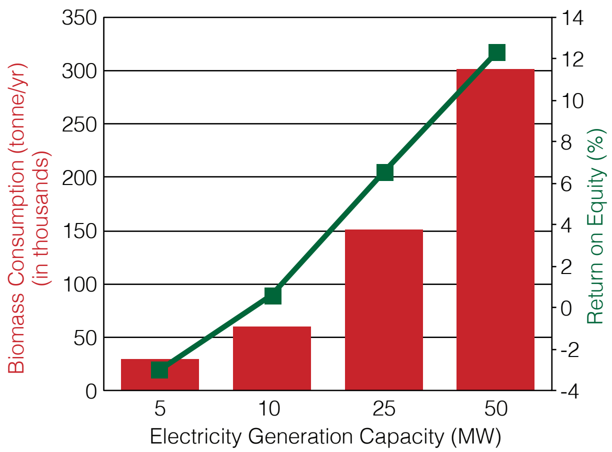


Figure 5.3 ROE of Direct Combustion Systems at Different Electricity Generation Capacities

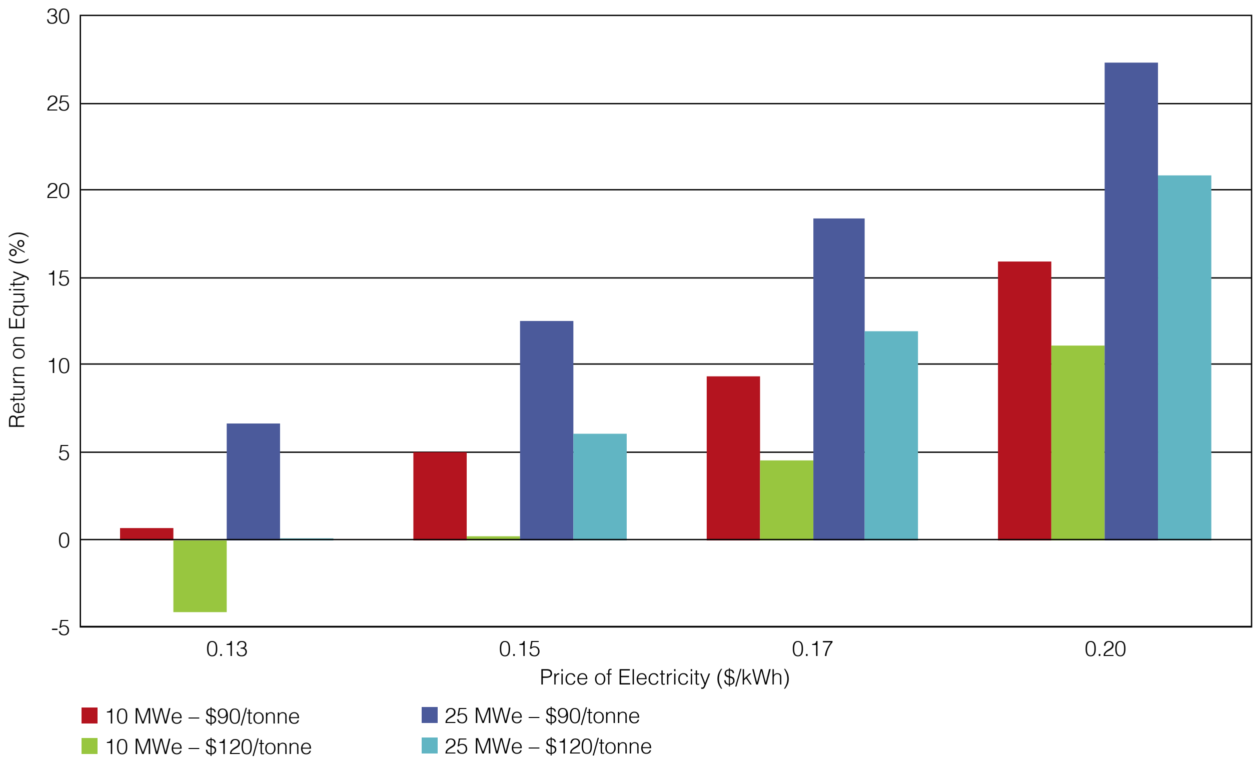


Figure 5.4 ROE of Direct Combustion Systems at Different Electricity and Biomass Feedstock Prices

combustion systems due to higher unit capital cost and operating expenses. A sensitivity analysis was performed to estimate the ROE of the biomass direct combustion energy systems at different electricity generation capacities and the results are shown in Figure 5.3. The electricity generation capacity should be greater than 25 MW for a reasonable ROE at the current price of electricity. The sensitivity of the ROE of direct combustion systems to the price of electricity and the cost of biomass feedstock is presented in Figure 5.4.

5.3 Bio-Ethanol and Bio-Diesel

Production of ethanol from starch/sugar crops has been commercialized around the world. Advanced bio-ethanol processes using non-food biomass such as cellulosic material are currently at demonstration stage. The bio-ethanol industry is largely supported by the Renewable Fuel Standard (RFS) or mandatory blending requirements in different jurisdictions. Ontario is the largest grower of grain corn in Canada, representing 65% of total (Statistic Canada). Approximately 30-35% Ontario grain corn is consumed by bio-ethanol industry (Grier et. al, 2012), and the rest is used for food processing, animal feed and other industrial applications. Bio-ethanol plants in Ontario are listed in Table 5.4.

The supply and demand of grain corn in Ontario is currently balanced with a small percentage imported or exported to nearby provinces/states, depending on the corn yield in a given year. An additional corn-ethanol plant with a significant capacity would require importing corn if corn acreages are not increased. The increasing price of grain corn in recent years and lower gasoline demand in North America has reduced the profit margin of bio-ethanol industry. This has led to the closures of many small to medium bio-ethanol plants which were built pre-financial crisis in 2008 in the USA. Uncertainty in RFS improvement is also an issue for the expansion of bio-ethanol industry. At current levels of RFS and gasoline demand, only bio-ethanol plants with greater economies of scale would be financially viable.

Table 5.5 exhibits the financial spreadsheet model for a corn-ethanol plant of 50 million gallon/yr (190 million litres/yr) capacity. The capital cost of this plant is estimated at $101 million. The long-tem price of corn is assumed at $5.75/bushel since the recent significant increase in corn price is largely due to the draught in many regions in USA. The wholesale price of ethanol is $2.20/gal; however, this should improve with the closure or temporary production halts of smaller corn ethanol plants. The wholesale price of by-product Dried Distillers Grains (DDG) is assumed at $180/tonne. Total revenue of the plant is $130.15 million/yr. Annual operating costs and financing cost are $119.23 million and $5.17 million, respectively. The cost of grain corn feedstock is $99.32 million, representing 83.3% of total operating cost. The ROE of this 50 million gal/yr corn ethanol plant is estimated at 9.07%. The sensitivity of ROE to the plant capacity and the prices of corn and ethanol are shown in Figure 5.5 and Figure 5.6.

Table 5.4 Bio-Ethanol Plants in Ontario

Plant	City	Capacity (million litre/yr)
Amaizeingly Green Products L. P.	Collingwood	58
GreenField Ethanol Inc. Chatham	Chatham	195
GreenField Ethanol Inc. Johnstown	Johnstown	230
GreenField Ethanol Inc. Tiverton	Tiverton	27
IGPC Ethanol Inc.	Aylmer	162
Iogen Corporation (Cellulosic)	Ottawa	2
Kawartha Ethanol Inc.	Havelock	80
Suncor St. Clair Ethanol Plant	Sarnia	400

(Source: Canadian Renewable Fuels Association)

Table 5.5 Financial Model for Corn Ethanol Production

General Parameters	Value
Capacity of the system (M gallon/yr)	50
Unit capacity cost (M$/M gal/yr)	2.03
Debt to equity ratio	1.0
Interest rate (%)	5.0
Loan repayment period	15
Price of ethanol ($/gal)	2.20
Price of DDG ($/tonne)	180
Cost of grain corn ($/bu)	5.75
Energy Generation and Revenue	**Value**
Bio-ethanol production (M gallon/yr)	47.5
DDG production (M tonne/yr)	0.14
Sale of bio-ethanol (M $/yr)	104.50
Sale of DDG (M$/yr)	25.65
Total revenue (M$/yr)	130.15
Cost Items	**Value**
Operating costs	
Grain corn feedstock (M bu/yr)	17.27
Grain corn cost (M$/yr)	99.32
Chemicals and energy cost (M$/yr)	16.63
Labour (M $/yr)	2.26
Repairs and maintenance (M $/yr)	0.71
Handling and storage (M $/yr)	0.32
Sub-total operating costs (M $/yr)	119.23
Financing costs	
Total capital cost (M $)	101.28
Loan (M $)	50.64
Equity (M $)	50.64
Interest (M $/yr)	1.80
Loan repayment (M $/yr)	3.38
Sub-total financing costs (M $/yr)	5.17
Net income (M $/yr)	5.74
Income tax (M $/yr)	1.15
Return on equity (%)	9.07

Most existing corn ethanol plants had been built before 2008, and the price of grain corn then was less than $5/bushel. At the higher gasoline demand before 2008, the wholesale price of ethanol was approximately $2.2/gal. As shown in Figure 5.6, the ROE of ethanol plants at those favourable prices of corn and ethanol are higher than 25%. The ROE of corn ethanol plants declines with increasing price of grain corn. At the current grain corn price of over $7/bushel, building a new corn ethanol plant is financially unattractive unless the wholesale price of ethanol significantly improves. More small to medium corn ethanol plants with higher operating costs are becoming uneconomical. The closure of those plants could eventually improve the price of ethanol. The mandatory blending of bio-ethanol with gasoline is expected to stay; therefore, the corn ethanol industry will likely continue to operate. However, operating ethanol plants at lower costs becomes critical at the current thin margin environment.

