Agriculture and Agri-Food Canada Agriculture et Agroalimentaire Canada



Quantifying the impact of increased renewable production from biomass for Canadian agriculture

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Canada

Background

Context for the analysis

- The objective is to assess to what extent agriculture could provide biomass for renewable energy in response to different economic and policy drivers
- This analysis reports on the results of a joint AAFC and Canadian Forest Service (CFS) Program of Energy Research and Development (PERD) project.
- Results will focus on:
  - Renewable energy production from agricultural biomass
  - Biomass production
  - Impact on crop production and income
  - Impact on livestock production and income
  - Land use change
- This analysis aims to provide information on potential challenges and opportunities. It does not provide policy recommendations.
- A carbon price is used as an analytical tool to represent the impact that could arise from a wide mix of policy instruments used to reduce GHG emissions

Background

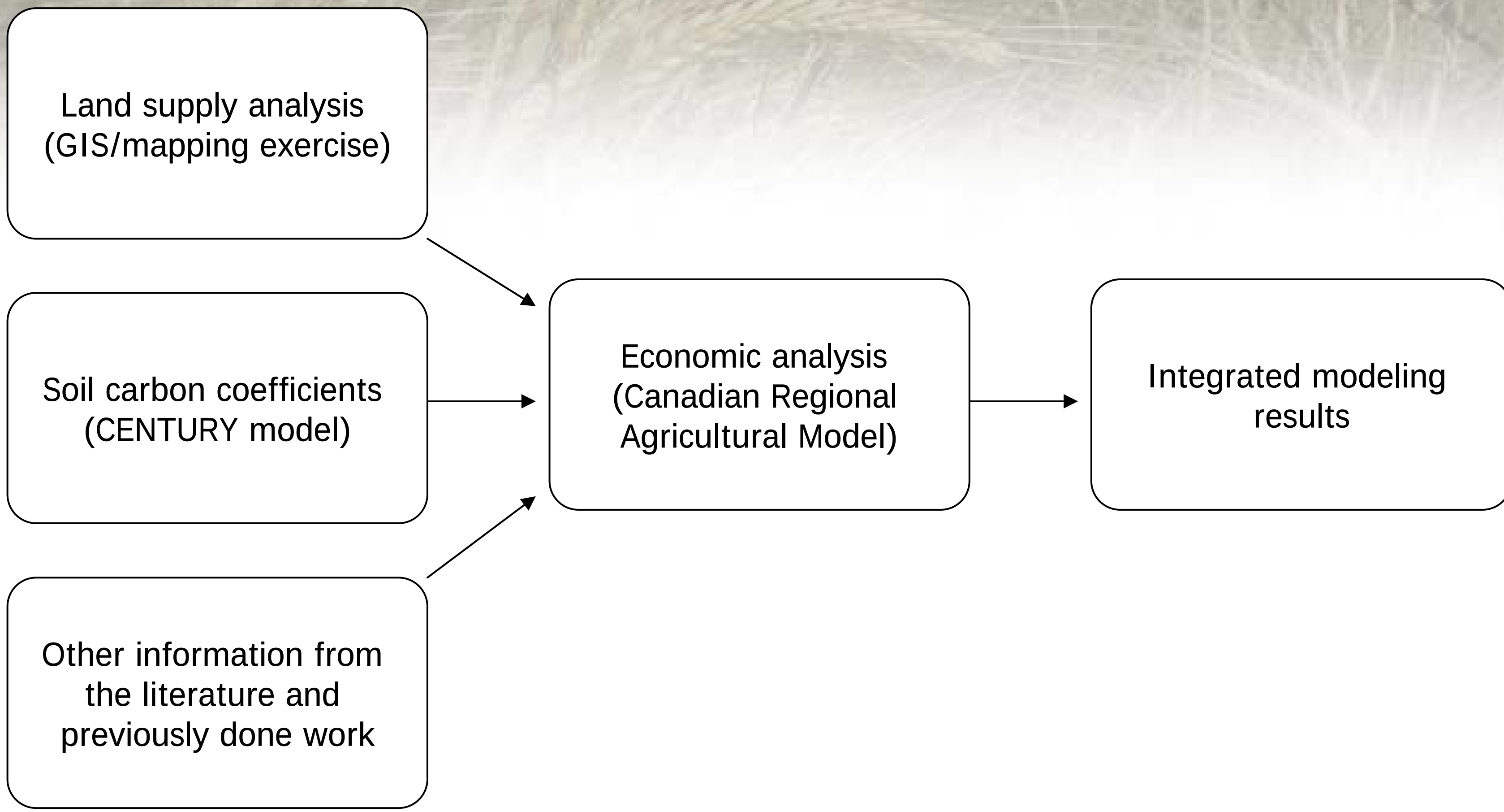
This analysis aims to build on previous work and provide updated information on how renewable energy production could impact agriculture

- Previous work had provided initial results on the impact on cropping and livestock activities, impact on income and some initial GHG results under a variety of scenarios

- New work built on this with a desire to ensure a better understanding of several key factors
  - Land use change (in Canada), which would require estimating supply of land suitable for agriculture as well as conversion costs
  - Impact on the GHG emissions from agriculture, both from the soil sink and the potential to displace downstream emissions of GHG from energy
  - How do changing energy prices and GHG policies impact production of renewable energy from agricultural biomass in the absence of mandates
  - What could be some of the impacts on food vs. fuel

