Prospect of Biomass Utilization for Heating for Greenhouse Industry in Nova Scotia

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***Abstract* - This paper reviews the performance of existing space heating systems used in greenhouse industry in Nova Scotia, Canada and evaluates alternative options. The results of on-farm assessment of combustion efficiency and emissions of greenhouse heating appliances are also presented. Many of the furnaces were oil fired and were found to be improperly tuned, a reason for low efficiency and/or high emissions. Tuning the furnaces properly is one possible option for reducing heating cost in existing systems, however the extent to improvement is limited. Biomass has identified as another potential option for greenhouse heating and although, there are some biomass-fired (wood log, premium wood pellets, industrial grade wood pellets) furnaces in Nova Scotia greenhouses, they typically use outdated technology. A properly designed biomass pellet heating system is recommended for Nova Scotia greenhouses to reduce heating cost and greenhouse gas (GHG) emissions.**

***Index Terms* - Biomass utilization, greenhouse industry, Nova Scotia, energy cost reduction, greenhouse gas emission reduction, combustion and emission.**

I. INTRODUCTION

The greenhouse industry is an important and growing segment of the Canadian agri-food industry. However, due to increasing energy costs and reduced farm returns, there has been a renewed interest in the identification and assessment of alternative energy opportunities for this agricultural sector. Canadian greenhouse technologies have developed rapidly with the support of research institutions to overcome the climatic limitation for vegetable production [1]. Greenhouses are controlled environments which regulate heat, water, nutrients, pests and diseases creating optimal conditions for plant growth. As a result, the yield produced per unit area in greenhouses is approximately 15 to 20 times that of the equivalent field area [2]. The greenhouse industry in Canada had a total area of 21.34 million square meters and generated C$2.3 billion revenue in 2006 which is 180% more than the revenue generated by this industry in 1995 [3]. These figures demonstrate that the greenhouse industry is one of the major contributing agricultural sectors in Canada. In 2008, the total greenhouse area was 20.8 million square meters, compared with 20.9 million square meters in 2007 and 21.34 million square meters in 2006. The total greenhouse area decreased for the second year in a row. Sales of greenhouse products decreased to $2.1 billion in 2008 [4]. Total number of greenhouses in Canada was 3476 in 2007, but it is decreased to 3295 in 2008.

There are over 200 greenhouse operations of different sizes located throughout Nova Scotia [5], producing cut flowers, potted plants, bedding plants, forestry tree seedlings, fresh herbs and greenhouse vegetables such as tomatoes, lettuce, cucumbers and peppers. This represents around 0.582 million square meters of greenhouse area under glass and/or plastic, with the comparatively higher numbers of greenhouses in Nova Scotia attributed to its moderate weather conditions. However, there is a need to make greenhouses more profitable through overall cost reduction. Labor and material are the highest input cost in greenhouse industries, but cost reductions in these are very difficult. Energy is the second highest input cost in Nova Scotia greenhouses, with heating oil (#2) the primary fuel used by the sector [6]. Improving the energy efficiency of such oil-fired furnaces is an important factor that can reduce input energy costs. Regular tuning of the furnaces to adjust excess air for the highest efficiency is an easy option of reducing costs in existing systems. However, the cost reduction is not significant enough, with fluctuating heating oil prices a great concern for greenhouse owners in Nova Scotia resulting in the need to find alternative less expensive and sustainable options for heating.

The use of biomass for energy purposes provides environmental benefits compared to fossil fuels. The most notable (and well known) ones have very low or net zero emissions of greenhouse gases and SO_2. Wood, with fuel characteristics of low ash and low sulfur content allows a direct comparison with coal, oil, and gas. The cost of wood burning, which offers good heating performance, is lower than that of heating oil [7], with prices of wood residue and wood pellets typically lower and more stable than that of heating oil. Burning wood is not a new concept. In fact, this old concept is gaining new popularity in many areas with plentiful wood supplies due to its cost effectiveness, low impact on the environment and the advent of safe, convenient and long lasting wood furnaces. In 2006, Delta Research Corporation (DRC) [8] conducted a survey to investigate the status of wood residue and wood pellets heating systems in the greenhouse industry within the Greater Vancouver Regional District (GVRD) and the Fraser Valley Regional District (FVRD), Canada. The survey indicated that the price of wood pellets had been stable for the past five years and was predicted to be steady for a number of years. DRC concluded that switching to biomass as an energy source could generate savings on fuel cost. The survey also predicted that more than 12 wood burning boilers will be installed in the region within the next few years. Techno-economic analysis of wood biomass boilers for the greenhouse industry in British Columbia, Canada was conducted by Chau et al. [9]. The net present value (NPV) show that installing a wood pellet or a wood residue boiler to provide 40% of the annual heat demand is more economical than using a natural gas boiler to provide all the heat. For an assumed lifespan of 25 years, a wood pellet boiler system could generate NPV of C$259,311 without electrostatic precipitator (ESP) and C$74,695 with ESP, respectively. Using a wood biomass boiler could also eliminate over 3000 tonne CO_2 equivalents of greenhouse gases annually. The report also indicated that wood biomass combustion generates more particulate matter than natural gas combustion. However, an advanced emission control system could significantly reduce particulate emission to a relatively similar level as natural gas. Although a lower biomass fuel price can generate savings for a greenhouse, the industry has some hesitations on converting to wood burning systems because of the high capital cost and the uncertainties regarding the long term availability of wood residue or wood pellets. Therefore other forms of biomass should be considered to create sustainable pellet markets.