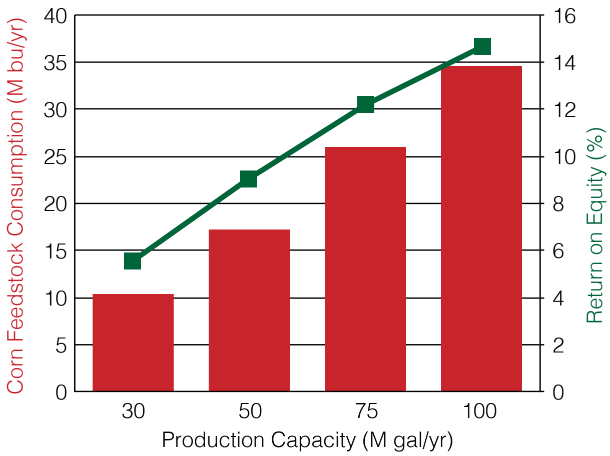


Figure 5.5 ROE of Corn Ethanol Plants at Different Production Capacities

A number of bio-diesel plants are in commercial operation in Ontario. Used cooking oils and animal Fats, Oil and Greases (FOG) from

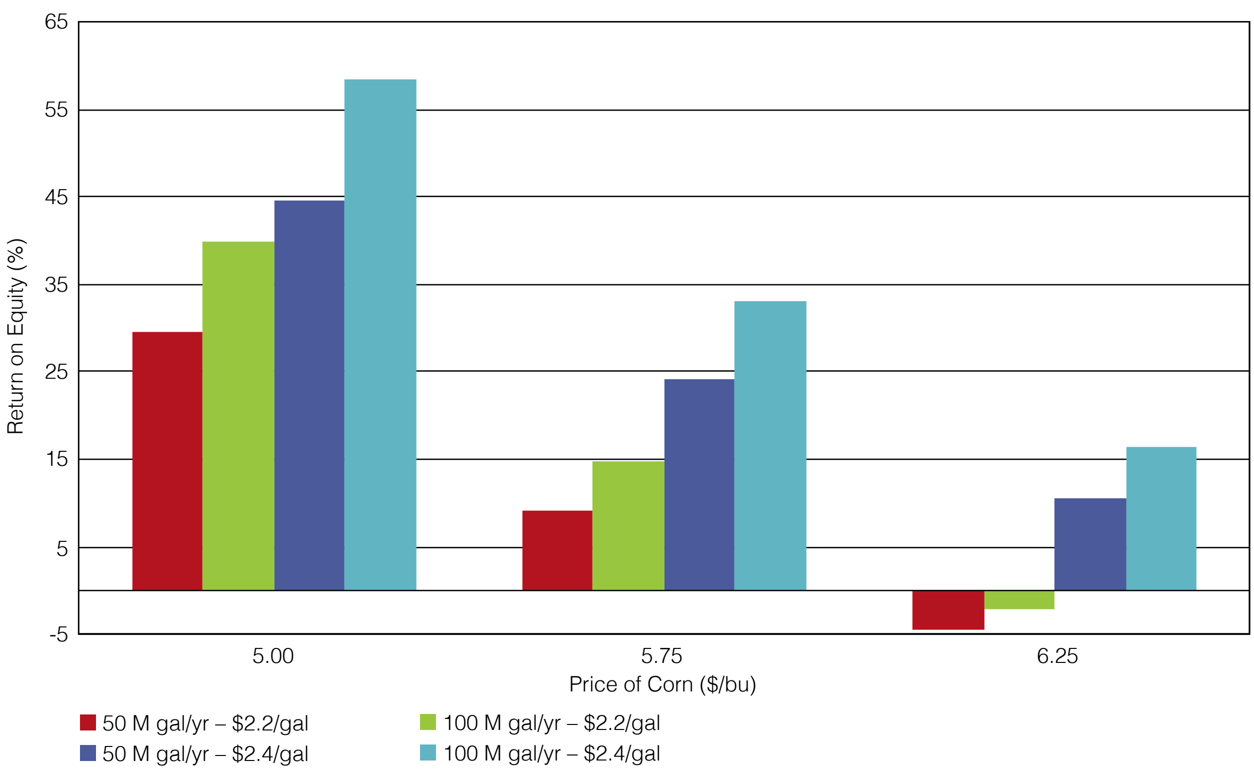


Figure 5.6 ROE of Corn Ethanol Plants at Different Prices of Corn Feedstock and Ethanol

slaughter houses are the most common feedstock for bio-diesel production in Ontario. Soybeans, one of the major crops in Ontario with 75% of Canadian soybeans produced in this province, can also be used to produce bio-diesel. However, the higher price of soybeans is not cost competitive in producing bio-diesel at present. Approximately 3% of canola produced in western Canada is used for bio-diesel production (Statistics Canada). Non-food grade corn oil, the by-product of corn ethanol plants, could be an attractive feedstock for bio-diesel production (Saville, 2006). Bio-diesel plants are usually small in comparison with corn ethanol plant since the availability of used cooking oils and FOG is limited. Bio-diesel plants in Ontario are given in Table 5.6.

The financial spreadsheet model for a 10 million gallons/yr (37.9 million litres/yr) bio-diesel plant is shown in Table 5.7. The capital cost of this bio-diesel plant is estimated at $28.32 million. The cost of feedstock oil which could be a combination of used cooking oils and corn oils is assumed at $400/tonne. Many existing bio-diesel plants in North America have no or negative feedstock costs since bio-diesel is produced from waste materials. However, bio-diesel producers will likely have to pay for waste feedstock as more and more bio-diesel plants are built. The price of by-products glycerol and soap-stock is $500/tonne; however, the sale of by-products represents only 8.8% of the total revenue. Total annual operating costs and financing costs are $18.92 million and $1.45 million, respectively. The ROE of this bio-diesel plant is estimated at 14.42%. It should be noted that the availability of inexpensive feedstock is critical in the financial feasibility of bio-diesel plants. Most bio-diesel plants are located close to the feedstock source and ideally not very far from the markets.

Table 5.6 Bio-Diesel Plants in Ontario

Plant	City	Capacity (million litre/yr)
BIOX Corporation	Hamilton	66
BIOX Corporation	Hamilton Plant 2	67
Methes Energies Canada	Mississauga	5
Methes Energies Canada	Sombra	50
Noroxel Energy Ltd.	Springfield	5

Source: Canadian Renewable Fuels Association

Table 5.7 Financial Model for Bio-Diesel Production

General Parameters	Value
Capacity of the system (M gallon/yr)	10
Unit capacity cost (M$/M gal/yr)	2.8
Debt to equity ratio	1.0
Interest rate (%)	5.0
Loan repayment period	15
Price of bio-diesel ($/gal)	2.20
Price of glycerol and soapstock ($/tonne)	500
Cost of feedstock oil ($/tonne)	400

Energy Generation and Revenue	Value
Bio-diesel production (M gallon/yr)	9.5
Glycerol and sopastock production (k tonne/yr)	4.05
Sale of bio-diesel (M $/yr)	20.90
Sale of glycerol and soapstock (M$/yr)	2.02
Total revenue (M$/yr)	22.92

Cost Items	Value
Operating costs	
Feedstock oil (k tonne/yr)	35.91
Cost of feedstock oil (M$/yr)	14.36
Chemicals and energy cost (M$/yr)	3.23
Labour (M $/yr)	0.99
Repairs and maintenance (M $/yr)	0.18
Handling and storage (M $/yr)	0.16
Sub-total operating costs (M $/yr)	18.92
Financing costs	
Total capital cost (M $)	28.32
Loan (M $)	14.16
Equity (M $)	14.16
Interest (M $/yr)	0.50
Loan repayment (M $/yr)	0.94
Sub-total financing costs (M $/yr)	1.45
Net income (M $/yr)	2.55
Income tax (M $/yr)	0.51
Return on equity (%)	14.42

The required feedstock oils and the ROE of bio-diesel plants at different capacities are shown in Figure 5.7. As mentioned earlier, feedstock availability and access to markets usually limit the size of bio-diesel plants under 30 million gallons/yr (113.7 million liters/yr). The economics of bio-diesel improves with the size of the plant. The estimated ROE of a 30 million gal/yr bio-diesel plant is 27.2%. However, the ROE of a bio-diesel plant depends significantly on the cost of feedstock oils and the wholesale price of bio-diesel as shown in Figure 5.8. If the cost of feedstock oils is $300/tonne, the bio-diesel plants are financially attractive. However, the bio-diesel plants will be unprofitable if the price of feedstock oils increases to $600/tonne. The price of soybeans oil is over $1,000/tonne, which is too expensive to produce bio-diesel. Therefore, used cooking oils, FOG and corn oil from ethanol plants are expected to remain as feedstock for bio-diesel.

Both bio-ethanol and bio-diesel industries are largely driven by government policies. The Renewable Fuel Standard (FS) in USA and mandatory blending rates in Canada should be increased to improve the bio-fuels demand. Without increases in the RFS, it will take some time to resolve the current overcapacity situation of the corn ethanol industry through rationalization of smaller plants with higher operating costs. Some smaller corn ethanol plants in the USA are planning conversion to produce butanol, which could have greater diversified applications than ethanol. The performance of these demonstration butanol plants should be observed with interest. At current Federal mandate of 5% renewable content for gasoline, corn ethanol production will likely continue in Ontario, and medium to large ethanol plants will financially perform better than smaller plants.

As noted in the economic analysis of the bio-diesel plants, the long-term availability of inexpensive feedstock is the key factor. The renewable diesel mandate of 2% in Canada could improve the increasing demand for bio-diesel. Renewable bio-fuel production in Canada is only 4% of that in USA (Grier et. al, 2012). The US is now exporting bio-ethanol to Europe and other countries (RFA, 2012), and the global supply and demand of bio-ethanol is very dynamic. Based on the fuel demand and lower renewable fuel mandatory blending rates, the bio-fuels industry especially bio-diesel in Canada has potential to expand. Monitoring the development in policy and economic drivers for bio-fuel industry in USA and Canada is essential to participate in this transportation liquid fuel production.

Advanced bio-fuels which are produced from non-food biomass feedstock can be considered as emerging technologies. A number of demonstration plants are being built around the world to commercialize cellulosic and other advanced bio-fuels and chemicals. The economics of advanced bio-fuels technologies are relatively unknown. Crop residues and potential purpose-grown biomass resources in