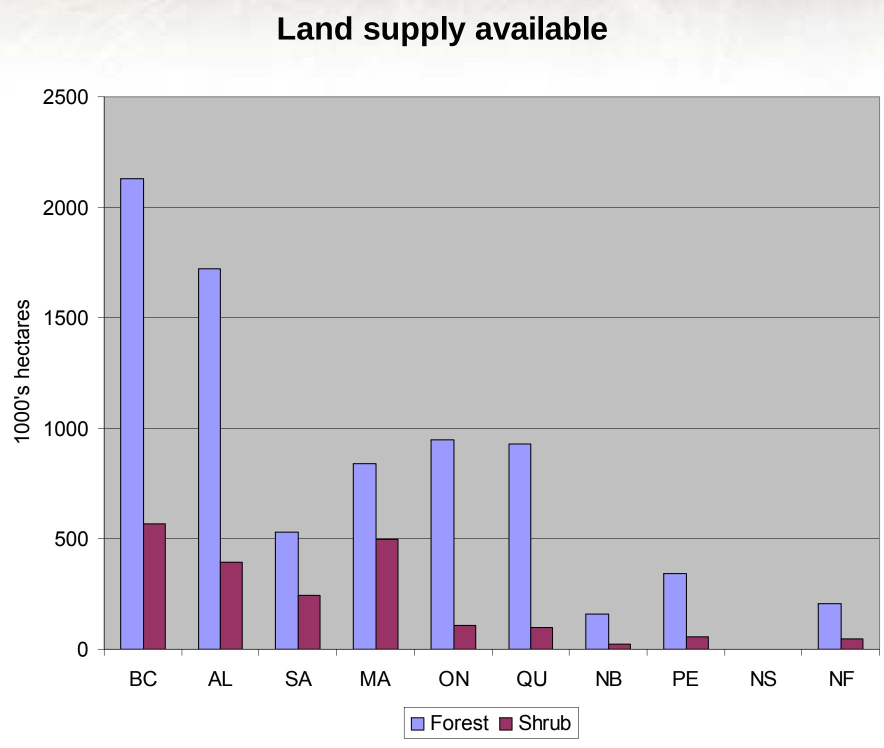
- To accomplish this it became necessary to draw on other models and studies to enhance our analytical framework

Model linkages used to conduct the analysis



A land mapping exercise provided information on potential land supply

- In order to assess the potential for land use change we first had to estimate the supply of land that could be suitable for agriculture
- To do this, suitable land was identified by examining the intersection of:
  - Land cover maps
  - Soil capability for agriculture maps
- This exercise was able to identify suitable agricultural land that is under forest or shrub cover and could be suitable for agricultural uses after clearing
- Estimates are available at the sub provincial level



Models

Soil carbon coefficients were estimated for a variety of practices

- The CENTURY model was used to determine the potential impact of agricultural practices on soil carbon balances
  - Impact of increased use of no-tillage
  - Impact of reduced summerfallow
  - Impact of increased use of perennial crops relative to annual crops
- Using CENTURY, trends were developed to estimate future changes in soil carbon levels as a result of changes in land management practices
- Including the benefit of soil organic carbon allowed us to be more comprehensive in how the carbon impacts of using certain crops or cropping practices impacted overall carbon impacts from renewable energy
  - Each applicable practice in each region has its own unique sequestration coefficient

In addition to linking with other models, key information was drawn from other studies

Information taken directly from the other models in the integrated modeling framework:

- The available supply of land that is in tree and shrub cover and could be cleared for agricultural use
- The soil carbon modeling which allows us to incorporate the impact of changing production practices on soil carbon balances
  - When combined with a carbon price this can represent a new source of revenue to the crop sector

Information from other scientific, engineering or economic sources:

- Technical data on bioenergy activities
  - Ethanol and biodiesel conversion rates grains and oilseeds (first generation)
  - Ethanol conversion rates biomass (second generation)
  - Electricity production from direct burning of pellets
- Non-food biomass that can be produced from agriculture
  - Crop residues: cereal straw and corn stover
  - Dedicated energy crops: hybrid poplar and perennial grass
- The impact of a carbon price (determined exogenously) on a variety of activities
  - The carbon benefit of renewable energy production if it displaces GHG intensive sources (example: coal)
  - Land use change must account for carbon impact
- The cost of clearing new land for agriculture

Models

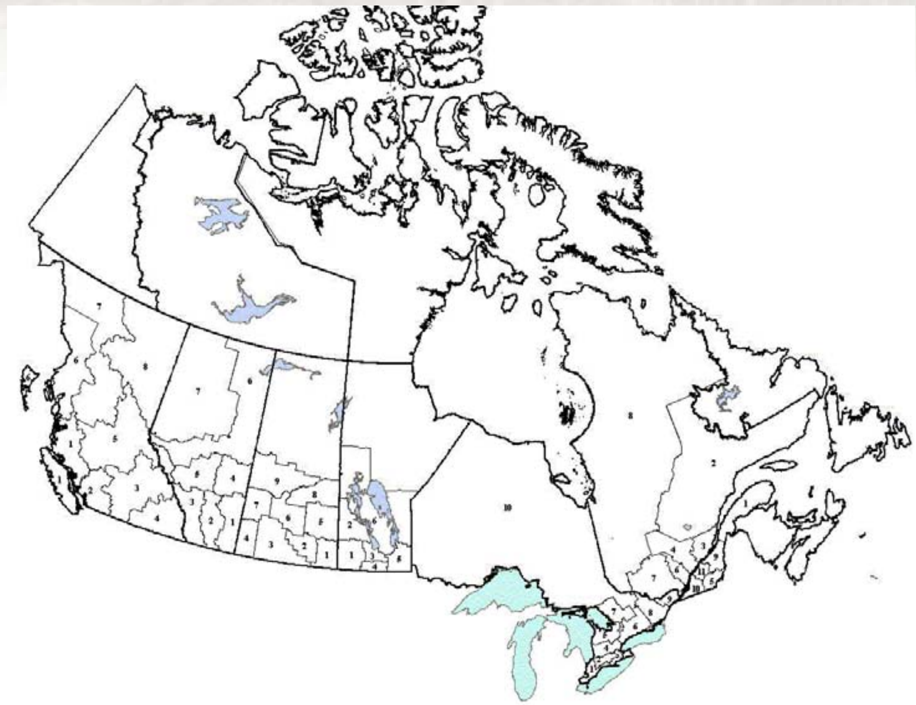
CRAM served as the platform to integrate all this information into an economic analysis

