Section D2. Research Program

2.1. BIOCAP's Objectives, Themes and Case Studies

The Objectives of the BIOCAP Network are to develop the scientific insights, technological innovations, economic & policy analyses that will:

- Optimize cost-effective biomass production and greenhouse gas sequestration by:
  Objective 1. Understanding and quantifying biosphere, economic and social processes that affect GHG exchange;
  Objective 2. Identifying and verifying cost-effective management strategies for sustainable approaches to sequester C and manage greenhouse gases (GHG) in the Canadian biosphere.
- Optimize biomass usefulness and reduce dependence on fossil fuels by:
  Objective 3. Selecting and engineering plants with enhanced biomass production and value;
  Objective 4. Developing bioprocess engineering tools that will use biomass as an alternative fuel, chemical or material resource.

The four primary objectives of the BIOCAP Network will be addressed though the

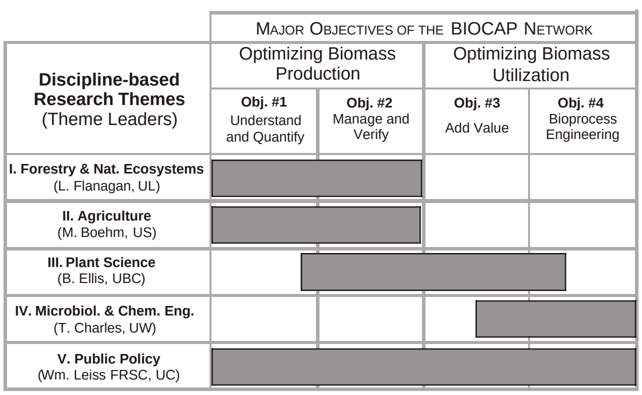

Fig. 2.1. *Relationships among the four Major Objectives of the BIOCAP Network, and the five Discipline-based research themes that will manage the projects and meet the objectives.*

collaborative research efforts of five, discipline-based research themes (Fig. D2.1). The research themes also provide the management structure for the BIOCAP Network since the Theme leaders report to the Program Leader, and are responsible for coordinating the research projects within each of their themes.

Case Studies: To facilitate the application of the Network's research objectives into concrete and achievable deliverables, working groups will be established in the first year to define and implement specific case-studies. Progress reports will be issued each subsequent year and the Research Planning Committee of the Network will draw on these reports to make decisions regarding future projects. This provides BIOCAP with the flexibility to direct research efforts and respond effectively to new results and emerging issues. Examples of case-studies (with most relevant Theme areas) and their objectives are:

- Forest Carbon Management (Themes 1,3, 5).
- Afforestation or Fibre Crops (Themes 1,2,3,5)
- Soil GHG Management (Themes 2,3,5
- Sustainable, Bio-based Industrial Processes (Themes 3,4,5).

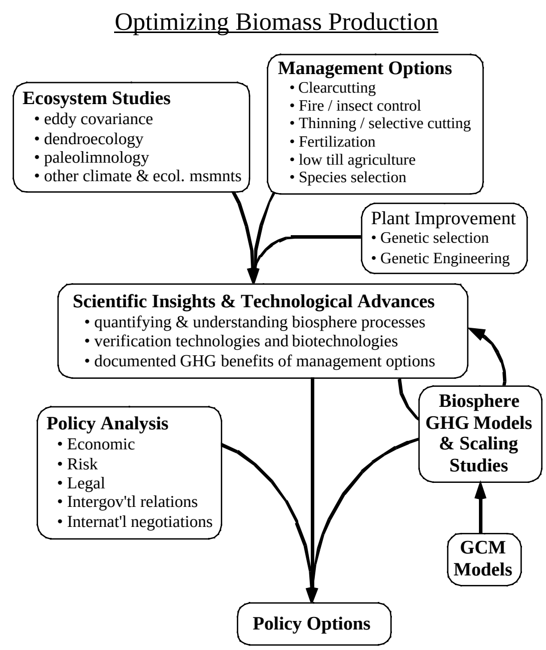

Fig. 2.2. *Strategic Plan for how the various projects within the BIOCAP Network will work together to develop policy options that would optimize biomass production.*

For example, Fig. 2.2 summarizes how the various research projects of the BIOCAP Network will work together to develop valuable policy options for using the Canadian biosphere to optimize biomass production and offset GHG emissions associated with fossil fuels. In this example, a number of sophisticated studies of natural and managed ecosystems, and plant breeding / genetic engineering, we will develop critical scientific insights and technological advances. These will be coupled with a number of models and scaling approaches to develop both a defendable national C budget and reliable predictive models on how land use change could be used to enhance biosphere C sequestration in this country.