The use of grass as a pellet fuel is raising great interest as an alternative to wood in the pellet industry due to its lower cost and higher GHG mitigation ability [10]. The major constraint to developing grasses for bioheat applications is its difficulty for efficient combustion in conventional boilers due to high ash content, clinker formation (agglomeration) and corrosion of the boilers. Through management and breeding however, grass biomass composition can be modified to minimize ash content and clinkering components and is a topic of current research [10a, 10b]. Agitation of fuel and/or the ash bed, vibrating grate firing and combustion chamber agitation can all serve to avoid ash agglomeration.

Currently there are few companies manufacturing stoves specifically designed to burn grass pellets, but some wood pellet and corn stoves have been adapted and used to burn grass pellets [11]. A recent study in Cornell University [12] found that even the best performing pellet burning equipment (multi-fuel stoves and boilers designed for pellets and grains) must be serviced on regular intervals (usually everyday) if using grass pellets. Gonzalez [13] investigated combustion of different biomass residue pellets (tomato, olive stone and cardoon) for domestic heating and compared them with forest pellets. The efficiencies of the three residues were found similar to that of forest pellet. Although they reported high efficiency, the emission of CO was very high, as high as 5000 ppm or more in some cases. A pellet boiler was tested with four different types of pellets showing a similar thermal performance with boiler efficiencies up to 77% [14]. Olsson [15] investigated wheat straw and peat pellet combustion. The results indicated that wheat straw and peat pellets are fuels with relatively low emissions during combustion. However, wood pellets burned efficiently with even lower emissions than straw and peat pellets during flaming burning. Andreasen [16] presented straw pellet combustion and compared it with the wood pellet. Five types of straw and wood pellets made with different binders and antislag agents were tested as fuel in five different types of boilers. The tests proved that the wood pellets could be used in all the boilers tested without any operational problems. There were many other studies that dealt with biomass pellet combustion and emissions including different types of grass pellets [17-22]. The CO_2 emissions with grass pellet combustion reduced by 90% as compared to coal combustion [18] and the energy balance of grass pellets was found distinctly superior to other biofuels production route such as corn ethanol and biodiesel [20]. Spring harvested reed canary grass showed improved combustion and less ash agglomeration due to reduced concentration of elements that are undesirable in combustion, and the initial ash deformation temperature was increased [21, 22].

Observation from the literature review is that biomass, especially in pellet form as heating fuel has great potential to substitute fossil fuel cost effectively with significant GHG mitigation. The use of grass pellets in combination with wood pellets can help increase the longevity of forest wood and may even prevent price increases of limited wood supply. Grass pellet production and its use in heating appliances can also help the local community in income generating activities with active participation in global warming abatement. From literature review, Nova Scotia greenhouse visits and hands on experiment for the assessment of combustion efficiency and emissions of their heating appliances, it is understood that pellet furnace with multi-pellet compatibility (wood pellet, grass pellet, etc.) can be a proper alternative to oil heating furnaces. Greenhouse owners who are not able to change the current oil heating system due to investment cost constraint; regular proper tuning of their heating furnaces can save 2-5% of heating bill annually. As most of the pellet burners developed so far commercially are able to handle premium wood pellet or low ash content wood pellets only, there is a need to develop a furnace that can efficiently, cleanly and reliably burn pellets from grass and agricultural wastes. It is to say that there are already some biomass-fired furnaces in Nova Scotia greenhouses (wood log, premium wood pellets, industrial grade wood pellets, etc.), but they are old and not using the up to date technology. The authors presented a prototype furnace developed and patented by LST energy [23], and investigated combustion and emission performance of premium wood pellets, industrial grade wood pellets and grass pellets on the furnace [24]. Grass pellet combustion, emissions and ash sintering was compared with that of wood pellets in a prototype pellet furnace. Ash content more than 2% in grass and 1.86% in barked wood pellet (industrial grade wood pellets) was burnt without any ash agglomeration problem. Grass pellets showed a similar thermal performance to that of wood pellets with overall furnace efficiency of 73% or more. In most cases, average CO emissions under steady state conditions were less than 150 ppm, with minimum values being achieved for O_2 concentrations in the flue-gases 11.5% or higher.