- CRAM is a static partial equilibrium model of the Canadian Agriculture sector, covering all of primary production (crops and livestock) and some processing activities

- CRAM is divided into 55 regions and can provide a very detailed regional breakdown of scenario results

- CRAM does not provide a forecast but gives a before (baseline) and after (policy scenario) picture of the agriculture sector

- The underlying strength of CRAM is the specification of production responses at the regional level and linking of output with provincial demand and world markets through a transportation matrix.



Assumptions

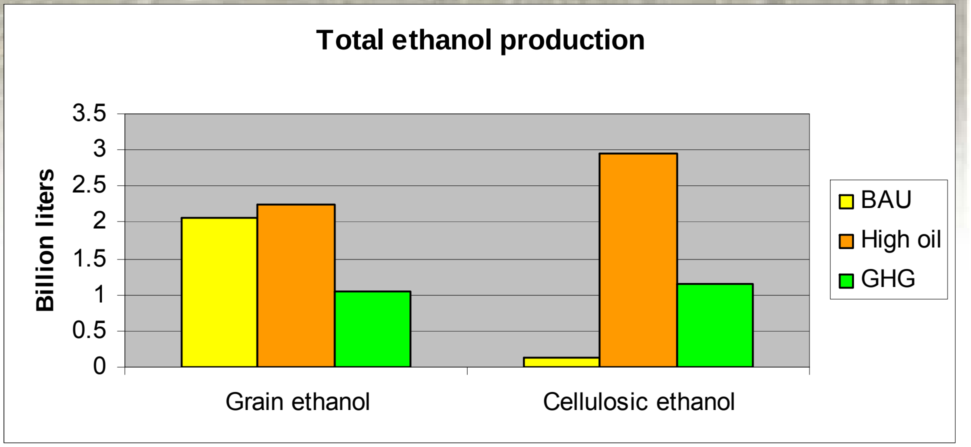
Three plausible worlds in 2020 demonstrate different possible outcomes

	Business as Usual (BAU)	Strong GHG policy (GHG)	High oil price (High oil)
GHG policy	No GHG policy	Strong GHG policy ≈ Carbon price of \$100/tCO2	No GHG policy
Oil price			
Consumer price	\$114 per barrel	\$123 per barrel	\$155 per barrel
Producer price	\$114 per barrel	\$80 per barrel (carbon price makes oil products more expensive for consumers while reducing the price oil producers receive)	\$155 per barrel
Input prices	Current projections	Impacted by carbon price and crude oil price	Impacted by crude oil price
Commodity prices	Medium term outlook	Impacted by crude oil price	Impacted by crude oil price

Results

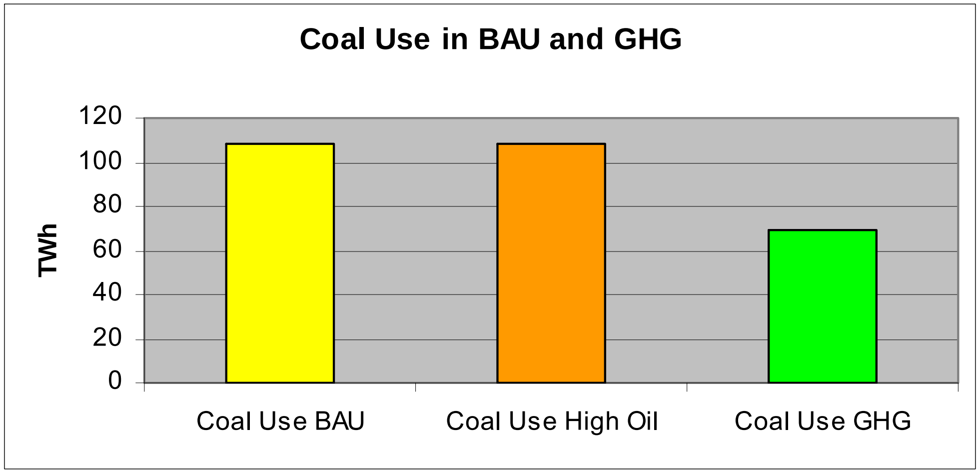
High oil price drives ethanol production, while high carbon price drives electricity production using biomass to replace coal

- **High Oil Scenario**
  - There is more production of cellulosic ethanol.
    - High grain and oilseed prices limits demand for grain ethanol.
  - Biomass does not replace coal for electricity production.