The more promising of the management strategies will be subjected to detailed policy analyses, including economic, risk dialog and an assessment of the legal, intergovernmental and international implications for implementation and C crediting.

This strategy would be relevant to the first three Case Studies mentioned about. A similar multidisciplinary approach will be used to develop the science, technology and policy options associated with alternative, bio-based fuel, chemical and material resources.

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The Research Projects are presented in the following sections according to the Theme to which they have been assigned. Each Theme will begin with a background discussion and literature review, followed by an overview of the projects, highlighting theinter-relationships and relevance to the Objectives. Finally, brief descriptions of the individual projects will be presented.

2.2. Theme 1. Forestry and Natural Ecosystems.

Theme Leader

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Background

If we are to manage our forests and natural ecosystems for GHG emissions, then we must better understand many of the processes that effect GHG uptake and release from the biosphere. We must gain an appreciation of how GHG uptake and release is affected by our climate, by severe weather events (ice storms, drought, floods), by natural processes (insect infestation, fire) and by human activity (forestry practice, etc.). Then we must be able to take these insights and develop the tools that will allow them to be scaled to a regional and national perspective. Such insights will be essential to effective policy decisions in this country.

The Mandate to Manage GHG's

Canada has never had a mandate to manage C within its biosphere, but the Dec 1997 Kyoto conference changed that in a fundamental way. Whether the Kyoto conference is ratified or not, GHG and C management is sure to be among the most important environmental, energy and economic challenges of the next century.

Currently there is much uncertainty about the global carbon budget and the role that terrestrial ecosystems play in that budget (Fan et al. 1998, Lloyd 1999). Over the last few years a number of independent techniques (atmospheric inversions, eddy covariance, forest inventory data, modeling studies) have all indicated that the terrestrial biosphere is a significant sink for carbon dioxide released to the atmosphere by human activities (Lloyd 1999, Tans and White 1998). However, mechanisms responsible for net carbon sequestration in terrestrial ecosystems and the exact spatial location of the ecosystems contributing most to the global terrestrial sink remain controversial (Lloyd 1999). A major research challenge is to define more accurately the mechanisms and location of terrestrial sinks for atmospheric carbon dioxide, and how these sinks will respond to changes in climate, land use and management practices.

In Canada two major approaches have been taken to calculate a national carbon budget. Kurz and Apps (1999) have applied the CBM-CFS2 model and calculated that Canadian forest ecosystems were a large net sink for atmospheric carbon dioxide during 1920-1980. Sequestration of carbon from the atmosphere, particularly during 1920-1970, resulted from regrowth of forests after natural disturbance caused by fire and insects. The period 1860-1920 had a higher rate of natural disturbance than 1920-1970, which allowed forest regeneration and the consequent carbon dioxide sink. However, the Kurz and Apps (1999) analysis indicated that the current rate of carbon sequestration has declined because of an increase in average forest age. In addition, because of the older average age of forests they are more susceptible to disturbance, and increased natural disturbance levels (greater than two-fold) have caused Canadian forest ecosystems to be a net source of carbon dioxide to the atmosphere during 1980-1990. The CBM-CFS2 model illustrates the important effects of disturbance and forest age on ecosystem carbon sequestration, however, it does not explicitly include the response of forest ecosystems to annual changes in environmental conditions such as temperature and moisture, atmospheric carbon dioxide, and nitrogen deposition. A number of recent studies have shown that variation in such environmental conditions can have substantial effects on ecosystem carbon sequestration (Braswell et al. 1997, Goulden et al. 1998, Tian et al. 1998, Chen et al. 1999c).

