Impact of biofuel production on water demand in Alberta

Shikhar Singh[1], Amit Kumar[1]* and Siddharth Jain[1]

[1]*Department of Mechanical Engineering, University of Alberta, Edmonton, AB, T6G 2G8 Canada*
*Email: amit.kumar@ualberta.ca
http://dx.doi.org/10.7451/CBE.2014.56.8.11
Received: 2014 August 30, Accepted: 2014 September 18, Published: 2015 January 26.

Singh, S., A. Kumar and S. Jain. 2014. **Impact of biofuel production on water demand in Alberta.** Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **56**: 8.11-8.22. The production of biofuels (e.g., ethanol and biodiesel) requires a significant amount of water during feedstock production, transportation, and its conversion into biofuels. Therefore present study devoted to study the impact of biofuel production on water demand in Alberta. In scenario #1, it is assumed that ethanol is produced from both wheat and wheat straw and that biodiesel is produced from rapeseed. Scenario #2 proposes ethanol production from wheat only and biodiesel production from rapeseed. The water requirements for biofuel production in both scenarios are calculated for Alberta for the year 2025. Data on the current availability of water in Alberta indicate that the Athabasca, North Saskatchewan, and Peace River basins of northern Alberta have enough water to grow crops for the production of biofuels. In 2025, Alberta will have to produce 3,754 million liters of ethanol and 270 million liters of biodiesel to meet the projected levels. If biofuels are produced from the crops grown in the above-mentioned northern river basins, the province of Alberta should be able to meet biofuel demand in 2025 sustainably. The water requirement from these river basins for biofuel production will increase to 5.2%, 0.6%, and 11.6%, respectively, of the natural flow in scenario #1 whereas, for scenario #2, the water requirement from these rivers basins will increase to 5.2%, 2.3%, and 16.1%, respectively, of natural flow. These increases in the requirements are much lower than the possible allowed withdrawal levels. ***Keywords:*** Biofuel, ethanol, biodiesel, Alberta, water requirement, wheat, canola, lignocellulosic biomass.

Produire des biocarburants (c.-à-d. éthanol et biodiesel) nécessite une quantité importante d'eau durant la culture de la matière première, le transport de celle-ci et sa transformation en biocarburants. Par conséquent, cette étude est consacrée à l'évaluation de l'impact de la production des biocarburants sur la demande en eau en Alberta. Dans le scénario n° 1, l'hypothèse étudiée était que l'éthanol produit provenait de blé et de paille de blé et, que la production biodiesel était faite à partir du colza (huile de canola). Quant au scénario n° 2, seulement du blé était utilisé pour la production d'éthanol et seulement du colza pour le biodiesel. La demande en eau pour produire du biocarburant dans les deux scénarios était calculée pour l'Alberta et pour l'an 2025. Les données disponibles actuellement sur la disponibilité de l'eau en Alberta indiquent que les bassins versants du nord de la province soient de l'Athabasca, de la Saskatchewan Nord et de la rivière de la Paix ont assez d'eau pour les cultures nécessaires à la production de biocarburant. En 2025, l'Alberta devra produire 3 754 millions de litres d'éthanol et 270 millions de litres de biodiesel pour satisfaire les besoins projetés. Si les biocarburants sont produits en utilisant les cultures qui proviennent des bassins versants mentionnés précédemment, la province de l'Alberta devrait pouvoir subvenir de manière durable à la demande en 2025. Pour le scénario n° 1, la production de biocarburants augmenterait les demandes en eau sur le débit naturel de chacun des bassins versants de 5,2 %, 0,6 % et 11,6 % respectivement. Pour ce qui est du scénario n° 2, ces augmentations seraient de 5,2 %, 2,3 % et 16,1 % respectivement. Ces accroissements en demandes sont de beaucoup inférieures au niveau de prélèvements permis. **Mots clés**: biocarburant, éthanol, biodiesel, Alberta, demande en eau, blé, canola, biomasse lignocellulosique.

INTRODUCTION

Biofuel production is increasing worldwide because biofuel is considered nearly carbon neutral. The United States, Brazil, and the European Union have made substantial progress in the use of biofuels in the last decade. In 2006, these countries together accounted for 75% of the world's total biofuel production (Varghese 2007). Canada, which has also made progress in biofuel production, operates bioethanol and biodiesel production plants on a commercial scale, but these plants produce less than 1% of the total fuel used in Canada (Klein and Roy 2009). An earlier study projected that in a most optimistic scenario bioethanol will replace 10% of the gasoline used and biodiesel will replace 2% of the diesel used by 2030 (NEB 2009).

Currently, corn and soybean are the major feedstocks used in the production of bioethanol and biodiesel, respectively, in the US. Sugarcane is the main feedstock for bioethanol production in Brazil (Bergmann et al., 2013). Wheat and rapeseed are the major feedstocks for bioethanol and biodiesel production, respectively, in Canada, where these crops are grown extensively (Baron 2009; Li et al., 2012). The use of these food crops for energy production competes with their use as food. There is growing interest in producing cellulosic bioethanol using feedstocks such as agricultural residues and corn stover. The technologies for the production of bioethanol from agricultural residues are at various stages of development, demonstration, and commercialization. There are a number of research efforts being made to facilitate the development of cellulosic bioethanol by reducing its capital and operating costs (GAO 2007).

Canada's Prairie Provinces (Manitoba, Saskatchewan, and Alberta) are considered as an agricultural hub. About 91% of Canadian wheat production and 99% of Canadian rapeseed production come from these three western provinces (CANSIM 2009). These figures suggest that there is significant potential for the growth of the biofuel industry in Western Canada.

Alberta is one of the key Prairie Provinces. This study focuses on Alberta-based biofuel industries. Currently, the commercial production of bioethanol and biodiesel in Alberta is in the preliminary stage. There is only one bioethanol production facility in the province. Situated in Red Deer and using wheat as feedstock, it has a production capacity of 28 million liters per year and an expansion capacity of up to 40 million liters per year (Racz 2007).