* Ethanol production takes place in the BAU and GHG scenario because of the 5% mandate

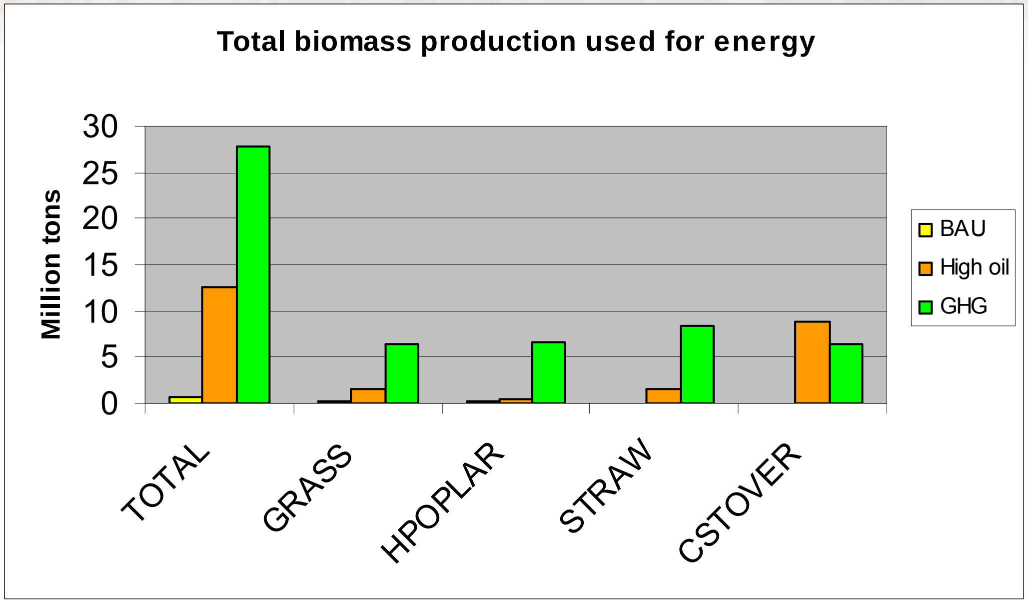
- **Strong GHG Policy Scenario**
  - Ethanol mandate is met but with shift to cellulosic ethanol.
  - High carbon price shifts significantly more biomass to electricity.
  - Biomass displaces 36% of coal.



- Biodiesel production does not go beyond the mandate.

A high oil price or carbon price leads to increased biomass production and utilization

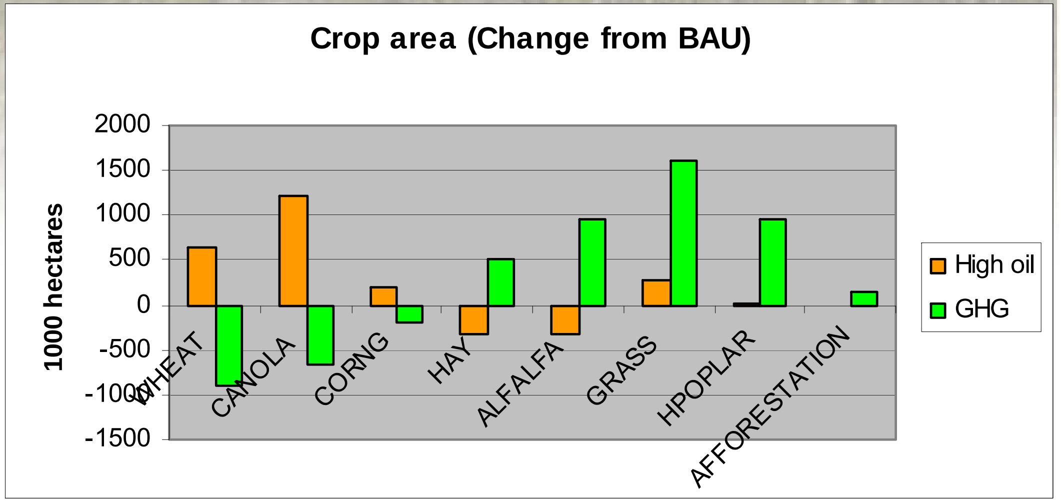
- **High Oil Scenario**
  - Corn stover is the primary biomass source used for production of ethanol.
  - The higher conversion factor of corn stover to ethanol leads to its higher utilization compared to straw.
- **Strong GHG Policy Scenario**
  - All of the potential straw and corn stover is used.
  - Significant amounts of dedicated energy crops are also grown.



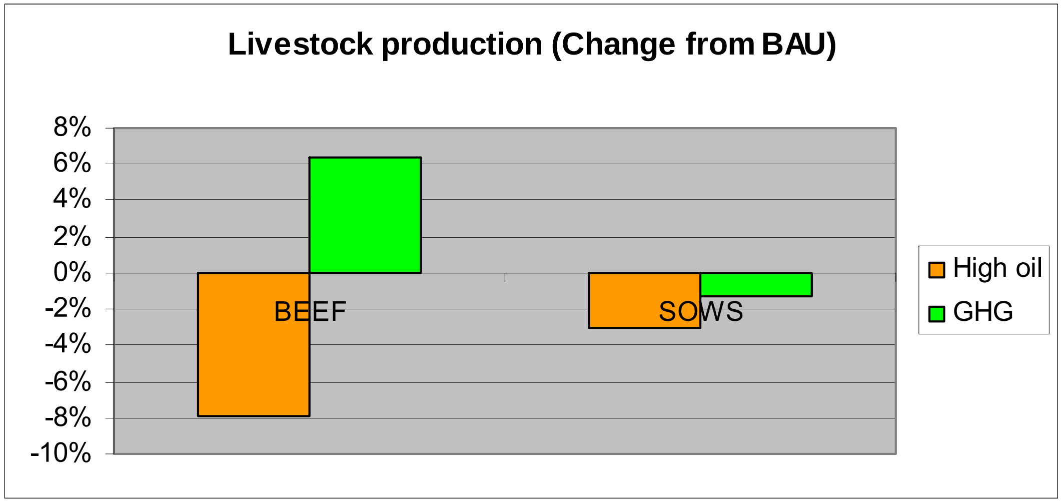
Results

Changes in prices lead to changes in agricultural activity levels

- **High Oil Scenario**
  - Canola production increases the most since the oil price impact on canola is larger than for other commodities.
  - Livestock production decreases due to higher prices of feed grains (such as corn grain) and hay.