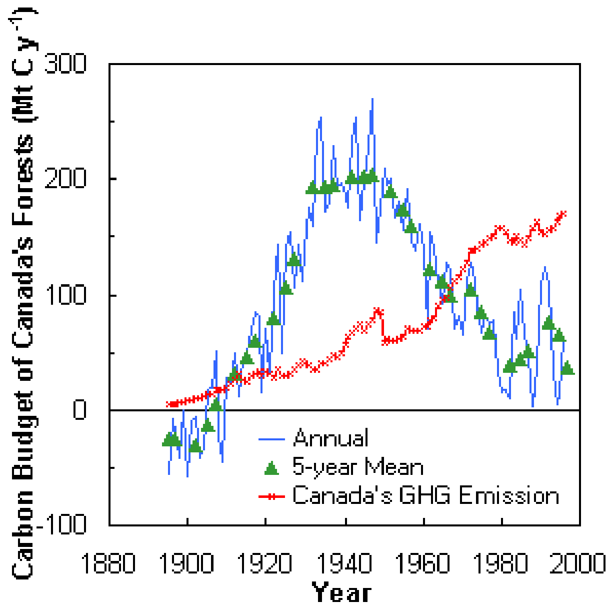

Fig. 2.3. *Carbon budget of Canada's forests from 1895 to 1996. Five-year means are plotted, the last point being only the average from 1995 to 1996. Also included is the record of Canada's greenhouse gas carbon emission rate. (Source CCRS web page: http://www.ccrs.nrcan.gc.ca/ccrs/tekrd/rd/apps/em/beps/nepe.html)*

A second approach to calculating a national carbon budget in Canada, and one that will be explored further in the Theme I project, makes use of an integrated model (InTEC) that includes process information on ecosystem responses to environmental variables and empirical information about disturbances and forest age class distributions (Chen et al. (1999ab). The InTEC model produces very similar results to the CBM-CFS2 model when only disturbances are the source of interannual variability from 1890 to the present. However, substantial differences were apparent between the two models when both disturbance and environmental factors (climate, atmospheric carbon dioxide concentration, N deposition) were included in InTEC calculations. The InTEC model calculated that Canadian forests were a large sink of approximately 170 Mt C per year during 1930-1970 (similar to CBM-CFS2), but that currently (1980-1996) forests are a moderate carbon sink of about 50 Mt C per year (in contrast to the CBM-CFS2 calculation of a source of 50-100 Mt C per year) (see Fig 2.3). Responses of forests to atmospheric N deposition, elevated carbon dioxide, and an increase in the growing season length, and environmental effects on decomposition/nutrient release were among the primary mechanisms contributing to the increase in carbon sequestration calculated by InTEC during 1980-1996 (Chen et al. 1999b). Furthermore, the InTEC model has calculated that forest management practices, such as N fertilization, could significantly increase forest carbon sequestration. Recent ecosystem carbon exchange measurements using the eddy covariance technique in boreal forests have shown substantial interannual variation in response to yearly variation in temperature and length of the growing season (Goulden et al. 1998, Chen et al. 1999c), consistent with InTEC model results.

Before the InTEC model results can be accepted, there needs to be extensive testing of model predictions for the response of ecosystem carbon exchange to yearly variation in environmental conditions and recovery of ecosystems from natural disturbance. This is best accomplished by using an integrated system of monitoring changes in carbon stocks and direct carbon dioxide exchange measurements (using the eddy covariance technique) to rigorously test and validate model responses to environmental conditions. In addition, measurements of gas exchange for ecosystem components are required to interpret the processes (plant and soil respiration, gross photosynthesis, sap flow) that cause the observed variation in net ecosystem carbon dioxide exchange.

Project Overview

The Forestry and Natural Ecosystem theme consists of a series of coordinated projects that will both improve our understanding of the processes that control biomass production in Canada (NETWORK Objective 1), and help to identify and verify management approaches for optimizing biosphere C sequestration in these ecosystems (NETWORK Objective 2).