The technology for producing cellulosic ethanol is not yet fully developed, but the demand for biofuels is growing. It is expected that grain and oil seed based plants will lead biofuel production in Alberta. Biofuels, especially grain and seed based, are water intensive, as discussed in an earlier study by the first author (Singh 2009). The growth in biofuel industry would increase the local water demand significantly. Present study investigated the impact of increased biofuel production on water demand in context to Alberta. This study also tried to answer the question: is Alberta ready to produce wheat and rapeseed based biofuels as projected (NEB 2009) As Alberta's water supply is already under stress in many regions, it is imperative to know how much water will be required in future for biofuel production in Alberta. This study helps in understanding the issues at stake.

Compared to other parts of Canada, Alberta has a dry climate. Alberta covers about 7% of the country's total land area but has only 2% of Canada's water supply (Alberta Environment 2009). The Alberta government caps water allocation in southern Alberta, where most of the crops are produced. There is limited availability of water for irrigation of further crop production (Alberta Environment 2007).

This study is based on the assumption that the cereal crops currently grown will be used for food only and additional crops will be grown to meet the demand for biofuels. This study projects the water demand for biofuel production in Alberta for 2025. This study also estimates the arable land available in Alberta for biofuel production.

Crop, land, and water requirements for biofuel production in Alberta (Scenario #1)

In this scenario, it is assumed that ethanol is produced with wheat and wheat straw and biodiesel with rapeseed. The ethanol yield from wheat and wheat straw and biodiesel yield from rapeseed were taken from an earlier study by Singh and Kumar (2011). From which it is considered that 3.61 kg of wheat per kg of ethanol, 3.90 kg of wheat straw per kg of ethanol and 2.53 kg of rapeseed per kg of biodiesel is needed. In this study, it is assumed that current levels of wheat and rapeseed production will be used for food only and that feedstock intended for biofuel production will be grown separately. The wheat straw requirement in 2025 would be 4979 million kg, which is lower than current levels (5490 million kg); therefore, it is considered that the current production level of wheat straw is able to meet the cellulosic ethanol demand in 2025.

On the basis of the last 8 years' average crop yields of 2,738 kg of wheat per hectare (CANSIM 2009) and 1,763 kg of rapeseed per hectare (CANSIM 2009) in Alberta, the arable land requirements for both feedstocks were calculated.

The river basin with the lowest irrigation requirement is given priority to grow the crops. On this basis, the Athabasca River Basin land is selected first, followed by the North Saskatchewan River Basin land. The available arable land in these two river basins is sufficient to meet the biofuel requirement in 2025.

In the Athabasca region, the irrigation requirement is 40 mm and 50 mm for wheat and rapeseed, respectively (Wright 2007a; Wright 2007b). In the North Saskatchewan River Basin, the irrigation requirement is 50 mm and 60 mm for wheat and rapeseed, respectively (Wright 2007a; Wright 2007b).

In Alberta, irrigation water is applied with an irrigation efficiency of 71% and transferred from river to fields with seepage losses of 2.5% and evaporation losses of 4% (AIPA, 2006). Thus, the total water withdrawn from the river is crop water requirement plus losses. Water consumption for scenario #1 is reported in Table 1.

The conversion stage water requirement for all three pathways is considered as industrial water requirement. Water requirements to produce 1 liter of ethanol from wheat and wheat straw in the conversion stages are 4.9 and 6.2 liters, respectively (Singh and Kumar 2011). The water requirement to produce 1 liter of biodiesel from rapeseed is 0.7 liter. Thus, total conversion water requirements are calculated and divided between the Athabasca and North Saskatchewan river basins in the ratio of land requirements for biofuel production. As cellulosic ethanol production mainly would be in central Alberta, the water requirement of cellulosic ethanol at the production stage is equally divided between the South Saskatchewan and Red Deer river basins.

Crop, land, and water requirements for biofuel production in Alberta (Scenario #2)

Table 2 gives the details of water consumption for scenario #2. In this scenario, it is assumed that a cellulosic ethanol plant will not be fully developed and that ethanol will be produced using wheat only till 2025. Biodiesel will be produced using rapeseed. The wheat and rapeseed required to produce ethanol and biodiesel, respectively, were calculated using yields from the respective processes as discussed in scenario #1.

The total land required to produce wheat and rapeseed using respective crop yields as discussed in scenario #1 was calculated. In this scenario, arable land available in the Athabasca and North Saskatchewan River Basins are not enough to produce the required quantity; therefore, arable land in the Peace River Basin is included in the calculations. In the Peace River Basin, 90 and 80 mm of water are required to produce wheat and rapeseed,

Table 1. Crop, land, and water requirement for biofuel production in Alberta for Scenario #1

Resource requirements		2005	2010	2015	2020	2025
Biofuels demand (million liters)	Ethanol from wheat	0	526	769	769	769
	Ethanol from straw	0	0	149	444	583
	Biodiesel	0	128	183	240	270
Crop requirements (million kg)	Wheat	0	1499	2190	2190	2190
	Wheat straw	0	0	1269	3799	4979
	Rapeseed	0	274	392	517	581
Land requirement by crop (km^2)	Wheat	0	5475	7998	7998	7998
	Rapeseed	0	1556	2227	2933	3298
Land requirement by river (km^2)	Athabasca	0	5631	5631	5631	5631
	North Saskatchewan		1400	4594	5300	5665
Agricultural water requirement (dam^3)	Athabasca	0	339294	339294	339294	339294
	North Saskatchewan	0	126546	415205	479023	511984
Industrial water requirement by feedstock (dam^3)	Ethanol from wheat	0	2558	3727	3737	3737
	Ethanol from straw	0	0	921	2756	3613
	Biodiesel	0	93	133	176	198
Industrial water requirement by river basin (dam^3)	Athabasca	0	2123	2131	2015	1961
	North Saskatchewan	0	528	1739	1897	1973
	South Saskatchewan	0	0	460	1378	1806
	Red Deer	0	0	460	1378	1806