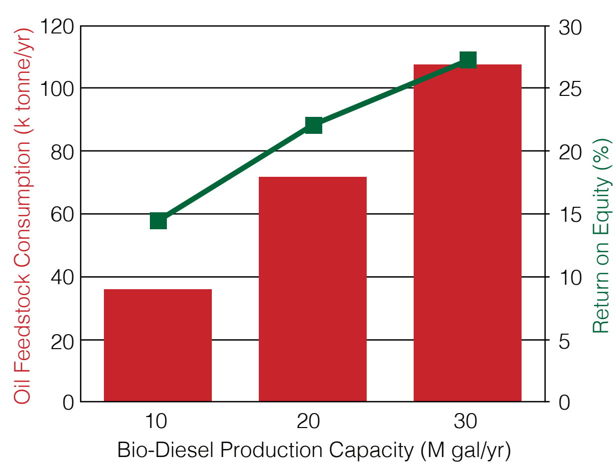


Figure 5.7 ROE of Bio-Diesel Plants at Different Production Capacities

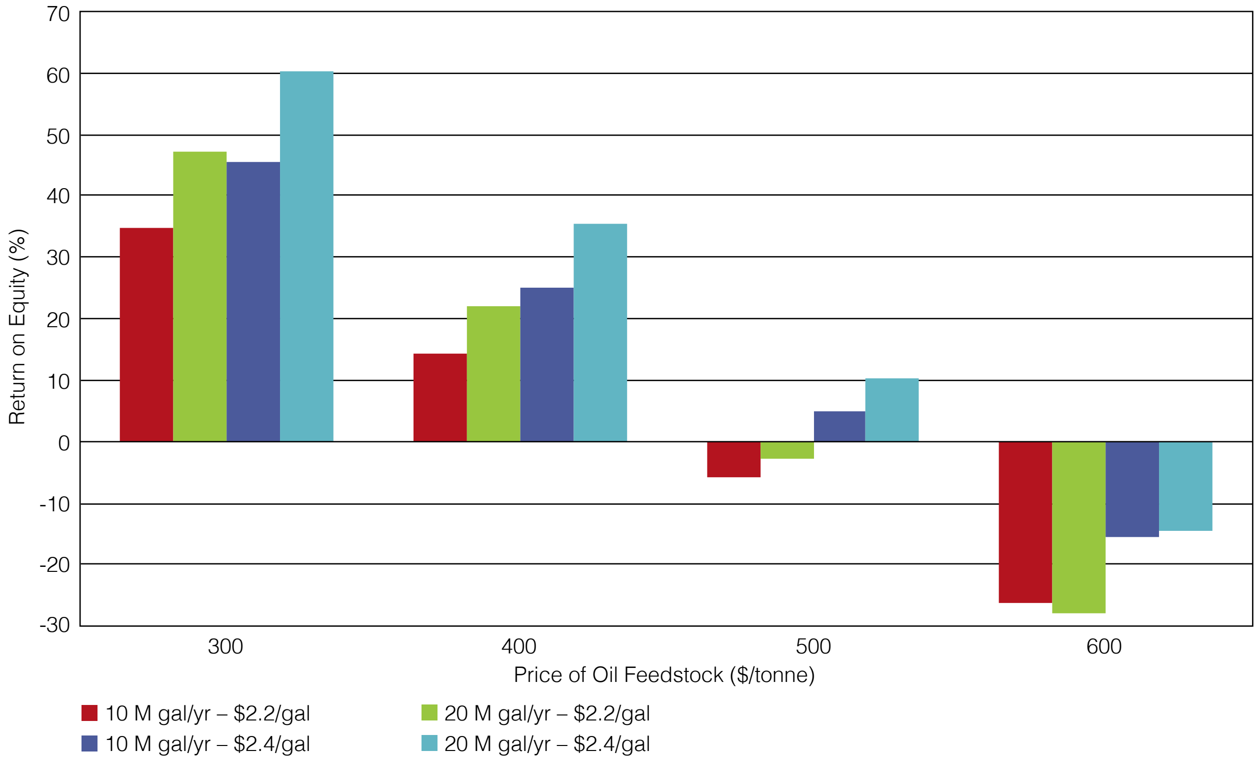


Figure 5.8 ROE of Bio-Diesel Plants at Different Prices of Feedstock Oil and Diesel

Ontario would allow the farm operators to participate in advanced bio-fuels industry once the technologies are commercially proven.

5.4 Pyrolysis and Gasification

Pyrolysis is one of the emerging technologies with a significant potential for producing energy, bio-oil and bio-char from agricultural biomass. Bio-char can be used to enrich soil so that pyrolysis is a great fit with the agricultural sector. There are pyrolysis systems in commercial operations producing speciality chemicals from forestry biomass. Pyrolysis technologies for energy applications using agricultural biomass as feedstock are mostly at pilot to demonstration stages. A number of assumptions are made for the financial analysis of pyrolysis since technologies are still under development and the products, bio-oil and bio-char, are currently not commercially traded commodities. The estimated values of the products of a pyrolysis process are shown in Figure 5.9. It should be noted that the process parameters could be modified to produce more bio-oil or more bio-char.

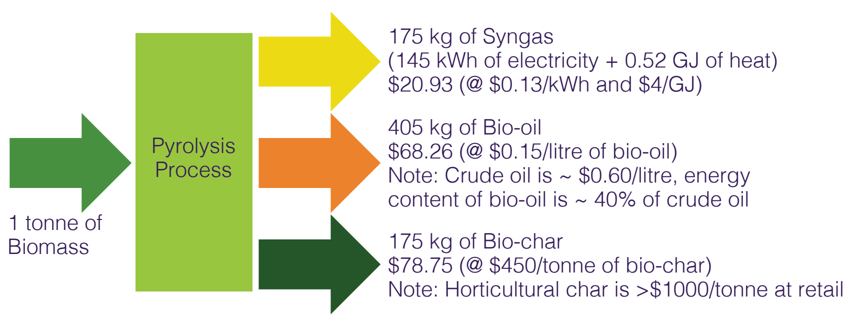


Figure 5.9 Values of the Products of a Pyrolysis Process

As shown in Figure 5.9, syngas produced by the pyrolysis process is used to generate electricity and heat. The price of electricity from biomass at FIT rate is $0.13/kWh, and the price of heat is assumed at $4/GJ. The total value of 175 kg of syngas is, therefore, $20.93. Bio-oil has less energy content per unit mass in comparison with crude oil. At $0.15/liter of bio-oil, the value of 405 kg of bio-oil is $68.26. As mentioned earlier, bio-char is not a commercially traded commodity. The price of horticultural char at retail gardening stores is over $1,000/tonne. If the wholesale price of bio-char is assumed at $450/tonne, the value of 175 kg of bio-char is $78.75. Therefore, total value of all pyrolysis products is $167.94/tonne.

Table 5.8 Financial Model for Pyrolysis System

General Parameters	Value
Capacity of the system (MWe)	1
Unit capacity cost (M$/MWe)	23.9
Debt to equity ratio	1.0
Interest rate (%)	5.0
Loan repayment period	15
Price of electricity ($/kWh)	0.13
Price of bio-oil ($/liter)	0.15
Price of bio-char($/tonne)	450
Cost of biomass bales ($/tonne)	90

Energy Generation and Revenue	Value
Electricity generation (MWh/yr)	8,160
Bio-oil production (Ml/yr)	25.46
Bio-char production (tonne/yr)	9,792
Sale of electricity (M $/yr)	1.06
Sale of bio-oil (M$/yr)	3.82
Sale of bio-char (M$/yr)	4.41
Total revenue (M$/yr)	9.29

Cost Items	Value
Operating costs	
Biomass fuel (tonne/yr)	55,954
Biomass fuel cost (M$/yr)	5.04
Labour (M $/yr)	1.27
Repairs and maintenance (M $/yr)	0.11
Handling and storage (M $/yr)	0.30
Sub-total operating costs (M $/yr)	6.71
Financing costs	
Total capital cost (M $)	23.85
Loan (M $)	11.93
Equity (M $)	11.93
Interest (M $/yr)	0.42
Loan repayment (M $/yr)	0.80
Sub-total financing costs (M $/yr)	1.22
Net income (M $/yr)	1.36
Income tax (M $/yr)	0.27
Return on equity (%)	9.10

The financial spreadsheet model of a pyrolysis plant with a processing capacity of 165 tonne/day of raw biomass is shown in Table 5.8. This pyrolysis system can generate 1,000 kW of electricity from syngas produced. Annual bio-oil and bio-char productions are 25.46 million litres and 9,792 tonnes, respectively. The capital cost of the system is estimated at $23.85 million. The estimated ROE of this pyrolysis energy system is 9.10%. It should be noted that there are no commercial markets for bio-oil and bio-char at present, and the financials of the system are based on the assumed price of the products.

The ROE of a pyrolysis system would improve with the processing capacity as shown in Table 5.9. Larger pyrolysis systems will likely benefit from economies of scale; however, they need to secure markets for the products. There are uncertainties in the price of bio-oil and bio-char in the financial estimates of pyrolysis systems. Table 5.10 gives the changes in ROE of a pyrolysis system with the processing capacity of 40 tonnes/day if the prices of bio-oil and bio-char are varied. The financial performance of pyrolysis systems could improve if bio-oil can be economically refined to produce speciality chemicals. A great deal of research and development is underway for pyrolysis and bio-oil refining technologies. Pyrolysis could potentially create value adding activities for the agricultural sector if it is commercialized.

Table 5.9 ROE of Pyrolysis System with Different Processing Capacities

	Small	Medium	Large
Biomass feedstock (tonne/day)	40	165	330
Syngas electricity generation capacity (kW)	250	1,000	2,000
Capital cost (M $)	9.55	23.85	37.68
Bio-oil production (M litre/yr)	6.37	25.46	50.92
Bio-char production (tonne/yr)	2,488	9,792	19,584
Return on Equity (%)	-4.02	9.10	17.66

Table 5.10 Changes in ROE of Pyrolysis System with Prices of Bio-Oil and Bio-Char

	Base case	Range	ROE of 40 tonne/day Plant
Price of bio-oil	$0.15/liter	+50%	3.98 %
		-50%	-12.02 %
Price of bio-char	$450/tonne	+50%	5.21 %
		-50%	-13.24 %

Biomass gasification technologies have been used in commercial operations around the world. Forestry biomass is the major feedstock for biomass gasification. The combustible gases from the gasifier can be fed into IC engines or gas-fired boilers for generating heat and electricity. Due to the higher alkali and other chemical compounds in agricultural biomass, gasification systems using agricultural feedstock are mostly in pilot to demonstration stages. If the nutrients from agricultural biomass can be effectively removed, gasification could be an attractive alternative energy technology for the agricultural sector.

The financial spreadsheet model for a gasification system with 10 MW of electricity generation capacity is shown in Table 5.11. The system will require approximately 72,000 tonne/yr of raw biomass. The estimated capital cost of this gasification system is $18.43 million. Annual operating costs of the system are $8.80 million, including the cost of biomass feedstock. Heat sale is considered for the system although it represents less than 4% of total revenue. The estimated ROE of this gasification energy system is 11.13%.

Table 5.11 Financial Model for Gasification System

General Parameters	Value
Capacity of the system (MWe)	10
Unit capacity cost (M$/MWe)	1.8
Debt to equity ratio	1.0
Interest rate (%)	5.0
Loan repayment period	15
Price of electricity ($/kWh)	0.13
Price of heat ($/GJ)	4.0
Cost of biomass bales ($/tonne)	90
Energy Generation and Revenue	**Value**
Electricity generation (MWh/yr)	81,600
Heat generation for sale (GJ/yr)	103,680
Sale of electricity (M $/yr)	10.61
Sale of heat (M $/yr)	0.41
Total revenue (M$/yr)	11.02
Cost Items	**Value**
Operating costs	
Biomass fuel (tonne/yr)	72,177
Biomass fuel cost (M$/yr)	6.50
Labour (M $/yr)	1.66
Repairs and maintenance (M $/yr)	0.31
Handling and storage (M $/yr)	0.34
Sub-total operating costs (M $/yr)	8.80
Financing costs	
Total capital cost (M $)	18.43
Loan (M $)	9.21
Equity (M $)	9.21
Interest (M $/yr)	0.33
Loan repayment (M $/yr)	0.61
Sub-total financing costs (M $/yr)	0.94
Net income (M $/yr)	1.28
Income tax (M $/yr)	0.26
Return on equity (%)	11.13

Biomass gasification systems should be built at certain scales to be financially attractive as shown in Figure 5.10. The gasification systems with less than 10 MW electricity generation capacity are unlikely to be profitable at the current prices of electricity and heat in Ontario.

Therefore, biomass gasification systems are more for farm cooperative scales rather than for individual farm operators. It should be noted that at present there are both technical and commercial risks associated with gasification systems which use agricultural biomass as feedstock. The development of speciality chemicals from agricultural biomass through gasification could change the economics of biomass gasification systems.