Project 1A is aimed at determining how carbon exchange and carbon storage in major Canadian ecosystems is currently affected by variation in climate on seasonal and annual time scales. This will be accomplished through ecosystem carbon dioxide exchange measurements made in a national network of towers using the eddy covariance technique. A variety of additional techniques would also be used at each tower site to measure changes in carbon stocks in plants and soil. These measurements will provide mechanistic insights into the processes controlling variation in carbon flux observed at the whole ecosystem.

In a related study, we examine the relationships between tree growth rings and climate, at eddy covariance sites and other locations across the country (**Project 1B**). This work will allow current measurements of forest carbon exchange and storage to be related to recent historical patterns and it may provide a valuable, low cost tool to quantify relative rates of C sequestration, thereby providing a verification of management interventions. The tree ring-climate studies will also allow estimates of changes in biomass sequestration in natural forest ecosystems that will result from projected climate changes, thereby assisting with the development of realistic future carbon budgets.

Since disturbance is a key component of forest ecosystems, **Project 1C** will study how disturbance influences the magnitude of ecosystem carbon exchange and carbon storage. The influence of forest fires and clear cutting on the rate of recovery to the status of positive annual carbon dioxide uptake will be studied using pairs of eddy covariance towers (one tall tower in undisturbed forest and one small tower in disturbed forest).

In related studies, a series of projects (**Projects 1D to 1G**) will use eddy covariance and other technologies to study how changes in forest management practices (thinning, selective cutting, fertilization) alter GHG exchange. Clear cutting mature forests can result in large carbon losses for decades after disturbance. Harmon et al. (1990) calculated that conversion of 1.5 Mha of old growth forest in Oregon and BC has resulted in the release of 1.6 Gt C to the atmosphere. There is potential for alternative forest harvest practices (thinning and selection cutting) to minimize carbon loss by reducing disturbance of the forest soil. We suggest that thinning and selection cutting will not alter the carbon sink strength of forests while providing for continuous long-term carbon sequestration in soils and wood products. However, at present there is little or no data to test this prediction. As demonstrated by InTEC model predictions, fertilization of Canadian forests may also substantially increase net ecosystem carbon storage. The information from **Projects 1D to 1G** is needed to evaluate the costs and benefits of forest management practices.

In **Project 1H** the rate of C sequestration will be investigated in existing and new poplar plantations. Measurements of carbon storage, both above- and below-ground are required for determining the C sequestration potential of poplar afforestation programs. The effect of fertilization on the distribution of C in trees and soil will also be assessed. This information will be used to model above- and below-ground biomass accretion under various management scenarios.

Finally, **Project 1J** will pull all of these data together and scale the insights and information from the landscape level to the regional and national scale. The flux tower stations within BIOCAP will be used to validate two independent process models. The models will then be used, with input parameters derived from remote sensing images and inventory data on climate, forest, and soil conditions, to calculate national carbon budgets. Since the models use independent approaches, their results will be compared and the differences analyzed to evaluate the effectiveness and sensitivity of the models.

A primary goal of this work is to develop a defendable national carbon budget. In addition, we intend to improve our understanding of the processes that influence carbon sequestration by developing, testing and refining models of the processes controlling ecosystem carbon budgets at a range of spatial and temporal scales. The carbon budget models that are developed will increase our ability to make effective decisions about management options for enhancing carbon sequestration. We will also have a better understanding of how Canadian ecosystems are likely to respond to future climatic scenarios.

Project Descriptions

Further details about each of the Theme 1 Projects are provided below. The name(s) of the Project Leader(s) is (are) underlined. The dollar values associated with each title are the average annual NCE request for each of the next 4 years / total annual NCE + Non-NCE budget.

Proj. 1A Spatial and Temporal Variability in Ecosystem C Budgets ($283K/$594K)

Objectives: (i) To document and quantify the impact of annual climate variations (eg. length of growing season, soil moisture, air temperature, etc.) on ecosystem CO_2 exchange and net carbon sequestration in range of important Canadian ecosystem types. (ii) To provide ecosystem CO_2, water and energy flux data for the development and testing of process-based models that operate at a range of spatial scales.