II. METHODS

A review of industry technology, best practices and hands on experiments were conducted in four greenhouse operations, which are representative of the sector in Nova Scotia. The objective of the review was to identify greenhouse heating cost, technology used and attitudes and opinions of the owners towards energy efficiency and renewable energy. Table 1 contains the data obtained from the review and shows that oil heating furnaces are predominantly used in Nova Scotia greenhouses. Some are using biomass-fired furnaces (wood log, premium wood pellets, industrial grade wood pellets, etc.). It was also revealed that heating costs represent 60-80% of total energy cost. Some of the owners are using wood pellets furnaces (who used oil-fired furnaces before) and are satisfied because they are more cost effective. However, most wish to further increase efficiency of their furnaces and identify a sustainable supply of wood pellets at reasonable price. Table 2 shows heating cost comparison between wood/grass pellets and # 2 heating oil. The price of pellet fuel is only 43-52% of # 2 heating oil for the similar amount of heat energy. However, oil-fired furnace is about 10% more efficient than pellet-fired furnace. There are some other costs associated with pellet burning such as ash disposal. Still pellet burning is 30-35% less costly than oil burning [25].

Table 1: Review results of four greenhouses in Nova Scotia (NS)

Greenhouse operation	**Type of heating energy**	**Heating cost ($)/yr**	**Total energy cost ($)/yr**	**Attitude towards energy efficiency and renewable energy use**
#1	# 2 heating oil	18,000.00	22,500.00	Expect higher efficiency of existing oil-fired furnaces, and wants to invest on biomass heating system
#2	# 2 heating oil, wood	20,000.00	25,000.00	Needs higher efficiency of wood boiler
#3	Industrial grade wood pellet	30,000.00	50,000.00	Wants to add another pellet boiler to replace oil-fired boiler
#4	Premium grade wood pellet	35,000.00	50,000.00	Wants to increase pellet furnace efficiency further, and to minimize ash sintering problem

Table 2: Heating cost comparison between pellet fuels and # 2 heating oil

Fuel type	**Price (in $)/GJ [25]**
Grass pellet	9
Premium grade wood pellet	11
Industrial grade wood pellet	10
# 2 heating oil	21

On-farm hands on experiment for the assessment of combustion efficiency and emissions of greenhouse heating appliances are also performed using Unigas 3000$^+$ flue gas analyzer. Proper tuning of the boilers/furnaces has also been done to improve the combustion efficiency of the system. The Unigas 3000$^+$ is a multi-functional flue gas analyzer. Electrochemical sensors are used for the measurement of O_2, CO, NO and SO_2. The CO_2 and NOx are calculated. In addition, the air inlet or ambient temperature and flue gas temperature are measured. Using the measured temperatures, gas concentrations and the known fuel parameters the analyzer calculates a variety of combustion parameters such as Stack Loss/chimney loss - S_L, Efficiency - η, Excess air - λ, etc. Based on the calculated chimney loss the analyzer estimates the efficiency of the combustion process η.

$$\eta = 100\% - S_L$$

where: η - combustion efficiency

The above formula assumes that the only quantity decreasing combustion efficiency is chimney loss. Thus it omits incomplete combustion losses, radiation losses etc. Because of this gross simplification in the formula above it should be remembered that the efficiency calculated in this way cannot be treated as precise. However, efficiency calculated like this is very convenient as a comparable parameter when tuning the furnace. The formula, though simplified, reflects precisely the tendencies of efficiency change, thus it is possible to observe whether the efficiency increases or decreases. It is sufficient information for the tuning process. The main purpose of the tuning was to improve the efficiency, so that the fuel cost is reduced. However, we also focused our attention to the emissions to prevent any significant increase after the tuning process.