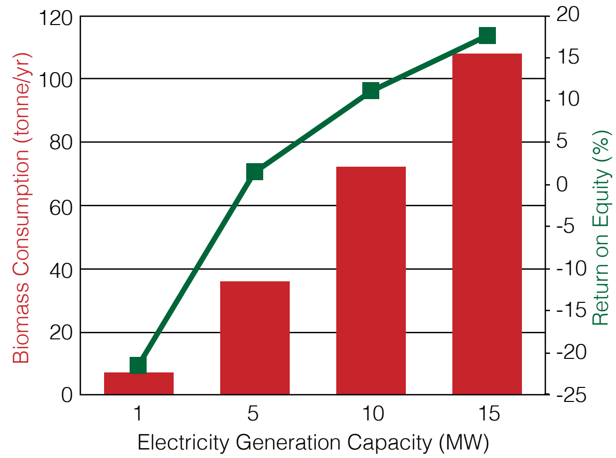


Figure 5.10 Biomass Consumptions and ROE of Gasification Systems

Chapter 6 – Bio-Energy Value Chain for Ontario Agricultural Producers

Generating electricity and heat from biomass includes a number of activities such as producing biomass, harvesting, transporting, pre-processing, generating energy and by-products, marketing and sale. These activities are the segments of the bio-energy value chain. Ontario agricultural producers could be the supplier of biomass to the bio-energy plants or can participate in the complete value chain. In this chapter, two economic models are discussed to analyse the bio-energy industry and investing options for Ontario producers. Based on the evaluation of alternative technologies and the economic analysis presented in previous chapters, recommendations are offered for Ontario producers on how to participate in the bio-energy value chain of selected technologies.

6.1 Five Forces Analysis of Bio-Energy Generation

Michael Porter of Harvard Business School (Porter, 1979) developed Five Forces Analysis which is a framework for industry analysis and business strategy. Porter identified five forces that determine the competitive intensity and therefore attractiveness of an industry. Figure 6.1 exhibits the five forces analysis. Three of Porter's five forces are the competition from external sources, and the rest are internal threats. An industry will be profitable if it can manage these forces. If the combination of these forces acts to weaken the profitability, the industry will be financially unattractive.

If an industry is highly profitable, it will attract new firms. This could lead to lower market shares for existing firms in the industry. This thread of new entrants is dependent on the existence of barriers to the entry. In general, the barriers include investment cost, economies of scale available to existing firms, regulatory and legal restrictions, and product differentiation, access to suppliers and distribution channels, and retaliation by established products. There are not a lot of existing firms for generating heat and power from agricultural biomass in Ontario. The FIT rate for electricity from biomass is not as attractive in comparison with solar and wind electricity. Since the bio-energy industry is for the most part unprofitable, the thread of new entrants is relatively low. Access to the electricity grid in Ontario is one of the major barriers for smaller energy producers such as AD power systems. For the larger bio-energy systems, the capital requirement is relatively high for individual farm producers.

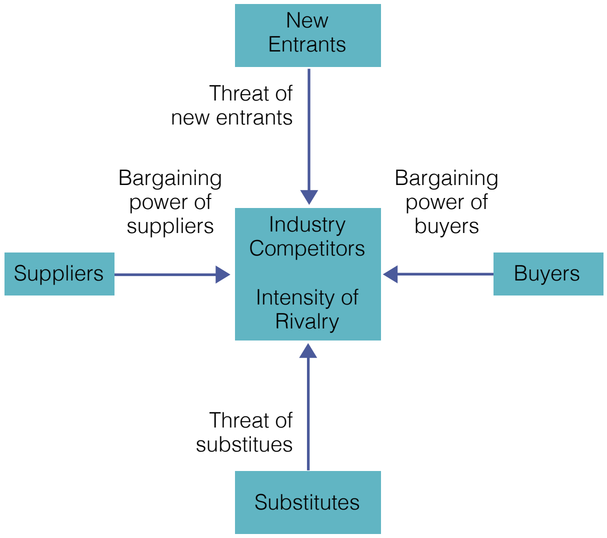


Figure 6.1 Five Forces Analysis of an Industry (Porter, 1979)

If the suppliers of an industry have bargaining power, they will exercise the power to increase the price of their products, thereby reducing the profit margin of the industry. In general, the suppliers have greater bargaining power when:

- There are only a few large suppliers
- The resource they supply is unique
- The cost of switching to an alternative supplier is high
- The customer is small and unimportant
- There are no or few substitute resources available

Ontario has significant agricultural biomass resources to be used as feedstock for generation of heat and power. In addition to the agricultural sector, forestry and municipal solid wastes can also provide a considerable volume of biomass. Therefore, the biomass suppliers in Ontario do not have a relatively high bargaining power for their feedstock for bio-energy generation. However, grain corn which is used to produce ethanol is in tight supply in Ontario.

A substitute product can be defined as the product that meets the same need. The extent of the thread from substitutes depends on the price and performance of the substitute, the customers' willingness to switch and the switching costs. The thread of substitutes for bio-energy sector in Ontario is significant. Biomass is not the only resource which can be used to generate heat and power. At the current low price of natural gas in Ontario, energy generation using natural gas as a feedstock is very attractive. The IGPC Ethanol Inc. is building a natural gas powered cogeneration unit at their plant, and a few coal-fired power plants in USA are switching to natural gas. It should be noted that for the emerging pyrolysis technology which produce bio-oil and bio-char, natural gas is not likely a substitute.

The customers or buyers with strong bargaining power can drive down the price of the industry products and therefore squeeze the profit margin. Factors determining the bargaining power of buyers include the number of customers, the number of suppliers, the size of orders, and the cost of switching to substitutes. For electricity generation from biomass, the FIT rate is determined by a government organization in Ontario. For heat generation from biomass, the bargaining power of buyers is associated with the substitutes which could be natural gas or propane or heating oil. For transportation liquid fuels from biomass, the mandatory blending rates and the demand of liquid fuels define the bargaining power of buyers.

If the competition from the industry participants is intense, the resulting price war combined with increased costs of marketing and sale promotion can, therefore, reduce the profit margin of the industry. However, innovation and emergence of new products can also be expected from industry with intense internal competition. Factors determining competition from the industry rivalries include number of competitors, market size and growth rate, product differentiation, competitive edge and innovation, and the cost structure of the industry. As mentioned earlier, generating heat and power from agricultural biomass in Ontario is relatively new, and the competition from the industry participants is not as significant in comparison with other issues such as access to the electricity grid. However, the competition in corn ethanol industry can be considered as intense due to the increasing price of grain corn and the existing production capacity.

6.2 Growth Pyramid and Investment Options

The core competencies of Ontario agricultural producers include growing crops, managing soil and crop residues, harvesting and transportation of agricultural products. As producers of biomass, Ontario producers could potentially participate in emerging bio-energy sector and diversify their business. It is important to determine to what extent in the value chain of the bio-energy generation Ontario producers should participate. McKinsey growth pyramid shown in Figure 6.2 is worth mentioning for this new business venture of bio-energy generation.

As shown in generic options of Figure 6.2 for Ontario agricultural producers, bio-energy generation would be new products and services, new delivery approaches, new industry structure and new competitive arenas. The geographies could also be new since most markets with higher demand of energy products could be away from the farms. McKinsey suggests that business growth strategies should be based on (http://tutor2u.net/business/strategy/mckinsey_pyramid.htm):

- Operational skills
- Privileged assets
- Growth skills
- Special relationships

Operational skills are the core competencies that a business has which can provide the foundation for a growth strategy. Ontario producers are skilful in operating agricultural machineries, and some of those skills could be transferrable to bio-energy generation. Privileged assets are those assets held by the business that are hard to replicate by competitors. Ontario producers have the privileged assets of productive lands to grow biomass feedstock. However, the competition from forestry biomass should not be underestimated. Growth skills are the skills that businesses need if they are to successfully manage a growth strategy. Farm cooperatives in Ontario are managed by business professionals, and Ontario producers are supported by a number of industry organizations. For bio-energy generation, Ontario producers need to develop special relationships with new organizations such as Ontario Power Authority, large energy users, and service providers for energy generation equipment.

As shown in Figure 6.2, McKinsey‘s model suggests a number of investment options with different risks to grow a business or to diversify a business. The investment options in the order of increasing risk are organic investment, marketing partnerships, strategic alliances, minority stakes, joint ventures and acquisitions.

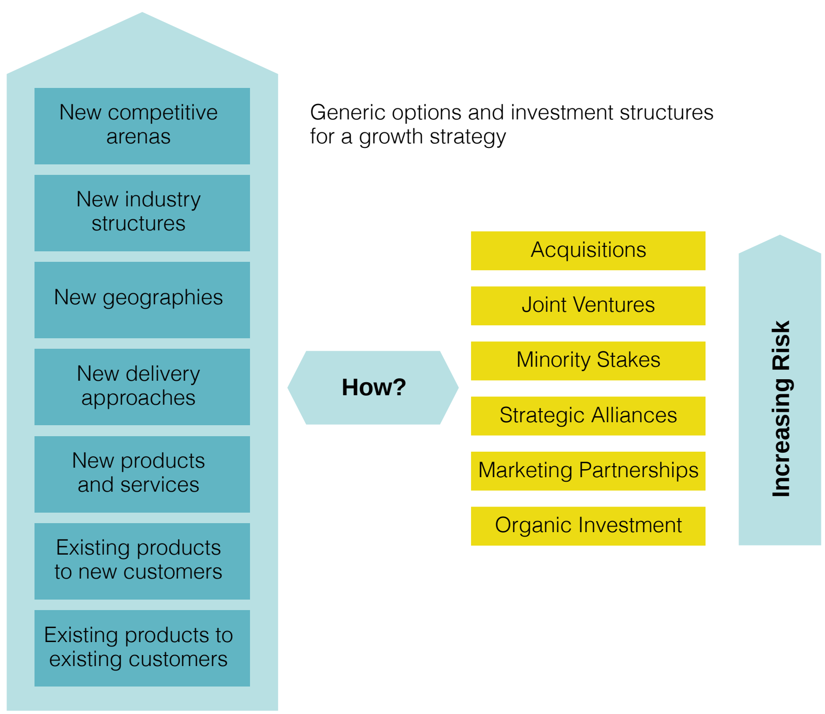


Figure 6.2 McKinsey Growth Pyramid

(http://tutor2u.net/business/strategy/mckinsey_pyramid.htm)

Ontario producers should evaluate these investment options for each technology to participate in the bio-energy value chain. For instance, at current mandatory blending rates and gasoline demand, only medium and large corn ethanol plants are likely to be financially attractive. The capital cost required to build a medium to large corn ethanol plant could be too high for an individual Ontario producer or even for a farm cooperative. Therefore, taking minority stakes in medium to large corn ethanol plants could be the best investment and participation option for Ontario producers.

6.3 Importance of Economies of Scale

The unit production cost can be generally reduced by producing more or by increasing the production capacity and this advantage is called economies of scale. If the unit production cost increases by producing more or by increasing the production capacity, it is termed as diseconomies of scale. Figure 6.3 shows the basic concept of the economies of scale. By increasing the production from Q to Q1, the unit production cost would decrease from C to C1, offering the cost advantage for the firm. However, if the production is increased beyond Q1, there will be diseconomies of sale.