Researchers: H. McCaughey (QU) & Table D2.1.

Table 2.1. Project 1A Researchers

SubProj	Researchers	Towers	Ecosystem
1A1	H. McCaughey (QU)	1 Existing	Jack Pine, SK
1A2	TA Black (UBC), A Barr (EC), N Livingston (UV)	3 Existing	Aspen, SK; B.Spruce, SK; D. Fir, BC
1A3	L.B. Flanagan (UL)	1 Existing	Grassland, AB
1A4	P. Lafleur (TU), N. Roulet (MU)	1 Existing	Wetland, ON
1A5	P. Lafleur (TU), N. Roulet (MU)	1 Proposed	Wetland, YK

Plan/Methods: We will establish a national network of eddy covariance flux towers to capture the spatial and temporal dynamics of the carbon balance for the major ecosystems of the Canadian landscape. We plan to provide expanded capability and stabilized funding for 6 existing eddy covariance flux towers (subprojects 1A1 to 1A4) as well as establish 5 new flux towers in important forest ecosystems in Canada. Of the proposed new flux towers, one (subproject 1A5) is included in this project and the other 4 (Projects 1D, 1E, 1F, 1G) have separate project descriptions included below because they also involve studies of forest management practices on ecosystem carbon balance.

Schedule/Milestones: Existing Flux Sites, **04/00-04/03:** continuous flux and regular C stock measurements. **09/01-04/01:** evaluation and testing of process-based models for ecosystem carbon, water and energy budgets**. 09/02-03/04**: tower flux and biomass measurements will be compared with those in other ecosystems of the network (and internationally in FLUXNET), and reports will be prepared on the results from the process models and experimental data comparison.

New Flux Sites, **04/00-04/01:** Site selection and equipment installation. **04/01-03/03:** flux measurement. The data and modeling will then be handled as described for the existing sites, above. There will be an annual meeting of researchers involved in the flux tower network. The workshop held in spring, 2003, will be used to integrate our network results with related international studies and identify future directions.

Proj. 1B Current and Historical Patterns of Climate Effects on Tree Growth ($229K/$382K)

Objectives: (i) To measure the observed variability in tree ring widths/volume (and biomass production) in natural forest systems and to relate this variability to fluctuation in climatic parameters. (ii) Utilise climate-tree ring relationships to define, model and predict changes in biomass sequestration in natural forests for future climate scenarios. (iii) To make direct measurements of radial growth using dendrometers at eddy covariance sites.

Researchers: B. Luckman (UWO), Y Bégin (ULa), D.J. Smith (UV).

Plan/Methods: These studies will address interannual and decadal scale variability in tree growth and carbon sequestration: (a) at a site over time with respect to climate variability; and (b) spatially across regions due to variation in local site conditions. These studies will provide a broad spatial and temporal context to assess and interpret the results from the eddy covariance work. Changes in biomass sequestration in natural forest ecosystems resulting from projected climate changes can also be estimated, thereby assisting the development of realistic future carbon budgets.

Schedule/Milestones: 04/00-09/01: a national database will be assembled of existing chronologies; and annual dendrometer studies will commence (**04/01-04/02** for new sites). **04/00-04/03:** new chronologies will be sampled and a climate-tree growth model will be developed. **04/02-04/04:** development of C sequestration models. The eddy covariance sites under Projects 1A, 1D-G will be sampled at various times for calibration at the end of the program.

Proj. 1C Disturbance Effects on Ecosystem C Budgets ($130K/$195K)

Objectives: (i) To assess the impact of disturbance (i.e., burning or harvesting) on net ecosystem carbon exchange by comparing the CO_2 fluxes from disturbed and undisturbed ecosystems. (ii) To determine the rate of recovery of disturbed forest ecosystems to the status of positive annual CO_2 uptake. (iii) To improve our understanding of the physical and biological processes controlling or affecting the exchange of CO_2 between disturbed forest surfaces and the atmosphere. (iv) To provide CO_2 flux data required for the development and testing of models used to simulate CO_2 exchange above disturbed forest surfaces.