III. ON-FARM HANDS ON EXPERIMENT

Table 3 to 6 show combustion efficiency and emissions data of different greenhouse furnaces before and after the tuning. Table 3 shows combustion and emission data of different furnaces of operation #1 before and after tuning. Operation #1 had six oil-fired furnaces, three of which were well-tuned. The other three had to be tuned to improve efficiency and/or emissions. Typical excess air for oil-fired furnace is 5-20%, and <100 ppm of stack CO emissions is recommended. Table 3 shows that excess air, before tuning, was about 58-271%, especially the third furnace which had very high excess air which makes combustion efficiency only about 49%. After tuning, the excess air was reduced to 28-56% levels, and the third furnace showed a significant efficiency improvement to about 80%. In general, combustion efficiency was increased 2.4-28.6 points (3.06-58.01%). This demonstrates the importance of tuning as a vital option to maintain the efficiency to manufacturers' level (75-85% usually). The emissions of CO and SO_2 are found very low before or after tuning and the NOx was also found less than 100 ppm.

Table 4 shows combustion and emission data of different furnaces of greenhouse operation #2, before and after tuning. Greenhouse operation #2 had six oil-fired and one log wood-fired furnaces. Three oil-fired furnaces were well-tuned. The remaining three oil-fired furnaces were tuned. The excess air was about 2-74%, notably the third furnace had lower excess air than required, which produces 286 ppm of CO emissions. Excess air was controlled to about 12-36%. Combustion efficiency of oil-fired furnaces was increased 1.68-15.42% by proper tuning the furnaces. The third furnace emitted much higher CO and that was tuned, resulting in a reduction of 98% CO. This greenhouse operation also had an old log wood furnace. It had no intake air controlling system (just on and off options), and we were not able to tune this furnace. Therefore, when the furnace runs at low load condition (high excess air), the combustion efficiency becomes low (62%), most of the heat goes out through the chimney, and at full load operation (low excess air) there is unacceptable level of CO emissions (over 4000 ppm).

Table 5 shows combustion and emission data of greenhouse, operation #3 before and after tuning. Greenhouse operation #3 had one wood pellet-fired furnace. Typical excess air for wood-fired furnace is 20-60%, and usually emits much higher stack CO than oil-fired furnaces. This furnace had excess air of 143% before tuning and CO emission was approximately 2200 ppm. After tuning, the excess air was 125% and the CO reduced to 1170 ppm. Here combustion efficiency was increased by 1.44% and CO was reduced by 46.75%.

Table 6 shows combustion and emission data of greenhouse operation #4, before and after tuning. This operation had one wood pellet-fired furnace. Before tuning, its excess air was about 62%. We reduced it to about 57% and there was 1.32% increase in combustion efficiency after tuning. There was no significant change in emissions before and after tuning.

Table 3: Combustion and emission data of different furnaces of greenhouse operation #1 before and after tuning

Before tuning									
Furnace type/No.	**O_2 (%)**	**Excess air (%)**	**CO_2 (%)**	**Flue gas temp. (˚C)**	**Air temp. (˚C)**	**Comb. eff. (%)**	**CO (ppm)**	**NOx (ppm)**	**SO_2 (ppm)**
Oil-fired, No. 1	8.2	66.16	9.5	362.4	22.8	74.7	7	67	3
Oil-fired, No. 2	8	57.88	9.7	307.8	30.9	78.5	2	58	8
Oil-fired, No. 3	15.6	271.26	4	387.4	25.2	49.3	0	22	3

After tuning									
Furnace type/No.	**O_2 (%)**	**Excess air (%)**	**CO_2 (%)**	**Flue gas temp. (˚C)**	**Air temp. (˚C)**	**Comb. eff. (%)**	**CO (ppm)**	**NOx (ppm)**	**SO_2 (ppm)**
Oil-fired, No. 1	6.5	41.53	10.9	345.2	24.8	77.8	1	80	4
Oil-fired, No. 2	7.9	56	9.8	285.1	28.9	80.9	5	61	26
Oil-fired, No. 3	4.9	28.73	12	374.7	27.7	77.9	20	80	4

Efficiency and/or emission improvement	
Furnace type/No.	**Efficiency improvement**
Oil-fired, No. 1	3.1 points (4.15 %) eff. Increase
Oil-fired, No. 2	2.4 points (3.06 %) eff. Increase
Oil-fired, No. 3	28.6 points (58.01 %) eff.. increase

Table 4: Combustion and emission data of different furnaces of greenhouse operation #2 before and after tuning

Before tuning									
Furnace type/No.	**O_2 (%)**	**Excess air (%)**	**CO_2 (%)**	**Flue gas temp. (˚C)**	**Air temp. (˚C)**	**Comb. eff. (%)**	**CO (ppm)**	**NOx (ppm)**	**SO_2 (ppm)**
Oil-fired, No. 1	7.8	54.84	9.9	329.9	23.7	77.2	34	48	2
Oil-fired, No. 2	8.4	74.29	9.4	342.6	23.5	72	41	47	2
Oil-fired, No. 3	0.5	2.2	15.3	166.6	24.8	88.6	286	82	3
Log wood, low load	18.2	634.1	2.7	128.2	19.2	62	2331	5	0
Log wood, full load	4.8	28.65	15.7	515.5	22.8	68.5	Over 4000	35	0