There are different economies of scale associated with each bio-energy technology. The economies of scale in bio-energy generation likely depend on availability of feedstock in the area, transportation costs, the staffing requirements of the system, and the demand of energy products in the area. For instance, the high transportation cost of wet biomass would limit the size of an AD power system. If a bio-energy system is sized so that biomass feedstock is to be transported from a longer distance, i.e. over 100 km in Ontario, there will likely be diseconomies of scale.

The unit processing cost is also an important factor in determining the optimum size of a bio-energy facility. In order to illustrate this, the unit production cost of wood pellets versus the production capacity is shown in Figure 6.4. The absolute cost numbers of Figure 6.4 may not currently be applicable since the estimates were done in 2006. However, Figure 6.4 highlights the order of magnitude difference in the wood pellet production costs of small and large plants. The

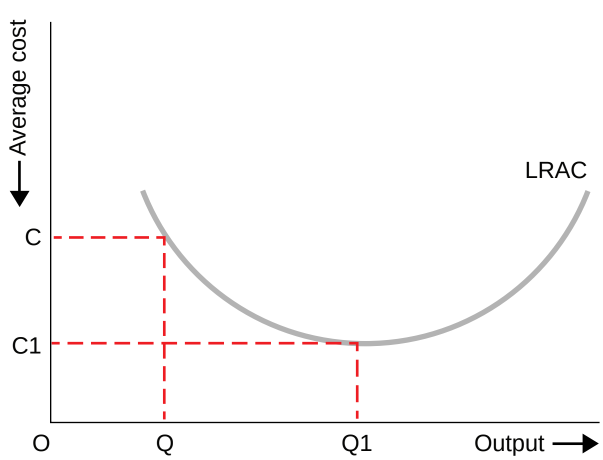


Figure 6.3 Economies of Scale Basic Concept

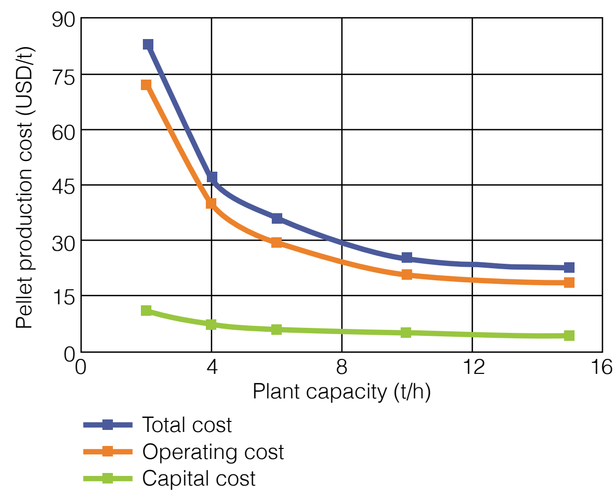


Figure 6.4 Unit Production Cost of Wood Pellets versus Plant Capacity (Mani et. al, 2006)

production costs of wood pellets at a 2 t/hr plant could be 3 – 4 times higher than that of a 15 t/hr plant. The average processing capacity of wood pellet plants in British Columbia is 15 -20 t/hr (personal communication with industry experts).

There have been activities in the development of portable biomass processing and bio-energy production units in recent years. They range from portable biomass pelletizer to mobile pyrolysis unit to small biomass gasification system. Most of these portable units can process 1 – 3 tonne/hr, i.e. fewer than 30,000 tonnes/yr, of raw biomass. In most Ontario counties, approximately 150,000 tonne/yr of biomass can be gathered within 100 km radius. Extreme care should be exercised in analyzing the financial feasibility of small scale bio-energy systems. Once the profitability of a small system is proven, there will likely be new larger entrants to the industry with favourable economies of scale.

6.4 Participation in Bio-Energy Value Chain

Bio-energy technologies are evaluated in this study. Some technologies are mature, and some are still considered as under development or emerging. The economics of selected bio-energy systems are also investigated in this study. Some technologies have lower financial risks, and some are well below investment grade threshold. Porter's five force analysis and McKinsey's growth pyramid also provide additional considerations for Ontario producers in participating in bio-energy industry. Economies of scale are also important for each bio-energy technology. Based on these discussions, the recommended participation in the bio-energy value chain for selected bio-energy systems are given in Table 6.1.

As previously discussed, the capacity of an AD power system in Ontario is limited by the average herd size and the high transportation cost of wet and bulky biomass feedstock. The competition from other biomass feedstock for AD power system is not intense. Ontario agricultural producers should participate in the complete value chain of AD bio-energy systems. Farm organization like OFA should lobby for better access to the electricity grid and for greater premium prices of energy generated from the AD systems. The environmental benefits of AD

Table 6.1 Participation in Bio-Energy Value Chain for Ontario Producers

Bio-Energy System	F	T	P	M&S	Recommended Approach/Investment
Anaerobic digestion	🟢	🟢	🟢	🟢	Lobby for better grid access and greater premium price for energy generated
Direct combustion	🟢	🟢	🟡	🟡	Minority Stakes to Joint Venture
Pyrolysis	🟢	🟢	🟠	🟠	Strategic Alliance to Minority Stakes
Gasification	🟢	🟢	🟠	🟠	Strategic Alliance to Minority Stakes
Bio-ethanol	🟢	🟢	🟡	🟡	Minority Stakes to Joint Venture
Bio-diesel	🟢	🟢	🟡	🟡	Minority Stakes to Joint Venture
Torrefaction	🟢	🟢	🟠	🟠	Strategic Alliance
Energy storage	🟢	🟢	🟡	🟡	Strategic Alliance to Minority Stakes
Bio-methane	🟢	🟢	🟡	🟡	Strategic Alliance to Minority Stakes
Hydrogen enriched natural gas	🟢	🟢	🟠	🟠	Strategic Alliance

F: Feedstock supply
T: Transportation of feedstock
P: Production of energy and co-products
M&S: Marketing and sales

🟢 Full participation recommended
🟡 Partial participation possible
🟠 Participation needs further analysis

systems which reduce the emissions of greenhouse gases from manure should be highlighted in the lobbying efforts.

The direct combustion of biomass integrated with steam turbines is a mature technology to generate renewable heat and power. To be financially attractive, the system should have a minimum electricity generating capacity of 10 MW, which requires a relatively large capital investment for individual agricultural producer. Furthermore, the competition from forestry biomass could be intense in some areas of Ontario. For the direct combustion bio-energy systems, Ontario producers could participate in feedstock supply and transportation of biomass. A partial participation in the form of taking minority stakes or joint venture with the energy producer could be possible in selected locations.

Pyrolysis and gasification are emerging bio-energy technologies. More research and development are required, especially using agricultural biomass as feedstock for commercialization of these technologies. If pyrolysis and gasification bio-energy systems are built in Ontario, agricultural producers should participate in the feedstock supply and biomass transportation of the value chain. Participation in energy production, marketing and sales of the energy and co-products would require further assessment for these technologies on a case-by-case basis. A similar approach could be employed for torrefaction and hydrogen enriched natural gas technologies.

Bio-ethanol and bio-diesel productions in Ontario will likely continue at current mandatory blend rates as the demand for renewable liquid transportation fuels is not expanding. Economies of scale would be an important factor for bio-ethanol industry, and availability of inexpensive feedstock is critical for bio-diesel industry. Participating in bio-ethanol and bio-diesel industries would provide a good hedging for Ontario producers who consume considerable amounts of transportation liquid fuels in farming activities. Taking minority stakes or forming joint ventures with financially performing bio-ethanol and bio-diesel manufactures are recommended.

Like in any other industry, risk management is vital in bio-energy industries. Risk management measures could be categorized into feedstock supply, technology, and marketing and sale. For managing risk of feedstock supply, it is desirable to locate the bio-energy facility in the region where the available biomass feedstock is significantly higher than required by the bio-energy facility. The involvement of local community from the planning stage and proper environmental and social assessments are important. Long-term contracts with biomass suppliers would secure the feedstock for the facility. Third party harvesting of some biomass is worth considering. For instance, the harvesting window for grain corn has been relatively narrow in Ontario in some years and producers concentrate their efforts on the grain harvest. If corn stover is the feedstock for the bio-energy facility, third party harvesting of corn stover would ensure the feedstock availability. Feedstock pricing options include fixed price, variable price linked to the price of other energy sources, and combined fixed and variable price.

Managing technology risks could be critical in bio-energy industry since some technologies are relatively at infant stage. It should be noted that risks can be transferred to a third party at a cost, similar to health or auto insurance. The amount of risk taken depends on the core competencies of the organization operating the bio-energy facility. Technology risk management measures include service contracts, extended warranty, partnerships with technology providers, and participation in industry organizations which provide consulting and technology management solutions.

For managing risks in marketing and sales, understanding the needs of customers and the strength of competitors are essential. In many jurisdictions, the bio-energy sector is driven by regulatory forces and market demand. Therefore, the assessment of regulatory drivers and the estimates of market demand for the bio-energy and co-products would be prudent. Marketing and sale risk management measures include long-term sale contracts, off-take agreements, ability to pass the rising costs to customers, and lobbying efforts to ensure regulatory support for the bio-energy sector.

Chapter 7 – Summary, Conclusions and Recommendations

This study reviews alternative technologies to transform biomass into energy and co-products and examines the applications of these technologies in the agricultural sector in Ontario. The consumption of different types of energy in the Ontario agricultural sector is analyzed, and potential energy generation from agricultural biomass is estimated. The alternative technologies to transform biomass into energy and co-products are evaluated for their technical and commercial maturity and suitability for the agricultural sector in Ontario. Biomass harvesting, storage, transportation and handling activities for the bio-energy sector are also discussed. Financial spreadsheet models are developed to estimate the return on investment for the selected technologies. The status of research and development of emerging bio-energy technologies are presented. Segments of the bio-energy value chain are analysed to determine to what extent agricultural producers should participate in the bio-energy industry.

7.1 Summary of Findings and Conclusions

The agricultural sector in Ontario consumes significant amount of gasoline, diesel, and propane, heating oil, electricity and natural gas for livestock and farming activities. Total energy consumption of the Ontario agricultural sector is approximately 41,500 TJ/yr, which represents 2% of the provincial energy demand. This annual energy consumption in the Ontario agricultural sector is equivalent to 3.35 million tonnes of biomass.

Ontario farms produce over 50 million tonnes of grains, beans, and feeds and about 14 million tonnes of crop residues annually. Approximately 3 million tonnes, i.e. 20% of total produced of crop residues can be sustainably harvested annually. Additional 3 million tonne/yr of biomass can be produced by planting purpose-grown crops such as miscanthus and switchgrass, on less than 4% of agricultural lands in Ontario. There are about 1.7 million cattle in Ontario (OMAFRA statistics) and approximately 5,500 TJ/yr, i.e. 1.55 TWh or over 60% of total electricity consumed in the agricultural sector of electricity could be theoretically generated from manure biogas. Approximately 30 to 35% of grain corn grown in Ontario is currently used to produce ethanol. Ontario's agricultural sector could not only be energy self-sufficient but could also be able to provide biomass for energy use in other economic sectors.