Table 2. Crop, land, and water requirements for biofuel production in Alberta for Scenario #2

Resource requirements		2005	2010	2015	2020	2025
Biofuel demand (million liters)	Ethanol	0	526	917	1213	1351
	Biodiesel	0	43	62	82	92
Crop production (million kg)	Wheat	0	1499	2613	3456	3849
	Rapeseed	0	274	392	517	581
Land requirement by crop (km^2)	Wheat	0	5475	9543	12622	14058
	Rapeseed	0	1556	2227	2933	3298
Land requirement by river basin (km^2)	Athabasca	0	5631	5631	5631	5631
	North Saskatchewan	0	1400	6139	8942	8942
	Peace	0	0	0	982	2783
Agricultural water requirement (dam^3)	Athabasca	0	339294	339294	339294	339294
	North Saskatchewan	0	126546	554831	808195	808195
	Peace	0	0	0	133113	377291
Industrial water requirement by feedstock (dam^3)	Wheat	0	2558	4458	5897	6568
	Rapeseed	0	93	133	176	198
Industrial water requirement by river basin (dam^3)	Athabasca	0	2123	2197	2198	2195
	North Saskatchewan	0	528	2395	3491	3486
	Peace	0	0	0	383	1085

Table 3. Biofuel demand in Canada

Year	Canadian biofuel requirement[a] (million liters)		Alberta biofuel production share (Scenario #1)[b] (million liters)			Alberta biofuel production share (Scenario #2)[c] (million liters)		
	Bioethanol	Biodiesel	Grain-based ethanol	Straw-based ethanol	Biodiesel	Grain-based ethanol	Straw-based ethanol	Biodiesel
2005	0	0	0	0	0	0	0	0
2010	1,462	128	526	0	43	526	0	43
2015	2,548	183	769	148	62	917	0	62
2020	3,370	240	769	444	82	1,213	0	82
2025	3,754	270	769	582	92	1,351	0	92

[a] Source : NEB (2009).
[b] Scenario # 1 is discussed below.
[c] Scenario # 2 is discussed below.

respectively (Wright 2007a; Wright 2007b). The industrial water requirement is calculated as discussed in scenario #1 and divided among the three river basins in the ratio of arable land used for the production of these crops.

Bioethanol and biodiesel demand projection in Canada

Currently, Canada produces 578 million liters of ethanol (Klein and Roy 2009) and 79 million liters of biodiesel annually (Dietrich 2009). The Canadian government plans to increase the share of biofuels in gasoline and diesel. Environment Canada intends to implement a federal regulation under the Canadian Environment Protection Act, 1999 (Environment Canada 2006). Under this regulation, the gasoline sold by producers and importers will contain no less than 5% bioethanol by volume (Environment Canada 2006). It is expected that this regulation will be implemented in 2010. In addition, Environment Canada will require 2% biodiesel in diesel fuel and heating oil by 2012 (Environment Canada 2006).

The projected demand for bioethanol and biodiesel over 25 years is shown in Table 3 (NEB 2009). These are very optimistic projections, based on the objective to balance economic, environmental, and energy requirements of the future.

In the most optimistic scenario, it is assumed that there will be only 0.2% growth in energy demand in the transportation sector in Canada, which is much lower than past growth due to efficiency improvement, behavioral changes, and slower economic growth (NEB 2009).

The technology for the production of grain-based ethanol is already commercialized, so grain based technology will take the lead in ethanol production. In later years, ethanol production based on lignocellulosic technology will start in Canada. About 5% (by volume) of 2030 gasoline demand will be met by grain based ethanol technology and 5% (by volume) will be met by lignocellulose-based ethanol technology (NEB 2009). The projected demand of biodiesel is 2% (by volume) of the total diesel use in Canada by 2030 (NEB 2009).

Selection of biomass feedstocks for biofuels production in Alberta

In Canada, wheat is the main feedstock for ethanol production (Racz 2007). In the future, corn, wood, or energy crops such as switchgrass may meet a small percentage of the ethanol requirement. In this study, ethanol produced from wheat and wheat straw is considered.

Among the varieties of wheat grown in Canada, the most popular is spring wheat, which is high in starch and yields 25% more than other varieties. These qualities make spring wheat the most suitable wheat for ethanol production (Racz 2007). At present, 36% of Canada's spring wheat is grown in Alberta (CANSIM 2009). Some new varieties of wheat are being developed that could provide higher yields.

Rapeseed, which contains 42% oil by weight, is a preferred feedstock for biodiesel production (Canada Canola Council 2006). Currently, 34% of Canadian rapeseed is produced in Alberta (CANSIM 2009).

Another biomass feedstock, one that is likely to be central to the bioethanol industry in the future, is lignocellulosic biomass, i.e., agricultural residues and wood. At present, the cost of ethanol produced from lignocellulosic biomass is $2.07 per gallon (Osborne 2007) due to high capital and operational costs. The Department of Energy (DOE) has set a target to reduce the cost of production to $1.07 per gallon by 2012 to make this fuel cost competitive (GAO 2007). It is expected that this technology will start contributing significantly to Alberta's biofuel production in 8 to 10 years (Racz 2007).

Alberta's share in meeting the demand for Canada's bioethanol and biodiesel (Scenario #1)

In this study, it is assumed that Alberta will produce biofuels to meet its demand in Canada in proportion to the production level of wheat and rapeseed grown in Alberta, i.e. Ethanol production in Alberta will be 36% of Canada's ethanol production and biodiesel production in Alberta will be 34% of Canada's biodiesel production.