- **Strong GHG Policy Scenario**
  - Changes in crop area are driven by the following:
    - Increased in production of dedicated energy crops to replace fossil fuels
    - Increased production of perennials (hay and alfalfa) due to carbon sequestration.
  - More hay and alfalfa benefits beef production.



- We do not consider the impact of increased emissions from livestock.

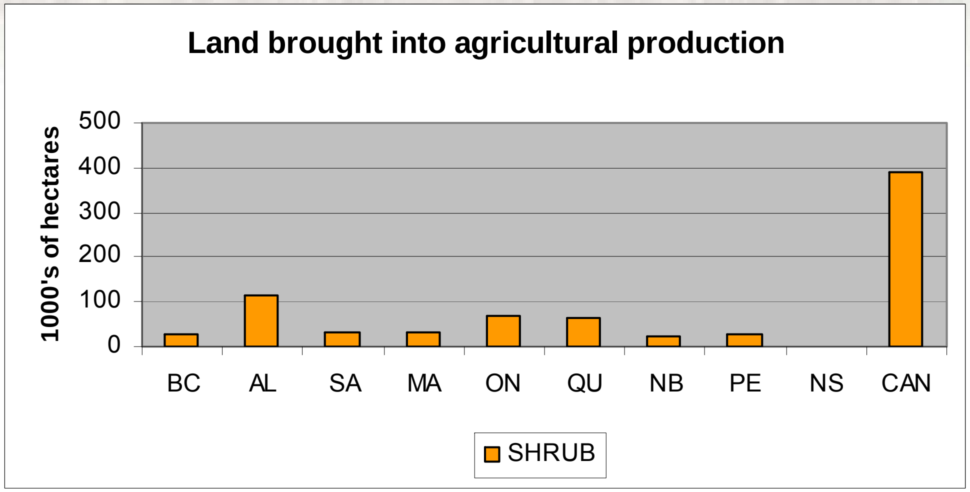
Results

Due to the increasing demand for biomass and increasing commodity prices, some new land is brought into agricultural production.

- **High Oil Scenario**

- Shrub land is the only source of land used due to the lower cost of clearing as opposed to cutting down trees.

- This represents an expansion of 1.2% of cropland.
  - 400 000 hectares
  - Alberta has the largest share because of its availability of land.



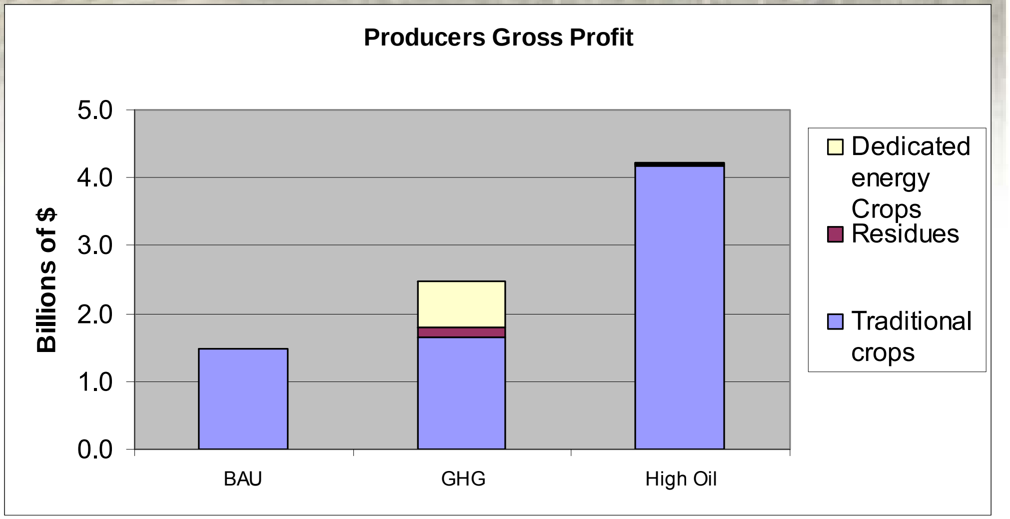
- **Strong GHG Policy Scenario**

•There is no land clearing because of the carbon cost imposed on clearing land.

Results

A high oil price or carbon price creates new opportunities for farmers

- Crop income increases by 66% and 184% in the "GHG" and "High Oil" scenario, respectively.
  - In the strong GHG policy scenario around 33% of the net revenue comes from residues and dedicated energy crops
  - In the High Oil scenario, higher commodity prices leads to higher income



- Livestock producers experience smaller changes.