Researchers: T.A. Black (UBC); B. Amiro (CFS), see additional researchers below.

Plan/Methods: Pairs of flux towers (one tall tower in undisturbed forest and one small tower in disturbed forest) will be used to compare CO^2 and water vapour fluxes above disturbed and undisturbed forest ecosystems. The two towers of each pair will be located within a few km of each other, so that the soils and weather conditions at

Table 2.2. Project 1C researchers

Sub Proj	Researchers	Disturbance	Ecosystem
1C1	TA Black (UBC), B Amiro (CFS), A Barr (EC), EH Hogg (CFS)	Fire	Aspen, SK
1C2	TA Black (UBC), B Amiro (CFS), A Barr (EC), EH Hogg (CFS)	Fire	B. Spruce, SK
1C3	H McCaughey (QU)	Harvest	Jack Pine, SK
1C4	TA Black, N Livingston (UV), D Spittlehouse (BCMF), M Whiticar (UV)	Harvest	D. Fir, BC

both sites will be extremely similar. The tall towers already exist and are described in project 1A above. There are four subprojects as shown in the table below. Subproject 1C4 will be included as an "adjunct" project of BIOCAP if it receives funds from a NSERC Strategic grant currently under review. No NCE funds are currently requested for this subproject 1C4.

Schedule/Milestones: 04/00-09/00: Installation of equipment. **08/00-09/03**: Measurement and analysis of flux data, first estimates of annual carbon loss from disturbed sites; analysis of seasonal and interannual flux variability, comparison of disturbed and undisturbed sites. **09/02-03/04**: collaboration with modelers to develop/test models for disturbed surfaces, writing of reports and papers.

Proj. 1D Carbon Balance in a Managed Hardwood Forest in Quebec ($104K/$719K)

Objectives: (i) To determine the effect of daily, seasonal and interannual variability in weather and climate on above- and below-canopy carbon, energy and water exchange in an eastern northern hardwood forest. (ii) To determine the effects of selection cutting on ecosystem fluxes and C balance; (iii) To scale these flux results to the regional scale by expanding the ECOLEAP modeling approach so that it can address net ecosystem carbon exchange.

Researchers: H. Margolis (ULa); C. Camiré (ULa); A. Munson (ULa), J-C. Ruel (ULa); P. Bernier (CFS); R. Fournier (CFS); R. Paquin (MRNQ)

Plan/Methods: Researchers will measure and model the net ecosystem exchange (NEE) of carbon, water and energy between a mature – hardwood forest and the atmosphere under both undisturbed and partial harvest (selection cut) conditions using above- and below-canopy eddy covariance flux technology. For pre-cut and post-cut conditions, research will (a) evaluate the influence of variability in climate and weather on ecosystem-level photosynthesis, respiration and net exchange at 30-minute time intervals; (b) link the ecosystem fluxes to net primary productivity and to flux measurements at different time scales ; (c) calibrate and validate ecosystem process models for estimating net ecosystem exchange; and (d) scale these flux estimates from local to regional scales under various climate and selection cut scenarios. This intensive study at the Duchesnay Forest will be imbedded within a more extensive study that examines the effects of selection cutting on carbon stocks and component fluxes across a range of other northern hardwood sites. The hypothesis is that selection cutting does not alter the carbon sink strength of these forests while providing for continuous long-term carbon sequestration in soils and wood products.

Schedule/Milestones: 04/00-09/00: Installation/ testing of equipment. **09/00-10/02**: Measurements and modeling of undisturbed forest, selection cuts at extensive sites. **11/02:** Selection cuts at tower site. **12/02-03/04**: Measurements of stocks and fluxes following partial cutting, modeling, publications and conferences.

Proj. 1E Carbon Sequestration in Managed Balsam Fir Forests ($95K/$239K)

Objectives: (i) To assess the impact of clearcut and partial harvest practices in balsam fir forests on net ecosystem carbon exchange by comparing the CO^2 fluxes from disturbed and undisturbed ecosystems. (ii) To compare rates of recovery from disturbance, to the status of positive annual CO^2 uptake, for clearcut and partially cut forest ecosystems. (iii) To determine the extent to which soil C stores are preserved or enhanced by partial harvesting. (iv) To scale up to landscape estimates for forest responses to alternative harvesting practices.