In scenario #1, it is assumed that by 2015 production of wheat-based ethanol will reach 769 million liters (5% of the 2030 gasoline demand), due to an increasing demand for ethanol and delays in lignocellulosic feedstock based ethanol production technology. It is assumed that commercial scale production of lignocellulosic ethanol will start after 2012 (the target of the Department of

Table 4. Average precipitation (1 May to 31 August), spring soil moisture, and irrigation for wheat and rapeseed crops in Alberta by river basin over 30 years (1971-2000)

River basin	Precipitation (mm)	Available Soil Moisture[d] (mm)	Irrigation requirement (mm) Wheat crop	Rapeseed
Milk	200	75	165	155
Oldman	240	100	100	90
Bow	275	90	75	65
South Saskatchewan	200	75	165	155
Red Deer	250	60	130	120
Battle[a]	250	50	140	130
North Saskatchewan	290	90	60	50
Beaver	275	75	90	80
Athabasca	300	100	40	30
Peace[b]	275	75	90	80
Hay	240	100	100	90
Liard	250	-	-	-

[a] This river basin includes Sounding Creek.
[b] This river basin includes Slave, Athabasca, Great Slave and Buffalo lakes.
[c] Source: Wright (2008).

Energy) (GAO 2007) and that this technology will meet the remaining demand for bioethanol in 2015, i.e., 148 million liters (as shown in Table 3).

Alberta's share in meeting Canada's demand for bioethanol and biodiesel (Scenario #2)

Production of lignocellulosic ethanol is likely to increase in future, as lignocellulosic biomass does not compete with food. In this study, we assumed a pessimistic scenario in which Canadian ethanol industries will be based primarily on wheat in 2025, as shown in Table 3.

Water requirement and yield for wheat crops in Alberta

As discussed in an earlier study (Singh 2009), water plays an important role in the development of any crop. A crop's water requirement, which determines the total water requirement for the production of biofuels, depends on ambient temperature, humidity level, soil texture, and wind velocity during the growing period (Canada Canola Council 2008). As a result, crop water requirements vary for the same crop from place to place.

In Alberta, spring wheat requires up to 480 mm of water during the growing season (McKenzie and Dunn 1997; Efetha 2008; Wright 2008; Bauder 2009b). With good growing conditions and proper management, 400 mm of water is required to achieve maximum yield (Wright 2008). In this study, an average crop water requirement of 440 mm for wheat is used to estimate the total water requirement of wheat based ethanol production in Alberta.

Crop yield is also a deciding factor for estimating water requirements. Crop yield varies with weather conditions from year to year. This study averages wheat yields of Alberta over eight years, from 2001 to 2008. The average yield was 2,738 kg per hectare (CANSIM 2009).

Water requirement and yield for rapeseed crops in Alberta

In Alberta, rapeseed (canola) consumes up to 480 mm of water (McKenzie and Dunn 1997; Bauder 2009a; Efetha 2009) during the growing season, and it performs well in cold conditions if more than 380 mm of water (Bauder 2009a) is available. This study considers 430 mm to be the average amount of water required by rapeseed and takes the average yield of 1,763 kg per hectare from the period 2001 to 2008 (CANSIM 2009).

Water requirements for ethanol and biodiesel production plants

Water is also consumed in the conversion stage of biofuel production. Water is used in wheat based ethanol production plants for wheat mashing. Water is also used for cooling and lost as steam. The make-up water requirement to produce 1 kg of ethanol is 5.13 liters (Singh 2009).

In an ethanol plant based on wheat straw, water is used for pretreatment and hydrolyzation. Water is also used in steam formation, which is a heating medium. The lignocellulosic biomass based ethanol plants are integrated with lignin-based power plants, and a large amount of water is used for cooling. The total make-up water requirement for the wheat straw based plant is 7.43 liters of water per kg of ethanol produced (Singh 2009).

During the conversion of rapeseed to biodiesel, rapeseed is crushed to produce canola oil and then canola oil is transesterified to produce biodiesel. Water is used to separate the gum from the canola oil in the crushing stage and to purify biodiesel in the transesterification stage. Total water used is 0.30 liters per kg of biodiesel production (Singh 2009).

Table 5: Water allocations, current and future use by river basin in Alberta

River basin	Water allocation as % of natural flow[a]	2005[b] Surface water use		2025[c] Projected surface water use	
		(dam^3)	(as % of natural flow)	(dam^3)	(as % of natural flow)
Milk	25	53,901	22.1	55,801	22.9
Oldman	70	1,134,540	35.6	1,245,512	39.1
Bow	70	1,133,931	31.0	1,332,041	36.4
South Saskatchewan	70	65,414	16.5	68,494	17.3
Red Deer	30	191,788	17.2	210,267	18.8
Battle	278	71,588	25.3	93,369	33.0
North Saskatchewan	30	182,714	3.0	246,812	3.8
Beaver	20	10,856	7.0	10,875	6.6
Athabasca	5	247,143	1.6	451,066	3.0
Peace	1	114,127	0.5	134,044	0.6
Hay	1	2,806	0.5	2,158	0.4
Liard	0	50	0.0	50	0.0

[a] Source: Alberta Environment (2009).
[b] Source: Alberta Environment (2007).
[c] Source: Alberta Environment (2007).

Precipitation and soil moisture levels in Alberta

Crop water requirement is normally met by precipitation during the growing period. When there is inadequate precipitation, soil moisture and/or irrigation supplements the crop's water requirement. Basically, the crop's water source is precipitation, which directly or indirectly waters through irrigation or soil moisture. When water is withdrawn from a river for irrigation, that water could affect the sustainability of the river. Average precipitation in Alberta is shown in Table 4.

In Alberta, the growing season for spring wheat and rapeseed normally runs from late April to early September. In general 50 to 60% of annual precipitation occurs in this period (Wright 2007a). In Alberta, this growing season precipitation is generally less than the crop water requirement; therefore, crop water requirement is fulfilled by soil moisture and irrigation (Wright, 2007b).

Because precipitation is uneven and varies significantly throughout the province (Alberta Environment 2009), irrigation requirements in the 12 river basins were assessed individually. The total precipitation in the different basins during crop growing period (May 1 to August 31) is shown in Table 4 as an average over 30 years (from 1971 to 2000).