Livestock producer surplus (change from BAU)

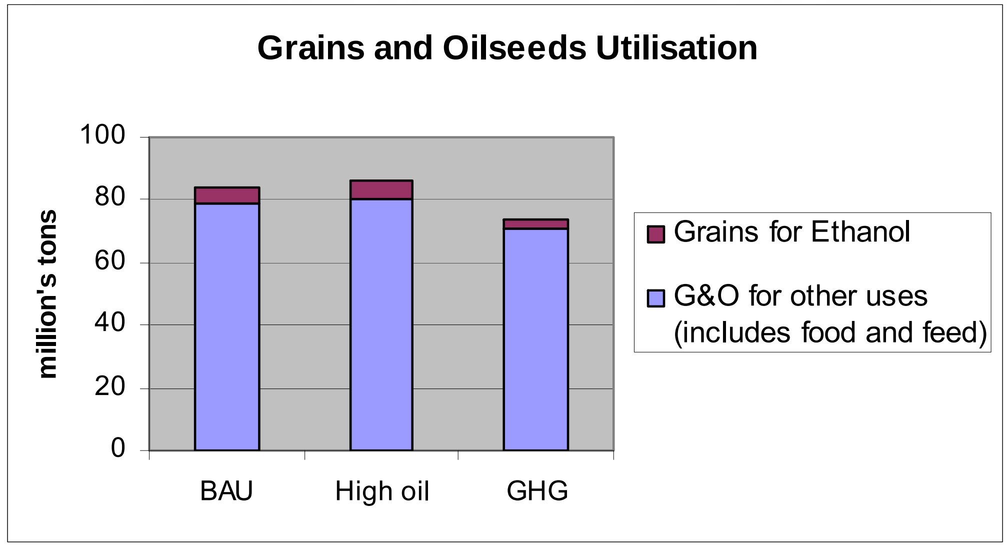
GHG	High Oil
+0.9 %	-2.9%

Results

Primary Agriculture in Canada still produces significant G&O for non-fuel uses

- High Oil Scenario
  - A higher oil price increases the price of major grains and oilseeds, and the value of residues further drives grain production.

- Strong GHG Policy Scenario
  - The carbon price causes grains and oilseeds to compete for land against perennials used to feed beef cattle or use for energy.



Results

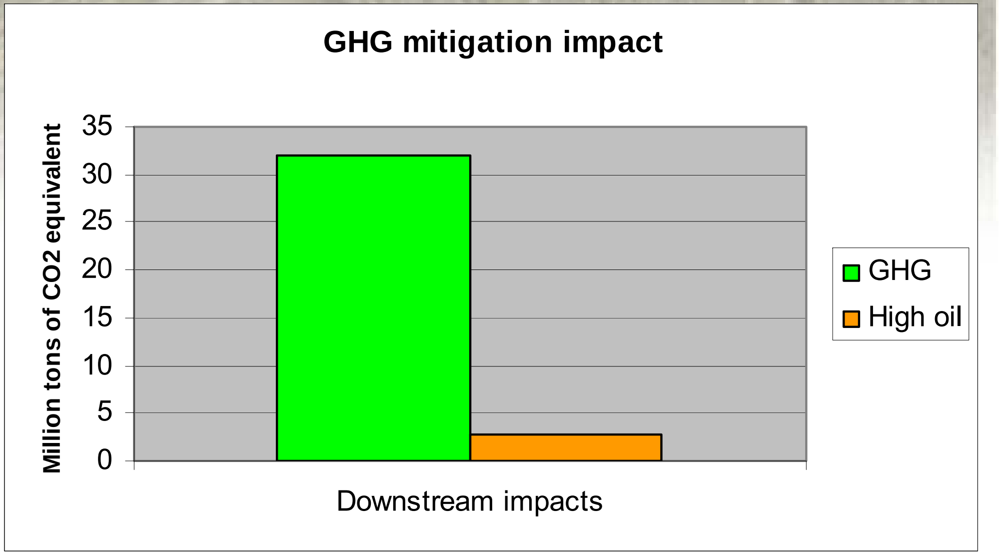
Significant downstream GHG mitigation can be achieved by the replacement of coal

- Replacing coal offsets more carbon than replacing gasoline - the downstream impacts in the “Strong GHG Policy” scenario is significantly higher than “High oil”.

- In this “Strong GHG policy” scenario, the net impact is a reduction of 32M tons of CO_2 equivalent.
  - Energy displacement is mostly coal electricity.

- “High oil” scenario increases production only of ethanol so it generates far fewer reductions

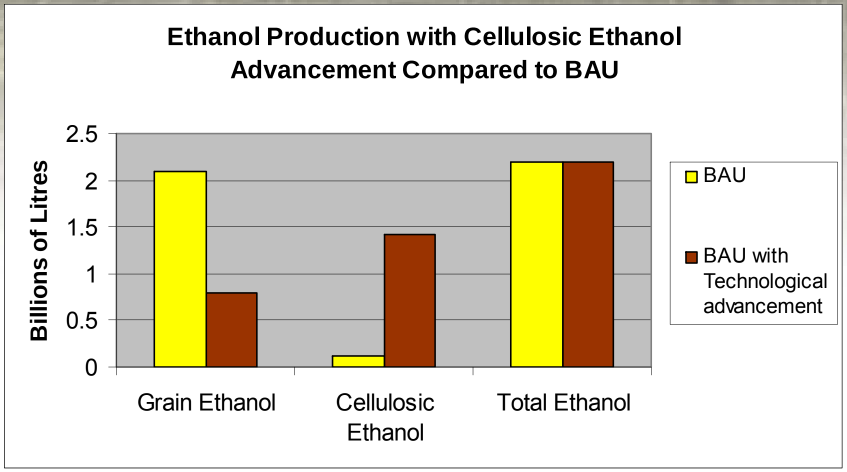
- GHG emissions in Canada are around 734M tons.