Large-scale use of biomass for energy applications would be relatively new for Ontario agricultural producers. Activities related to field harvesting, transporting, storing and handling of biomass are investigated in this study. Specialized biomass harvesting equipment/machineries are under development although some are available commercially. In comparison to conventional raking and baling, this specialized harvesting equipment can offer better yield and quality of biomass and favourable implications to grain harvest. For instance, high density balers could increase the density of biomass bales by 25%, reducing the storage space requirement and transportation costs. Bale accumulators could offer greater efficiency in collecting and clearing biomass from the field. The lower price of natural gas in Ontario could lead to the use liquid natural gas powered trucks in transportation of biomass. There are health and safety issues in handling biomass in storage and at the bio-energy facilities. The best biomass handling practices especially from Europe should be adopted, and the industry standards need to be developed.

Alternative technologies to transform biomass into energy and co-products are evaluated using ProGrid Global Evaluator with the participations of industry experts. ProGrid Global Evaluator is a software package developed as a decision making tool and used by a number of organizations including Alberta Innovates and Ontario Centres of Excellence. The technical and commercial strengths of bio-energy technologies are evaluated. The evaluation matrix includes agricultural suitability, technology maturity, complete system availability, financing, skill labour availability, infrastructure existence, energy production, co-products, and the value chain. The evaluation suggests that the most feasible integrated bio-energy systems in Ontario at present are anaerobic digestion, direct combustion, bio-ethanol and bio-diesel productions.

The evaluation panel considers pyrolysis, gasification, torrefaction, micro turbines, and small scale energy storage as emerging technologies for agricultural bio-energy generation. Pyrolysis can produce syngas, bio-oil and bio-char from agricultural biomass. Pyrolysis could be an excellent fit to the agricultural biomass since bio-char can be utilized as fertilizer. The current areas of research and development for pyrolysis include higher acidity and instability of bio-oil, syngas cleaning, bio-oil processing, and bio-char products. Gasification of biomass mainly using wood feedstock has been in commercial operation around the world. Cleaning of gas products and emission of particulate matters are the areas of improvement for the gasification of agricultural biomass.

Torrefaction is essentially roasting of biomass to drive off moisture and volatile components and potentially produces hydrophobic and energy dense coal-like materials. Torrefaction technologies currently focus on improving product consistency, hydrophobicity and grindability and reducing mass losses. Micro turbines and small scale energy storage are relatively more mature technologies which could play an important role in bio-energy industry when the economics of bio-energy improves.

Financial spreadsheet models are developed to estimate the Return on Equity (ROE) of selected integrated bio-energy systems. The cost estimates for the financial models are based on industry data and the literature. The minimum cattle size for an on-farm AD power system is 500 dairy cows for a positive ROE at current FIT rate for electricity from biogas. The ROE of an on-farm AD power system with 1,000 dairy cows generating 400 kW of electricity is about 10%. Availability of off-farm feedstock materials could improve the financial performance of the AD systems. Generation of heat and power from biomass through direct combustion integrated with steam turbines could offer an ROE of up to 12% at the current FIT rate. The electricity generation capacity of direct combustion systems should be greater than 10 MW for a positive ROE. The economics of two emerging technologies, pyrolysis and gasification, are also investigated. The ROE of a pyrolysis plant with the raw biomass processing capacity of 165 tonnes/day is estimated at 9.1%. It should be noted that there is uncertainty in the price of bio-oil and bio-char since they are not commercially traded commodities at present. The ROE of biomass gasification plant with 15 MW electricity generation capacity is about 16%.

Approximately 30 to 35% of grain corn produced in Ontario is currently used for ethanol production, and the rest is consumed for animal feed and industrial applications. Due to the increasing price of grain corn and lower gasoline demand, the profit margin of corn ethanol is lowered. Medium to large corn ethanol plants with favourable economies of scale can operate profitably during these high price periods. At current prices of grain corn and ethanol, the ROE of a 100 million gal/yr ethanol plant is about 15%. At current grain corn production levels in Ontario, the addition of a large corn ethanol facility would create the need to import grain corn to Ontario from nearby regions. The availability of inexpensive feedstock oils for a long-term time horizon s critical in bio-diesel production. Used cooking oils and FOG are the major feedstock for bio-diesel plants in Ontario, and corn oil from ethanol plants is a potential feedstock. Soybean oil is too expensive for bio-diesel production. The ROE of a bio-diesel plant could be as high as 27%, depending on the capacity of the plant and the cost of feedstock oils.

Ontario agricultural producers could be the supplier of biomass to bio-energy facilities or can participate in the complete value chain. Two economic models are reviewed to analyse the bio-energy industry and investing options for Ontario producers. Porter's Five Forces analysis identifies the internal and external threats/competitions of an industry. The FIT rate for electricity from biomass is not very attractive in comparison to solar and wind electricity. Since the bio-energy industry is not highly profitable, the thread of new entrants is relatively low. Access to the electricity grid in Ontario is one of the major barriers for smaller energy producers such as AD power systems. For the larger bio-energy systems, the capital requirement is relatively high for individual farm producers. Ontario has significant agricultural biomass resources to be used as feedstock for generation of heat and power. In addition to the agricultural sector, forestry and municipal solid wastes can also provide a considerable volume of biomass. Therefore, the biomass suppliers in Ontario do not have a relatively high bargaining power for their feedstock for bio-energy generation. However, grain corn which is used to produce ethanol is in tight supply in Ontario.

The thread of substitutes for bio-energy sector in Ontario is significant. Biomass is not the only resource which can be used to generate heat and power. At the current low price of natural gas in Ontario, energy generation using natural gas as a feedstock is very attractive. For electricity generation from biomass, the FIT rate is determined by a government organization in Ontario. For heat generation from biomass, the bargaining power of buyers is associated with the substitutes which could be natural gas or propane or heating oil. For transportation liquid fuels from biomass, the mandatory blending rates and the demand of liquid fuels define the bargaining power of buyers. Generating heat and power from agricultural biomass in Ontario is relatively new, and the competition from the industry rivals is insignificant in comparison with other issues such as access to the electricity grid. However, the competition in corn ethanol industry can be considered as intense due to the increasing price of grain corn and the existing production capacity.

McKinsey's growth pyramid provides a basis for business diversification and investment options to be considered and is used to analyze the bio-energy industry for Ontario agricultural producers. Bio-energy generation would create new products and services, new delivery approaches, new industry structure and new competitive arenas for Ontario producers. The geographies could also be new since most markets with higher demand of energy products could be located away from the farms. Ontario producers are skilful in operating agricultural machineries, and some of those skills could be transferrable to bio-energy generation. However, the research and development of emerging bio-energy technologies is not likely the core competency of Ontario producers. Ontario producers have the privileged assets of productive lands to grow biomass feedstock. Nevertheless, the competition from forestry biomass should not be underestimated. Farm cooperatives in Ontario are managed by business professionals who could steer the growth in bio-energy industry, and Ontario producers are supported by a number of industry organizations. For bio-energy generation, Ontario producers need to develop special relationships with new organizations such as Ontario Power Authority, large energy users, and service providers for energy generation equipment.

Economies of scale are extremely important in bio-energy generation. The unit generation/production cost of a small facility could be 3 to 4 times higher than that of a large facility. There have been activities in the development of portable biomass processing and bio-energy production units in recent years. They range from portable biomass pelletizer to mobile pyrolysis unit to small biomass gasification system. Most of these portable units can process 1 to 3 tonnes/hr, or fewer than 30,000 tonnes/yr of raw biomass. In most Ontario counties, approximately 150,000 tonne/yr of biomass can be gathered within 100 km radius, suggesting 15 to 20 tonne/hr of biomass could be processed with favourable economies of scale. Extreme care should be exercised in analyzing the financial feasibility of small scale bio-energy systems. Once the profitability of a small system is proven, there will likely be new larger entrants to the industry with favourable economies of scale.

7.2 General Recommendations

Generation of heat and power and production of co-products from agricultural biomass could provide additional income and a reasonable hedging against the raising energy costs for Ontario agricultural producers. However, risks associated with bio-energy technologies must be carefully managed.

The following general recommendations are provided to OFA and its affiliates:

- Anaerobic digestion is a mature bio-energy technology at farm scale, ranging from 300 to 3,000 kW of electricity generation capacity. Ontario agricultural producers should participate in the complete value chain of AD bio-energy systems. Farm organization like OFA should lobby for better access to the electricity grid and for better premium price of energy generated from the AD systems. The environmental benefits of AD systems which reduce the emissions of greenhouse gases from manure should be highlighted.

- The direct combustion of biomass integrated with steam turbines is a mature technology to generate renewable heat and power. To be financially viable, the system should have a minimum electricity generating capacity of 10 MW, which requires a relatively large capital investment for individual agricultural producer. Competition from forestry biomass could be intense in some areas of Ontario. For the direct combustion bio-energy systems, Ontario producers could participate in feedstock supply and transportation of biomass. A partial participation in the form of taking minority stakes or joint venture with the energy producer could be possible in selected locations.

- Bio-ethanol and bio-diesel productions in Ontario will likely continue at current mandatory blend rates and the demand of liquid transportation fuels. Economies of scale would be an important factor for bio-ethanol industry, and availability of inexpensive feedstock is critical for bio-diesel industry. Participating in bio-ethanol and bio-diesel industries would provide a reasonable hedging for Ontario producers who consume considerable amounts of transportation liquid fuels in farming activities. Taking minority stakes or forming joint ventures with financially performing bio-ethanol and bio-diesel manufactures are recommended.

- Pyrolysis and gasification are emerging bio-energy technologies. More research and development are required, especially using agricultural biomass as feedstock for the commercialization of these technologies. If pyrolysis and gasification bio-energy systems are built in Ontario, agricultural producers should participate in the feedstock supply and biomass transportation of the value chain. Participation in energy production, marketing and sales of the energy and co-products would require further assessment for these technologies on a case-by-case basis. A similar approach could be employed for other emerging bio-energy technologies.

- Torrefaction development and implementation should occur at the end user site in Southern Ontario for small to medium scale applications due to relatively short transportation distance.

- Forming alliances with bio-energy industry organizations and R&D centres is recommended to monitor the development of emerging bio-energy technologies.

- Since most renewable energy receives regulatory supports, it is important to influence policy makers by highlighting the potential socio-economic benefits of responsible bio-energy production to the agricultural and rural sectors.

- The low price of natural gas and increasing electricity cost in Ontario could result in significant changes in energy consumption mix in medium to long term time frame. Further analysis is required to investigate their effects on the bio-energy industry.

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Appendix A – Opportunity Profiles of the Alternative Technologies

An important feature of ProGrid is its bar charts that show the strengths and weaknesses of each of the alternative technologies based on the assessments of the evaluators. These bar charts are called "Opportunity Profiles". In the Opportunity Profiles, the x-axis shows the criteria of the Evaluation Matrix, and the Relative Strength is shown on the y-axis. The Relative Strength of each criterion is a function of the rating assigned by the evaluators. High Language Ladder ratings from the majority of evaluators for a specific criteria result in a high Relative Strength bar for that criteria in the Opportunity Profile. A high Relative Strength indicates a strength of the technology, whereas a low Relative Strength represents a weakness.