Available soil moisture is a vital supplement in regions where precipitation levels are below the crop's water requirement. In Alberta, soil moisture that is stored during the non-growing season (September 1 to April 30) is very useful during the growing season (May 1 to August 31) whenever precipitation fails to meet the crop water requirement. Crops use only about 50% of the total moisture holding capacity of the soil (Wright 2007). The soil moisture available for a plant is determined by root depth (Canada Canola Council 2008). The active root zone of wheat and rapeseed plants is 1.0 m (Efetha 2008) and 1.2 m (Canada Canola Council 2008), respectively.

The available soil moisture also depends on soil texture. About 120 cm of fully water saturated clay soil can provide 200 mm of water to plants. A120 cm deep root zone in sandy soil can provide only 100 mm of water to the plants (Wright 2007a). In Alberta, different river basins have soils of different textures. Table 4 shows the average available soil moisture of different river basins for a root depth of 120 mm.

Water availability and use in Alberta

To meet the fresh water requirement of a specific region, there are two sources: surface water and ground water. Surface water is the primary source of water, whereas ground water is used only for small industrial, commercial, or residential purposes where surface water is not available. In Alberta, 97% of the water supply is met by surface water and the remaining 3% by ground water (Alberta Environment 2007). The availability of surface water makes it reasonable that only the use of this water be considered for biofuel production in this study.

In Alberta, surface water availability is measured by river flow. The allocation and use of the natural flow of the twelve main rivers is shown in Table 5. Water in southern rivers (the Milk, Oldman, Bow, South Saskatchewan, and Red Deer) is used heavily. The water use (% of natural flow) in northern rivers (the Athabasca and Peace) and central rivers (the Beaver and North Saskatchewan) is very low.

Under the 1909 international Boundary Waters Treaty, the US is entitled to 75% and 25% of the natural water flow from the Milk and St. Mary rivers, respectively (Alberta Environment 2006). In the Milk River Basin (which includes the St. Mary River), 22.1% of the natural flow is already being used; therefore, it is difficult to increase water use in this basin.

Under the 1969 Master Agreement on Apportionment between Alberta and Saskatchewan, 50% of the natural flow of the Oldman, Bow, South Saskatchewan, Red Deer, Battle, North Saskatchewan, and Beaver rivers is allocated to Saskatchewan (Alberta Environment 2004).

Table 6. Projected percentage change in water use from 2005 to 2025 by sector in Alberta.

Sector	Water use (dam^3)[a] 2005	2025	% change from base year water use	% of change as % of total increase in water use
Municipal	114,332	143,229	25.3	4.5
Agricultural	2,175,955	2,471,046	13.6	46.0
Commercial	54,181	82,343	52.0	4.4
Petroleum	231,011	491,027	112.6	40.5
Industrial	175,520	179,456	2.2	0.6
Other	457,859	483,388	5.6	4.0
Total	3,208,858	3,850,489	20.0	100.0

[a] Source: Alberta Environment (2007)

In Alberta, 70% of the water used by the agricultural sector is withdrawn from those rivers during the crop-growing period (Alberta Environment 2007). Due to this about 25% of the annual flow, after apportionment obligations, goes to Saskatchewan every year due to lack of demand (AEDA 2009).

The Alberta government capped the water allocations of the Oldman, Bow, South Saskatchewan and Red Deer river basins under the 1991 South Saskatchewan Basin Water Allocation Regulation (Alberta Environment 2007), so water use from these rivers cannot be increased. Water use from the Battle River has not been capped, but it seems difficult to increase water use here due to the above-mentioned limitations and extremely high allocation of natural flow (i.e., 278%, as shown in Table 5).

The 1969 Master Agreement also applies to the North Saskatchewan and Beaver Rivers, but low water use (3% and 7% of the natural flow, respectively) allows for irrigation.

Water use from the northern rivers (Athabasca, Peace, Hay, and Liard River) is being monitored under the 1997 Mackenzie River Basin Transboundary Waters Master Agreement (Alberta Environment 2004), but there is no agreement on water allocation between the provinces for these river basins. Water in these river basins is abundantly available for use as shown in Table 5; therefore, irrigation could be increased comfortably.

The water use projected for 2025 by river basin and demand sector is shown in Tables 5 and 6, respectively. This 2025 water use projection is based mainly on two assumptions (Alberta Environment 2007). The first is that southern Alberta will continue to be able to use water from the Oldman and Bow river basins for irrigation within the water allocation limit decided by the 1991 South Saskatchewan River Basin Allocation Regulation. The second assumption is that water demand from the Athabasca River Basin will go up due to the expansion of the bitumen upgrade industry.

The projections of water use in 2025 for Oldman, Bow, and Athabasca river basins are shown in Table 5. Major changes are reflected in the agricultural and petroleum sectors as shown in Table 6. The remaining water changes in different sectors are due to changes in Alberta's population, livestock population, etc.

Available arable land in Alberta by river basin

The land required for biofuel production is a crucial factor. As wheat and rapeseed crops need arable land, it is important to assess the availability of arable land. In Alberta, about 31% of the land is arable; about 19% is currently being used for agricultural purposes, and the remaining 12% will be used for agriculture (Alberta Environment 2007). The total used and unused arable land for different river basins of Alberta is shown in Table 7.

It is clear from Tables 7 that most of the remaining arable land in the Alberta is in the southern river basins (i.e., the Milk, Oldman, Bow, South Saskatchewan, Red Deer, and Beaver river basins), where there is a water scarcity. Less arable land is available in the northern river basins, where water is abundantly available.