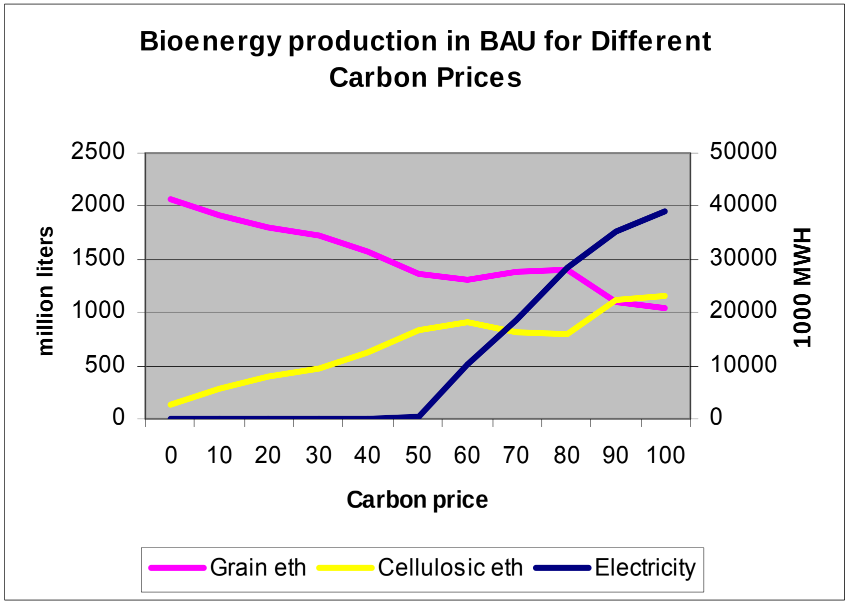


Percentage of gasoline offset		
BAU	High oil	GHG
5%	12%	5%
Percentage of coal offset		
BAU	High oil	GHG
0%	0%	36%

Changes in technology and carbon prices would have different market impacts

- Improved conversion rates (~50%) would make cellulosic ethanol more competitive
  - Cellulosic ethanol would capture a greater share of domestic ethanol production
  - Cellulosic ethanol would still not be competitive with gasoline
- Low carbon prices benefit cellulosic ethanol while high carbon prices shift the emphasis to electricity production
  - Increasing the carbon price causes cellulosic ethanol to increase its share of domestic production, but it is still not competitive with gasoline
  - Electricity generation from agricultural biomass starts around $55/tCO_2$





* 5% ethanol mandate and 2% biodiesel mandate still in effect

Summary

Implications

- Higher energy prices and strong GHG policies could result in high levels of bioenergy produced from agricultural biomass:
  - High carbon prices drive biomass use for electricity production
  - High oil prices drive biomass use for biofuel production
  - Cellulosic ethanol would benefit from a rising carbon price and improved conversion rates
- Overall land use change is small
  - Only a small portion of agriculture land might be used for hybrid popular for energy.
  - Only a small amount of land might be cleared for crops (food and/or energy).
- Agriculture still produces mainly food and feed.
- Agriculture could make a significant contribution to GHG mitigation, but at carbon prices above $50/T CO2e

Possible Future Work

- Improving our understanding of the potential for land use change and using less productive land
  - More thorough analysis of land-use change from shrub and forest to cropland as well as the implications of growing biomass crops on cropland
  - Better estimates of crop productivity by land type and climate to assess the potential use of marginal land for biomass
  - Understanding the potential for using more perennial crops on vulnerable lands
- Improving our understanding of the economic and technological constraints facing bioenergy production
  - More thorough evaluation of supply costs and logistics including weather driven variation in supply
  - Additional analysis on costs and technology to convert biomass to liquid fuels
- Improving our understanding of the broader environmental impacts
  - How does large scale residue removal affect long term soil erosion risk
  - What are the implications for eutrophication
- Improved linkages with other work on biomass availability
  - Link with BIMAT (Biomass Inventory Mapping and Analysis Tool)

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ANNEX SLIDES

Detailed assumptions

- A wide variety of biomass can be transported to bioenergy facilities.
  - Perennial grass, hybrid poplar, straw and corn stover
- The 5% ethanol and a 2% biodiesel mandate has to be met in all scenarios
- We assume changes in the oil price are reflected in input costs and prices of key commodities used for biofuels.

1% increase in the oil price leads to				
change in commodity prices				
Corn	0.499 %		Canola	0.119 %
Wheat	0.370 %		Canola oil	0.625 %
Barley	0.370 %		Soybeans	0.119 %
			Soybean oil	0.625 %
change in biofuel prices				
Ethanol	0.860 %		Biodiesel	0.917 %
change in input costs				
Fertilizer	0.426 %		Farm fuel	0.500 %

Assumptions

GHG policy could have numerous impacts on the sector

- A carbon market has been implemented for emission reductions
  - For simplicity carbon refers to CO2e (equivalent) emissions

- Land use impacts
  - Practices that benefit from improving CO_2 sequestration can receive payment.
    - Land management decisions, such as tillage choice, annual vs. perennial, dedicated energy crops or agro-forestry.
  - Land clearing must consider the cost of carbon emissions released.
    - When land is converted there can be a very large one time emission of carbon
    - Clearing Forest land releases up to 500 tonnes/hectare
    - Clearing shrub land releases up to 250 tonnes/hectare

- The carbon market has impacts on input prices
  - It affects general energy prices and agricultural inputs, such as farm fuel and fertilizer
    - $1 increase of the carbon price increases fertilizer cost by 0.238% and farm fuel cost by 0.14%.
  - Renewable energy benefits from displacing fossil fuel based energy and reducing emissions.
    - Reductions in GHG per unit of biomass used for renewable energy are as follows