Each figure of Appendix A presents the Opportunity Profile of an alternative technology examined in this study.

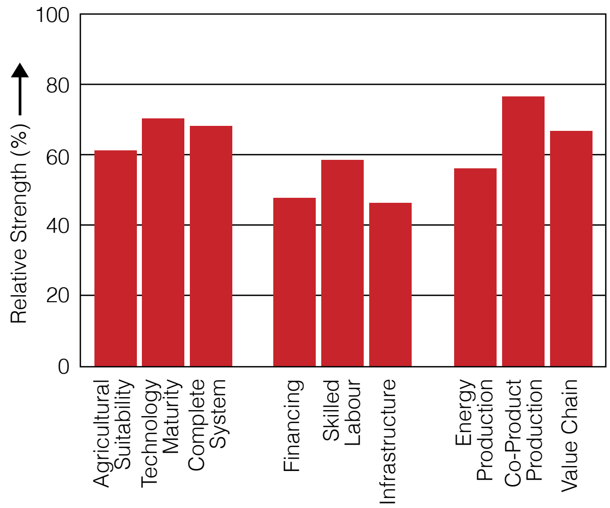

Figure A1. Opportunity Profile for Anaerobic Digestion

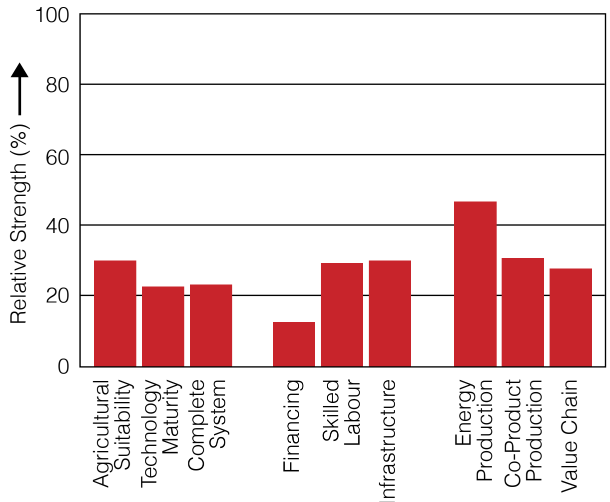

Figure A2. Opportunity Profile for Gasification

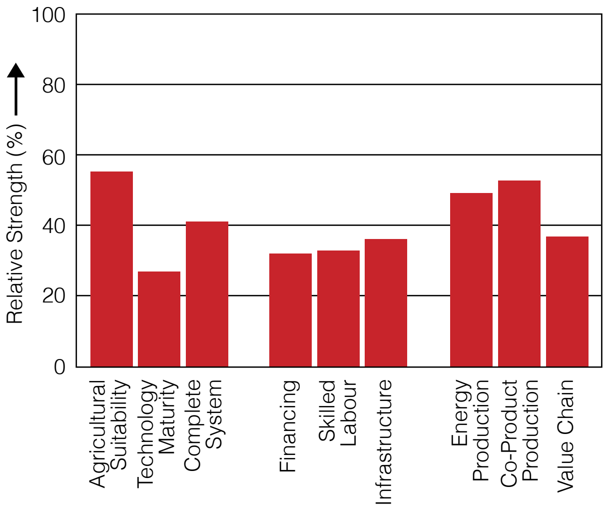

Figure A3. Opportunity Profile for Pyrolysis

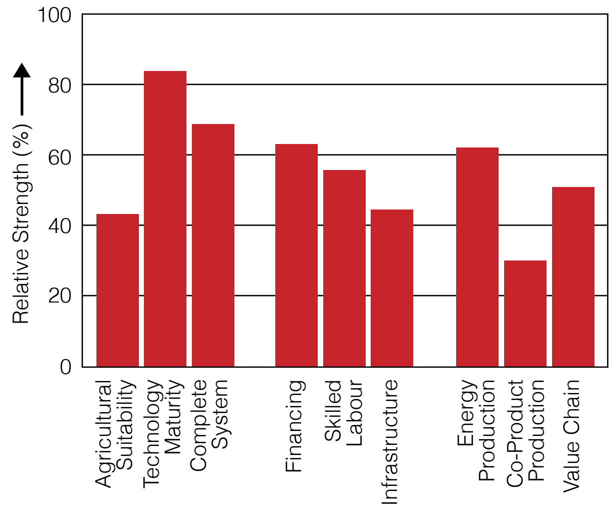

Figure A5. Opportunity Profile for Direct Combustion

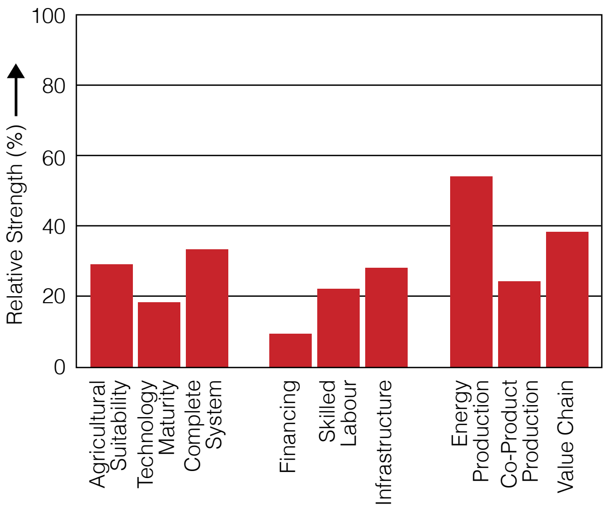

Figure A4. Opportunity Profile for Torrefaction

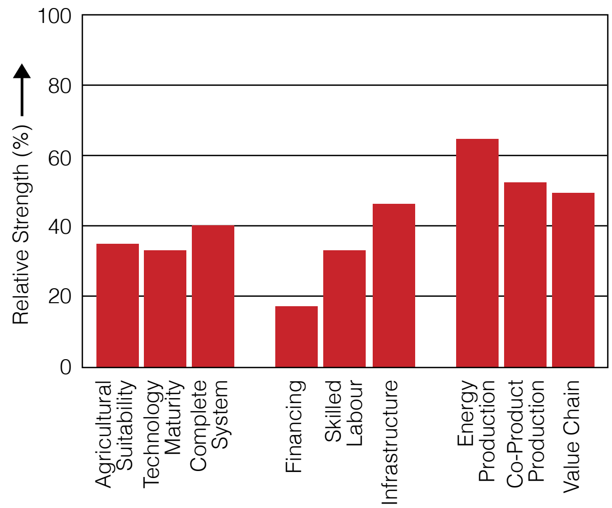

Figure A6. Opportunity Profile for Biogas to Biomethane

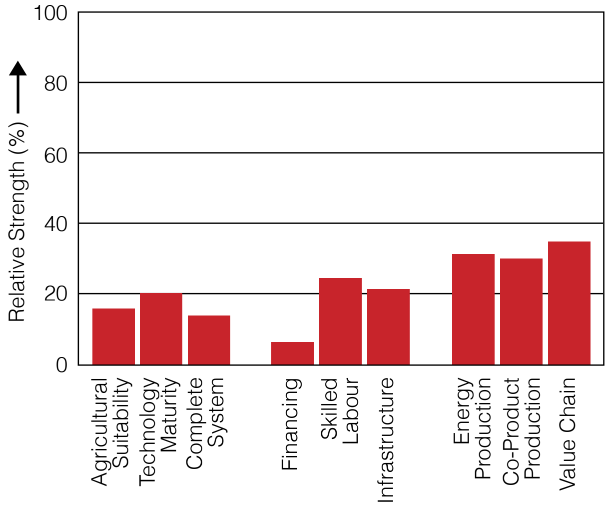

Figure A7. Opportunity Profile for Hydrogen Enriched Natural Gas

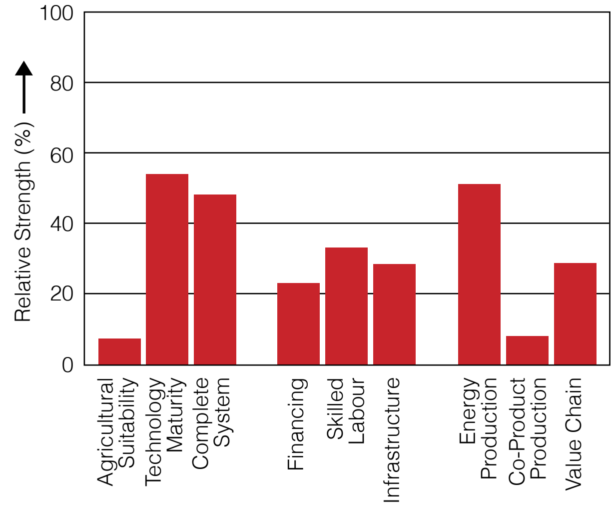

Figure A9. Opportunity Profile for Large-Scale Battery

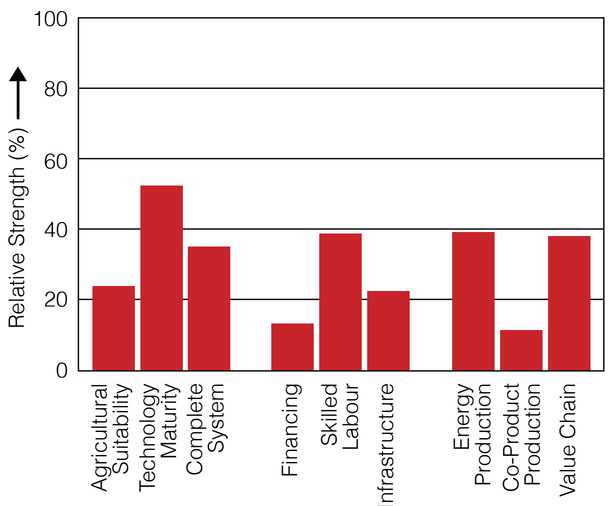

Figure A8. Opportunity Profile for Compressed Air Energy Storage

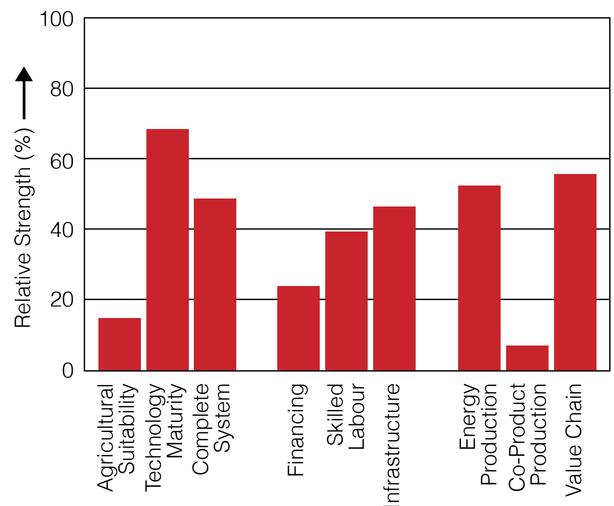