Table 7. Total used and unused arable land by river basin in Alberta

River basin	Arable land (km^2)[a]	Arable land in use[a] (km^2)	% of total unused land
Milk	10996	6295	7
Oldman	21227	12499	12
Bow	13966	8257	8
South Saskatchewan	11327	4567	10
Red Deer	48743	28473	27
Battle	23213	14538	11
North Saskatchewan	31057	22115	10
Beaver	5842	3149	3
Athabasca	16128	10497	6
Peace	23794	16947	6
Hay	2063	1292	1
Liard	0	0	0

[a] Source: (Alberta Environment, 2007)

Irrigation and selection of river basins for wheat and rapeseed production

For sustainability in the biofuel industry, the life cycle water requirement of biofuels should be as low as possible. A great deal of water is required to produce crops for biofuel production (Shikhar 2009). This crop water requirement can be fulfilled by precipitation, soil moisture, and irrigation. Precipitation is the primary source of water supply for crops in any region. If precipitation is not enough, soil moisture is used by the plant. If soil moisture falls below 50% of total moisture (Wright 2007b), it is necessary to irrigate the crop. The irrigation requirement can be calculated using the equation (1) as below:

$$Irrigation\ requirement = Crop\ water\ requirement - Precipitation - Soil\ moisture \qquad (1)$$

Soil moisture is stored precipitation from the non-growing season. This precipitation is naturally available water, and irrigation is an extra requirement for a specific region. Irrigation water is withdrawn directly from rivers and the impact of this withdrawal on the water availability in a river basin is considerable; therefore, in this study, river basins with minimal irrigation water requirements are given first priority as sites for growing biomass crops. This minimum irrigation criterion is used to select river basins for growing wheat and rapeseed for biofuel production.

The crop water requirements of 440 mm and 430 mm for wheat and rapeseed, respectively, were used to calculate the irrigation requirements for different river basins; these calculations are shown in Table 4. The southern river basins (the first 6 river basins shown in Table 4) are water scarce zones. As water is already scarce in these zones, setting up biofuel industries would not be sustainable there.

The water requirement in the Athabasca River Basin is the lowest among the bottom 6 river basins shown in Table 4. The requirement is only 40 mm and 30 mm for wheat and rapeseed, respectively. As the available arable land in the Athabasca River Basin would not be able to produce the all biofuels for which Alberta will be accountable, the remaining biofuels would have to be produced in the next river basin. The next river basin with a relatively low water requirement is the North Saskatchewan, where 60 mm and 50 mm of irrigation is required for the production of wheat and rapeseed, respectively. The Peace and Beaver River basins, where 90 mm and 80 mm of irrigation would be required for wheat and rapeseed, respectively, follow this river basin.

Irrigation management in Alberta

The quantity of water withdrawn from a river is always more than what is actually supplied to the crop. Water is lost through seepage and evaporation when being conveyed from river to field or farm in what is known as conveyance efficiency (Rogers et al. 1997). In the field, water is also lost through drift, evaporation, and percolation below the root zone, depending upon the type of irrigation system. This is referred to as irrigation efficiency (Rogers et al. 1997).

The Alberta Irrigation Projects Association estimates irrigation efficiency to be about 71% (AIPA 2006). In Alberta, seepage losses and evaporation losses are estimated to be about 2.5% and 4% of license volume, respectively (AIPA, 2006).

Availability of lignocellulosic biomass feedstock in Alberta

For lignocellulosic biomass based ethanol production, the availability of lignocellulosic biomass is an important issue. This biomass can be wood or agricultural residue from any cereal crop. In Alberta, wheat and barley is produced in significant quantities, and currently, most of the residues from these crops are not used for any specific purpose; only a small portion of the residues are used for livestock and preventing soil erosion (Sokhansanjet al. 2006). In this study, these lignocellulosic residues are considered as potential feedstocks for ethanol production. On average in Alberta, 5.09 and 2.60 million tonnes of wheat and barley straw, respectively, are available annually after livestock and soil erosion use (Sokhansanj et al. 2006). In Alberta, the south, central, and northeast zones produce about 75% (Atkinson 2001) of Alberta's total wheat production. This makes it more favorable to locate the lignocellulosic biomass based ethanol plant in the central regions (i.e., the South Saskatchewan and Red Deer river basins).

RESULTS AND DISCUSSION

The demand for water with and without biofuel production in 2025 is shown in Table 8. With biofuel production, future water demand projections for a few river basins are higher than the projection for the reference case (i.e., feedstock growth for food rather than for biofuel production). In the base year (i.e., 2005) biofuel production is zero and water requirements for the two scenarios (with and without lignocellulosic bioethanol production) are the same as for the reference case. Water requirements in 2025 for the two scenarios with biofuel production for different river basins are different than water requirements for the 2025 reference case, as shown in Table 8. There are significant changes in water use from 2005 to 2025 in the North Saskatchewan, Athabasca, and Peace River basins. The water projections and calculation methodology from 2005 to 2025 at 5-year intervals are given for both scenarios in the above sections.

The water requirement for the North Saskatchewan River Basin is 11.6% and 16.1% of the natural flow in scenarios #1 and #2, respectively, in contrast to 3.8%, as given in the reference case. Because the projected water use of this river for 2025 is lower than the current percentage water use for southern Alberta Rivers, it is expected that this water demand will be manageable.

The water requirement for the Athabasca River Basin is expected to go up from 3.0% to 5.2% for both scenarios. Though this is a significant portion of total increase in water demand for 2025, there is so much unused water flow this increase will have little impact on the water supply in Athabasca River Basin. Water will not be a

Table 8: Albert's water demand without and with biofuel production by river basin in 2025

River basin	2025 water use without biofuels[a]		2025 water use with biofuels			
			Scenario # 1		Scenario # 2	
	(dam^3)	(% of natural flow)	(dam^3)	(% of natural flow)	(dam^3)	(% of natural flow)
Milk	55,801	22.9	55,801	22.9	55,801	22.9
Oldman	1,245,512	39.1	1,245,512	39.1	1,245,512	39.1
Bow	1,332,041	36.4	1,332,041	36.4	1,332,041	36.4
South Saskatchewan	68,494	17.3	70,300	17.7	68,494	17.3
Red Deer	210,267	18.8	212,073	19.0	210,267	18.8
Battle	93,369	33.0	93,369	33.0	93,369	33.0
North Saskatchewan	246,812	3.8	760,769	11.6	1,058,492	16.1
Beaver	10,875	6.6	10,875	6.6	10,875	6.6
Athabasca	451,066	3.0	792,321	5.2	792,554	5.2
Peace	134,044	0.6	134,044	0.6	512,420	2.3
Hay	2,158	0.4	2,158	0.4	2,158	0.4
Liard	50	0	50	0.0	50	0.0

[a] Source: Alberta Environment (2007)

constraint for the production of biofuels, but arable land in this river basin is limited. Even if all the available arable land in the Athabasca River Basin is used, crops will have to be produced in the Peace River Basin for scenario #2. As a result, water use for the Peace River will increase from 0.6 % to 2.3 % of natural flow.