    ~ 1.4 tonne CO_2 reduction per tonne biomass for thermal-generated electricity

    ~ 0.17 tonne CO_2 reduction per tonne biomass for cellulosic ethanol

    ~ 0.1 tonne CO_2 reduction per tonne biomass for grain ethanol

CRAM provides significant coverage of most major agricultural activities

- CRAM's coverage of agricultural activities includes:
  - All major grains and oilseed crops by region and cropping practice (grown on summerfallow or stubble, use of tillage)
  - Livestock: beef, hogs, poultry and dairy
  - Some processing activities: oilseed crushing, dairy products, biofuels
  - All of these activities are fully integrated. For example changes in the cropping sector that affect feed availability will have an impact in the livestock sector
- CRAM allows interprovincial trade and international trade
  - Limited characterization of the international market which assumes price taker for most agricultural commodities
- CRAM relies on a variety of data sources to construct its baseline
  - Census of Agriculture
  - AAFC's Medium Term Outlook
  - OECD and USDA for international indicators

CRAM

CRAM uses the positive mathematical programming (PMP) methodology to create a non-linear model

- The basic idea of the PMP approach is to build the model in steps:
  - A LP-model calculates dual values
  - Dual values are used to construct non-linear cost curves
- The PMP methodology has several attractive characteristics
  - Artificial constraints can be eliminated and production technology that was represented by a fixed input mix can be replaced by upward sloping supply relationships.
  - Data requirements are relatively modest
  - PMP models can be calibrated exactly to their reference situation
- CRAM uses PMP on costs as opposed to yields
  - The underlying assumption is that as more land is brought into production, costs increase to preserve yields
  - This represents the heterogeneity of land
- Howitt (1995) provides a detailed overall description of the PMP methodology

CRAM

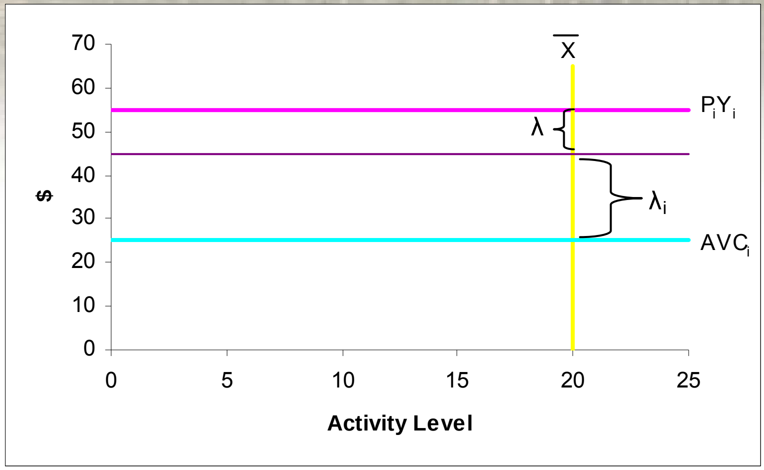
A mathematical and geometric representation of how the PMP methodology functions

A short overview of the mathematics behind the PMP technique:

1. A LP-model calculates dual values

$$\underset{X_i}{Max}\,\ell = \sum_{i=corn}^{I}(P_iY_i - AVC_i^{LP})X_i + \lambda^{LP}(\bar{x} - \sum_{i=corn}^{I}X_i) + \sum_{i=corn}^{I}\lambda_i(\bar{x}_i + \varepsilon_i - X_i)$$

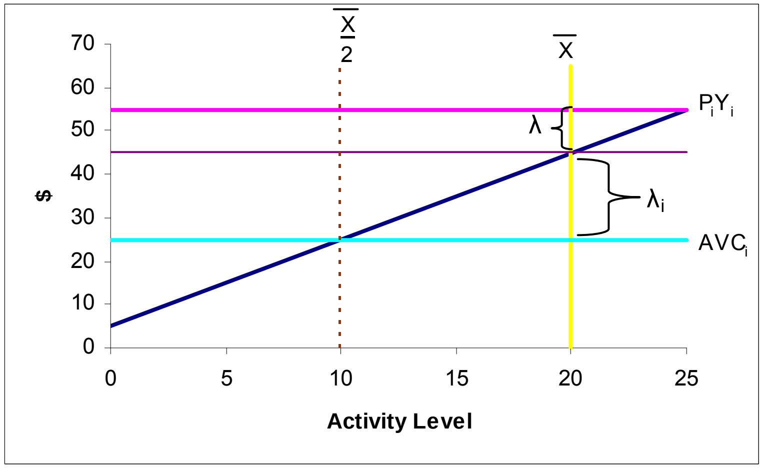
$$\frac{\partial \ell}{\partial X_i} = P_iY_i - AVC_i^{LP} - \lambda^{LP} - \lambda_i = 0 \qquad P_iY_i = AVC_i^{LP} + \lambda^{LP} + \lambda_i$$



2. The information contained in dual values are built directly into the cost functions which are assumed to be quadratic

$$\underset{X_i}{Max}\,\ell = \sum_{i=corn}^{I}(P_iY_iX_i - C_i(X_i)) + \lambda^{NLP}(\bar{x} - \sum_{i=corn}^{I}X_i)$$

$$\frac{\partial \ell_i}{\partial X_i} = P_iY_i - \frac{\partial C_i}{\partial X_i} - \lambda^{NLP} = 0 \qquad P_iY_i = \frac{\partial C_i}{\partial X_i} + \lambda^{NLP}$$



3. Based on work by Howitt we can make a link between the linear and non-linear phases of the model

$$\frac{\partial C_i}{\partial X_i} + \lambda^{NLP} = AVC_i + \lambda^{LP} + \lambda_i \qquad \text{since } \lambda^{NLP} = \lambda^{LP}$$

$$\frac{\partial C_i}{\partial X_i} = AVC_i^{LP} + \lambda_i$$