After tuning									
Furnace type/No.	**O_2 (%)**	**Excess air (%)**	**CO_2 (%)**	**Flue gas temp. (˚C)**	**Air temp. (˚C)**	**Comb. eff. (%)**	**CO (ppm)**	**NOx (ppm)**	**SO_2 (ppm)**
Oil-fired, No. 1	5.9	36.27	11.3	340.4	23.6	78.5	32	52	3
Oil-fired, No. 2	3.2	17.8	14	195.2	23.2	83.1	0	89	4
Oil-fired, No. 3	2.4	12.21	13.9	184.1	25.7	87.1	4	91	4
Log wood, low load	No tuning was possible, because there was no intake air controlling system (only on and off options).								
Log wood, full load									

Efficiency and/or emission improvement	
Furnace type/No.	**Efficiency improvement/ CO reduction**
Oil-fired, No. 1	1.3 points (1.68 %) eff. Increase
Oil-fired, No. 2	11.1 points (15.42 %) eff.. increase
Oil-fired, No. 3	282 ppm (98.6 %) CO decrease

Table 5: Combustion and emission data of greenhouse operation #3 before and after tuning

Before tuning

Furnace type	O_2 (%)	Excess air (%)	CO_2 (%)	Flue gas temp. (˚C)	Air temp. (˚C)	Comb. eff. (%)	CO (ppm)	NOx (ppm)	SO_2 (ppm)
Industrial grade wood pellet-fired	12.5	143.02	8.2	175.2	14.6	76.5	2197	69	0

After tuning									
Furnace type	**O_2 (%)**	**Excess air (%)**	**CO_2 (%)**	**Flue gas temp. (˚C)**	**Air temp. (˚C)**	**Comb. eff. (%)**	**CO (ppm)**	**NOx (ppm)**	**SO_2 (ppm)**
Industrial grade wood pellet-fired	11.8	125.06	8.9	174.1	14.5	77.6	1170	70	0

Efficiency and/or emission improvement	
Furnace type	**Efficiency improvement/ CO reduction**
Industrial grade wood pellet-fired	1.1 points (1.44 %) eff. increase, 46.75% CO reduction

Table 6: Combustion and emission data of greenhouse operation #4 before and after tuning

Before tuning									
Furnace type	**O_2 (%)**	**Excess air (%)**	**CO_2 (%)**	**Flue gas temp. (˚C)**	**Air temp. (˚C)**	**Comb. eff. (%)**	**CO (ppm)**	**NOx (ppm)**	**SO_2 (ppm)**
Premium wood pellet-fired	8.2	62.34	12.4	266.5	15.5	76	1010	46	2

After tuning									
Furnace type	**O_2 (%)**	**Excess air (%)**	**CO_2 (%)**	**Flue gas temp. (˚C)**	**Air temp. (˚C)**	**Comb. eff. (%)**	**CO (ppm)**	**NOx (ppm)**	**SO_2 (ppm)**
Premium wood pellet-fired	7.7	56.84	12.9	259.3	18.7	77	1061	51	15

Efficiency and/or emission improvement	
Furnace type	**Efficiency improvement**
Industrial grade wood pellet-fired	1 point (1.32 %) eff. increase

IV. CONCLUSIONS

From the review of energy use for heating for greenhouse industry in Nova Scotia, Canada and on-farm hands on experiment for the assessment of combustion efficiency and emissions of greenhouse heating appliances, the following conclusions are drawn. It was known from the review that oil heating furnaces are predominantly used in Nova Scotia greenhouses. It was also revealed that heating cost is 60-80% of total energy costs. Many of the furnaces were found to be improperly tuned resulting in low efficiency. By tuning the furnaces properly, 2-5% combustion efficiency in the existing system was increased. Although, there are some biomass-fired (wood log, premium wood pellets, industrial grade wood pellets) furnaces in Nova Scotia greenhouses, they typically use outdated technology. In some cases, they lack proper air controlling system, which causes significant efficiency losses when the furnace runs at low load conditions. On the other hand, the furnace produces unacceptable amounts of CO and other emissions in the case of full load operation. A properly designed multi-pellet fuel compatible heating system can be a solution for Nova Scotia greenhouses to reduce heating cost and greenhouse gas emissions.

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