The water demand for the South Saskatchewan and Red Deer rivers will be increased by 0.4% and 0.2% of their natural flow, respectively, in scenario #1, when lignocellulosic biomass based ethanol plants are set up in these river basins. This shows that lignocellulosic biomass based ethanol plants do not change water demand of any region significantly. In this study, only wheat straw was considered to fulfill future ethanol requirements, but at least 2.6 million tonnes of barley straw (mostly from the southern region) are also available for ethanol production (Sokhansanj et al. 2006). If lignocellulosic biomass based technology for ethanol production becomes cost competitive in the future, Alberta will be able to produce more ethanol without significantly affecting the water supply of southern Alberta.

To illustrate the impact of producing biofuel, Table 9 shows the water demand projections for 2025 by sector. The percentage change in demand from 2005 is also shown on Table 9. In the agricultural sector, the water demand is projected to rise to 13.6 % from the base year (2005) in the reference case. Whereas the projected increases for scenarios #1 and #2 are 52.7% and 83.6%, respectively.

The water demand in the petroleum sector is not affected by biofuel production (i.e., the water requirement for both scenarios and the reference case is the same). The demand for water in the petroleum sector is projected to increase by 112.6 % in the reference case. But the change in the petroleum sector is only 17.3 % of the total change in water demand in scenario #1. This is due to the significant increase in water demand in the agricultural sector for biofuels.

The demand for water in the industrial sector will be 5.6% of total water use in 2025 for both scenarios, as compared to 2.2% in the reference case. This is due to water requirements for the bioethanol and biodiesel production stages.

As far as the total water demand in Alberta is concerned, in 2025 the reference case projects an increase in water demand of 20% from the 2005 level, whereas scenarios #1 and #2 project increases of 46.8% and 67.7%, respectively.

CONCLUSION

In this study, two scenarios for biofuel production were developed to assess the impact of this production on the water demand in Alberta. In scenario #1, biofuel production in Alberta was considered using wheat and wheat straw based ethanol production and rapeseed (canola) based biodiesel production. In scenario #2, biofuel production in Alberta was considered based on wheat and rapeseed only. The water requirements in both scenarios were calculated along with the water demand projected for 2025. Southern Alberta has 64% of the unused total arable land in Alberta, but biofuel production from grain and oil seed is not feasible in this region because there is not enough water to meet the high irrigation water requirements. The present availability of water and arable land in Alberta indicates that the Athabasca, North Saskatchewan, and Peace River basins of northern Alberta have 21% of the unused arable land, whereas only 1.6%, 2.8%, and 0.5% of natural flow of the respective rivers is currently being used.

Table 9. Water use in Alberta with biofuel production by sector in 2025

Sector	Year 2025 water use (dam^3)		% change from year 2005 water use		% of change as % of total increase in water use	
	Scenario # 1	Scenario # 2	Scenario # 1	Scenario # 2	Scenario # 1	Scenario # 2
Municipal	143,229	143,229	25.3	25.3	1.9	1.3
Agricultural	3322,323	3,995,826	52.7	83.6	76.4	83.7
Commercial	82,343	82,343	52.0	52.0	1.9	1.3
Petroleum	491,027	491,027	112.6	112.6	17.3	12.0
Industrial	187,003	186,222	6.5	6.1	0.8	0.5
Others	483,388	483,388	5.6	5.6	1.7	1.2
Total	4709,313	5,382,034	46.8	67.7	100	100

In 2025, Alberta will have to produce 3,754 million liters of ethanol and 270 million liters of biodiesel to meet the projected levels. If biofuels are produced from the crops grown in the three northern river basins (Athabasca, North Saskatchewan, and Peace River basins), the water requirement to meet this biofuel demand in 2025 will be 858,824 dam3 and 1,531,545 dam3 for scenarios #1 and #2, respectively. As a result, water use in 2025 will be 46.8% and 67.7% higher than that of 2005 for scenarios #1 and #2, respectively. Alberta should be able to meet the demand for biofuels in 2025 sustainably as water requirement from these river basins for biofuel production will increase to 5.2%, 0.6%, and 11.6 % of the natural flow in scenario #1 and 5.2%, 2.3%, and 16.1 % of the natural flow for scenario #2. In scenario #1, a study of lignocellulosic ethanol production shows that wheat straw is available in sufficient quantity in Alberta to meet the ethanol demand in 2025. As wheat straw is mainly available in southern and central Alberta, the wheat straw based ethanol production plants would most likely be based in the Red Deer and South Saskatchewan river basins. The production of lignocellulosic bioethanol will be sustainable, increasing the water requirement in the Red Deer and South Saskatchewan rivers only slightly, by 0.2% and 0.4% of the natural flow, respectively.

REFERENCES

AEDA. 2009. "Sustainable water management and economic development in Alberta." Retrieved March 20, 2009, from https://aeda.alberta.ca/reportsandstudies/aedastudies/Documents/AEDAWaterStudy-Final%20version%20with%20appendix.pdf.

AIPA. 2006. "Alberta irrigation sector improves efficiency of water use." Retrieved March 30, 2009, from http://www.fossilwater.ca/fossilwater-report-aug-sep06.pdf.

Alberta Environment. 2004. "Mackenzie river basin transboundary waters master agreement (1997)." Retrieved March 15, 2009, from http://www3.gov.ab.ca/env/water/GWSW/Quantity/WaterinAlberta/Apportionment/TB_Transboundary/TB11_mackenzie_river_basin_tma.html.