Figure A10. Opportunity Profile for Small-Scale Battery

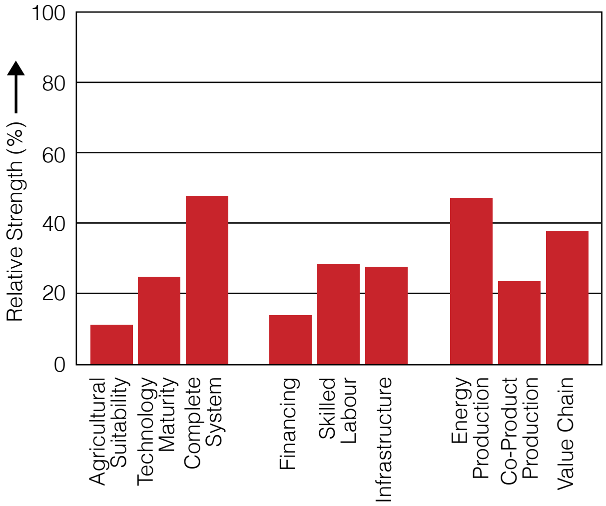

Figure A11. Opportunity Profile for Fuel Cell

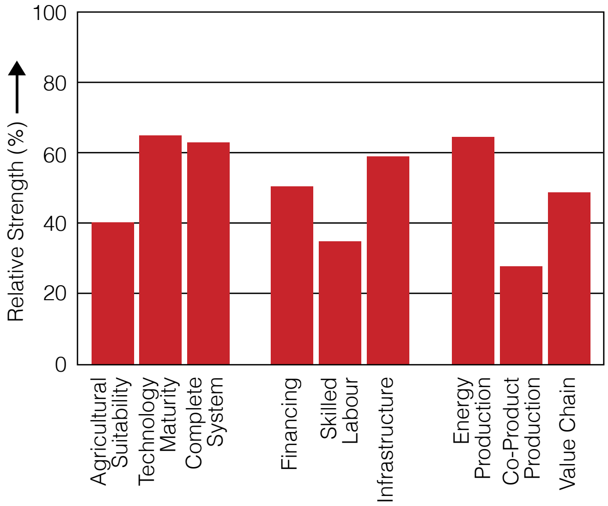

Figure A13. Opportunity Profile for Gas Turbine

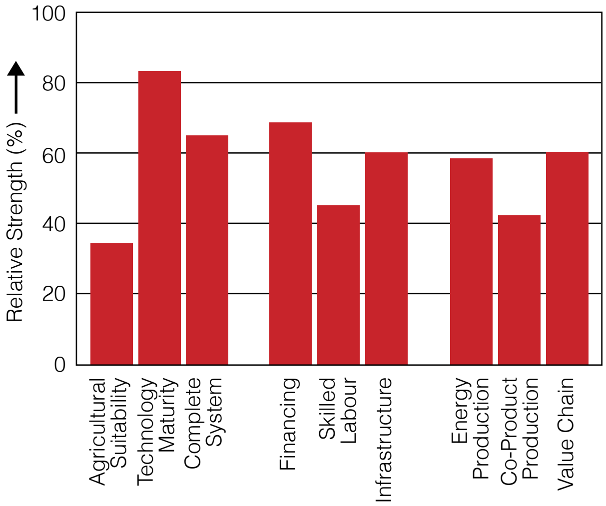

Figure A12. Opportunity Profile for Gas Fired Boiler

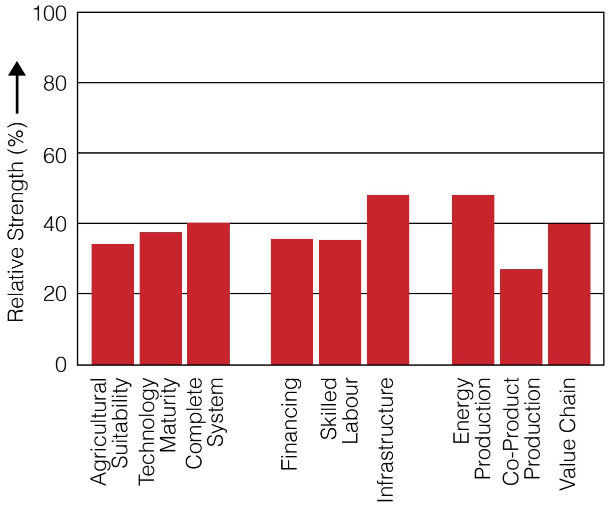

Figure A14. Opportunity Profile for Indirect Gas Fired Turbine

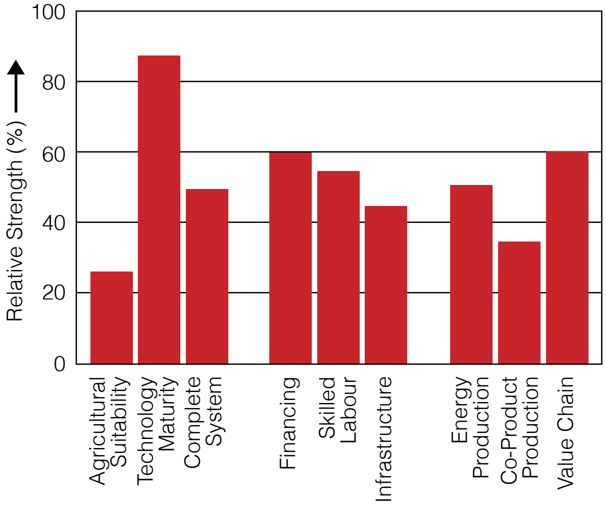

Figure A15. Opportunity Profile for Internal Combustion Engine

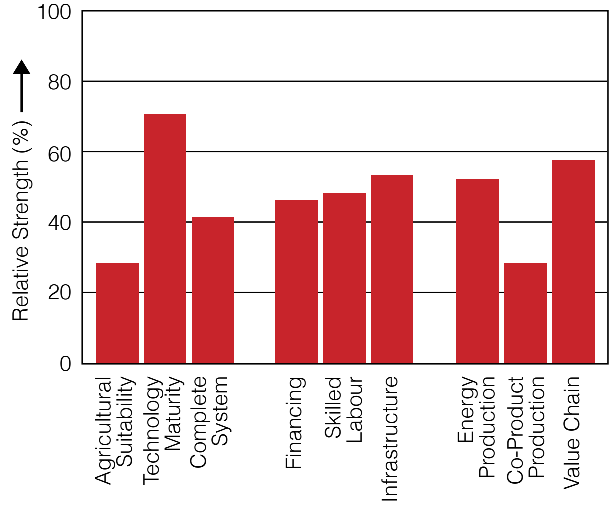

Figure A17. Opportunity Profile for Steam Engine

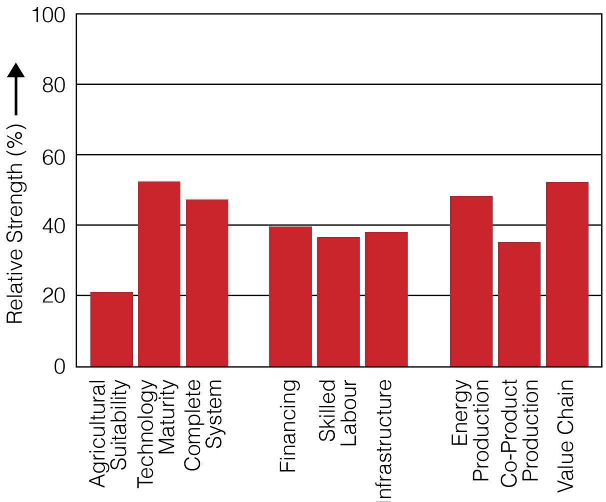

Figure A16. Opportunity Profile for Microturbine

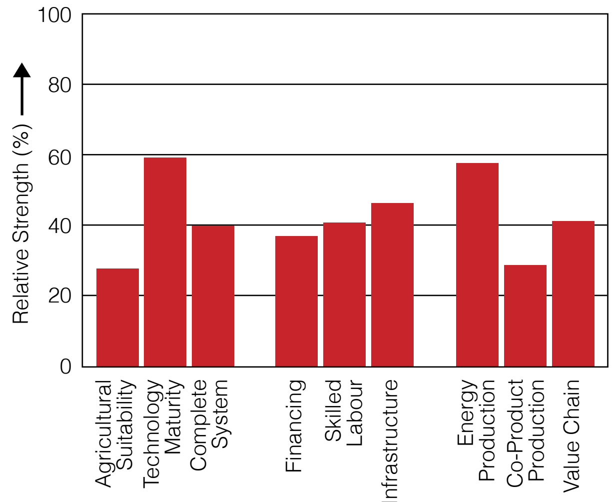

Figure A18. Opportunity Profile for Stirling Engine

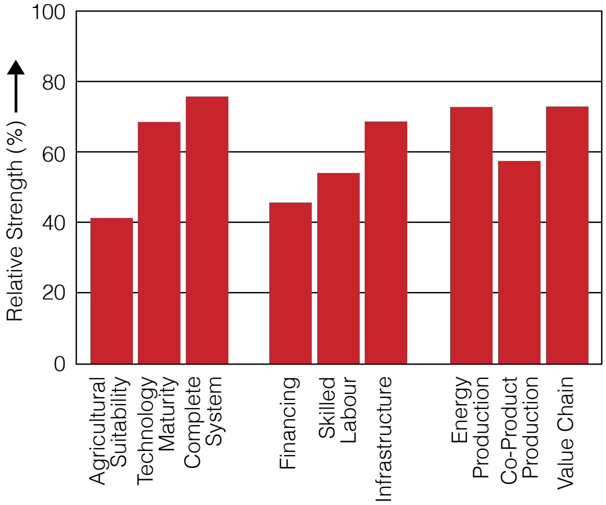

Figure A19. Opportunity Profile for Biodiesel Production

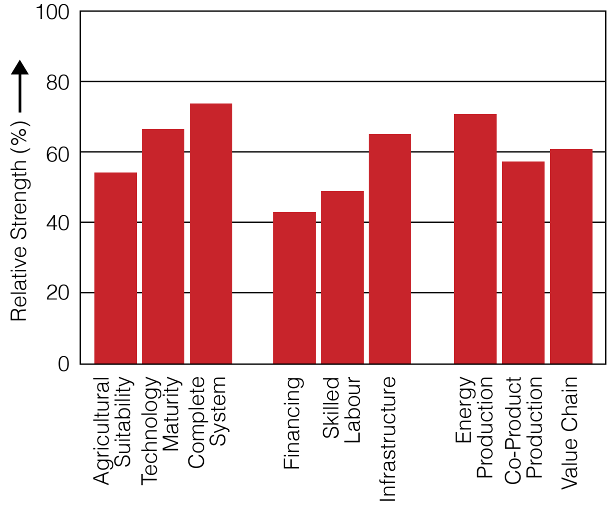

Figure A20. Opportunity Profile for Ethanol Production

Notes

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