Alberta Environment. 2004. "Master agreement on apportionment (1969)." Retrieved March 15, 2009, from http://www3.gov.ab.ca/env/water/GWSW/Quantity/WaterinAlberta/Apportionment/TB_Transboundary/TB5_master_agree_apportionment.html.

Alberta Environment. 2006. "Boundary waters treaty (1909)." Retrieved March 15 2009, from http://www3.gov.ab.ca/env/water/GWSW/Quantity/WaterinAlberta/pubs/SharingtheWaters-Supplement.pdf.

Alberta Environment. 2007. "Current and future water use in Alberta." Retrieved March 02, 2009, from http://www.assembly.ab.ca/lao/library/egovdocs/2007/alen/164708.pdf.

Alberta Environment. 2009. "Water in Alberta." Retrieved March 25, 2009, from http://www3.gov.ab.ca/env/water/gwsw/quantity/waterinalberta/index.html.

Atkinson, G. 2001. "Census of agriculture for Alberta." Retrieved April 15 2009, from http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd5726.

Baron, V. 2009. "A Canadian perspective on land management risks associated with biofuels and their production." Retrieved February 25, 2009, from http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/crop12131.

Bauder, J. W. 2009a. "The right strategy for irrigating your canola crop." Retrieved April 3, 2009, from http://waterquality.montana.edu/docs/irrigation/canolastrategy.shtml.

Bauder, J. W. 2009b. "Wheat irrigation." Retrieved March 30 2009, from http://waterquality.montana.edu/docs/irrigation/wheatirrigation.shtml.

Bergmann, J.C., D.D. Tupinambá, O.Y.A. Costa, J.R.M. Almeida, C.C. Barreto and B.F. Quirino. 2013. Biodiesel production in Brazil and alternative biomass feedstocks. Renewable and Sustainable Energy Reviews 21: 411-420. http://dx.doi.org/10.1016/j.rser.2012.12.058

Canada Canola Council. 2006. A review of environmental assessments of biodiesel displacing fossil diesel.

Canada Canola Council. 2008. "Canola growers manual." Retrieved December 6, 2008, from http://canola-council.org/chapter4.aspx#ch4_sec2.

CANSIM. 2009. "Agriculture." Retrieved March 20, 2009, from http://dc1.chass.utoronto.ca/cgi-bin/cansimdim/c2_subjects.pl.

Dietrich, J. 2009. "Central peace conservation society biodiesel project." Retrieved February 20, 2009, from http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/crop12154.

Efetha, A. 2008. "Irrigation management of soft white spring wheat." Retrieved 30 March, 2009, from http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/irr4429.

Efetha, A. 2009. "Irrigation management of canola." Retrieved 2 April, 2009, from http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/irr4425.

Environment Canada. 2006. "Notice of intent to develop a federal regulation requiring renewable fuels." Retrieved March 30, 2009, from http://www.ec.gc.ca/Ceparegistry/documents/notices/g1-14052_n1.pdf.

GAO. 2007. "DOE lacks a strategic approach to coordinate increasing production with infrastructure development and vehicle needs." Retrieved May 15 2009, from http://www.gao.gov/new.items/d07713.pdf.

Klein, K. K. and D. G. L. Roy. 2009. "The bioenergy frenzy." Retrieved Februrary 15 2009, from http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/crop12133.

Li, X., E. Mupondwa, S. Panigrahi, L. Tabil, S. Sokhansanj, and M. Stumborg. 2012. A review of agricultural crop residue supply in Canada for cellulosicethanol production. *Renewable and Sustainable Energy Reviews* 16: 2954–2965. http://dx.doi.org/10.1016/j.rser.2012.02.013

McKenzie, R. and R. Dunn. 1997. "Irrigated crop recommendations." Retrieved December 3 2008, from http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex139.

NEB. 2009. "Canada's energy future - reference case and scenarios to 2030." Retrieved March 25 2009, from http://www.neb.gc.ca/clf-nsi/rnrgynfmtn/nrgyrprt/nrgyftr/2007/nrgyftr2007chptr5-eng.html.

Osborne, S. 2007. "Energy in 2020: assessing the economic effects of commercialization of cellulosic ethanol." Retrieved March 25, 2009, from http://www.ethanolrfa.org/resource/cellulosic/documents/cellulosic2007.pdf.

Racz, V. J. 2007. "Canadian biofuel Industry: western canada perspective and opportunities." Retrieved February 22, 2009, from http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/crop12127.

Rogers, D. H., F. R. Lamm, M. Alam, T. P. Trooien, G. A. Clark, P. L. Barnes, and K. R. Mankin. 1997. *Efficiencies and water losses of irrigation systems*. Irrigation Management Series, Kansas State University Research and Extension Service, Publication MF-2243, Manhattan, Kansas.

Singh, S. 2009. Development of water consumption factors for biomass conversion pathways. Department of Mechanical Engineering. Edmonton, AB, University of Alberta. **M. Sc.**

Singh, S. and A. Kumar. 2011. Development of water requirment factors for bi9omass conversion pathways. Bioresource Technology 102: 1316- 1328. http://dx.doi.org/10.1016/j.biortech.2010.08.092

Sokhansanj, S.,S. Mani, M. Stumborg, R. Samson and J. Fenton. 2006. "Production and distribution of cereal straw on the Canadian prairies." *Canadian Biosystems Engineering* 48:3.39-3.46.

Varghese, S. 2007. *Biofuels and global water challenges*. Minneapolis, Minnesota: Institute for agriculture and trade policy. http://www.iatp.org/files/451_2_100547.pdf

Wright, R. 2007a. "Agroclimatic atlas of Alberta: agricultural climate elements." Retrieved April 5, 2009, from http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag6301.

Wright, R. 2007b. "Agroclimatic atlas of Alberta: soil moisture conditions in alberta." Retrieved April 5, 2009, from http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag6302.

Wright, R. 2008. "May 1 to August 31 total precipitation: 1961 to 2000." Retrieved March 30, 2009, from http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag6435?opendocument.