Researchers: M.B. Lavigne (CFS/UNB), P.A. Arp (UNB), C.A. Bourque (UNB), F.R. Meng (UNB)

Plan/Methods: We will compare carbon cycling in mature balsam fir stands in northwestern New Brunswick with carbon cycling in partially-harvested and clearcut balsam fir sites. The focal point of our experiment is a forest where ecosystem-level carbon exchange will be measured by eddy covariance, before and after a partial harvest. Carbon exchange rates of major ecosystem components will also be measured using chambers in control, partial harvest and clearcut sites.

Schedule/Milestones: 04/00-09/00: Select sites/install equipment. **09/00-09/02**: eddy flux and ecosystem component flux measurements; **09/02**: partial cut and clearcut harvest treatments; reports on undisturbed fluxes and comparison of chamber and eddy flux measurements. **10/02-03/04**: Measurements of stocks and fluxes following partial cut and clear cutting; modeling; publications and conferences.

Proj. 1F Effect of Thinning on Lodgepole Pine Ecosystem C Budgets ($95K/$170K)

Objectives: (i) To document and quantify the impact of annual climate variations on ecosystem carbon dioxide exchange and net carbon sequestration in a lodgepole pine ecosystem in SW Alberta. (ii) To provide ecosystem carbon dioxide, water and energy flux data for the development and testing of process-based models. (iii) To determine the effect of thinning on forest productivity, and ecosystem carbon sequestration.

Researchers: L. Flanagan (UL); J. Wilson (UA); T. Hogg (CFS); R. Whitehead, (CFS)

Plan/Methods: Eddy covariance would be used to measure total ecosystem fluxes above and below the forest canopy. In addition, a range of other techniques would be used to measure carbon acquisition and loss from ecosystem components (eg. allometric equations for tree biomass, litter fall, root growth using rhizotrons, branch photosynthesis and respiration, tree sap flow, soil respiration). Measurements would be conducted in the "treatment" forest for two growing seasons before the thinning treatment was applied. A subset of measurements (biomass increments and major component fluxes) would be conducted at a nearby "control" site that was not thinned. The measurements in the control site would occur both before and after the treatment plot was thinned.

Schedule/Milestones: 04/00-09/00: Select sites/install equipment. **09/00-09/02**: eddy flux and ecosystem component flux measurements; **09/02**: thinning treatment; reports on undisturbed fluxes and comparison of component and eddy flux measure-ments. **10/02-03/04**: Measurements of stocks and fluxes following thinning; modeling; publications and conferences.

Proj. 1G. Forestry Practices and Carbon Sequestration in Ontario ($90K/$298K)

Objectives: (i) To document and quantify the impact of annual climate variations on ecosystem carbon dioxide exchange and net carbon sequestration in black spruce forests in N. Ontario. (ii) To provide ecosystem carbon dioxide, water and energy flux data for the development and testing of process-based. (iii) To determine the effects of thinning, clearcutting, and fertilization on forest productivity and ecosystem C sequestration.

Researchers: H McCaughey (QU); G. Munroe (OMNR); A. Groot (CFS), R. Fleming (CFS), and N. Foster (CFS)

Plan/Methods: Eddy covariance will be used to measure total ecosystem fluxes at 4 sites: control, thinned, clear cut, fertilized. In addition, a range of other techniques would be used to measure carbon acquisition and loss from the ecosystems. Measurements would be conducted in the three "treatment" forests for two growing seasons before any treatment was applied. Fertilization studies using ^{15}N will be used assess the impact of nitrogen limitation on forest productivity.

Schedule/Milestones: 04/00-09/00: Select sites/install equipment. **09/00-09/02**: eddy flux and ecosystem component flux measurements; **09/02**: treatments applied; reports on undisturbed fluxes and comparison of component and eddy flux measure-ments. **10/02-03/04**: Measurements of stocks and fluxes following treatments; modeling; publications and conferences.

Proj. 1H Carbon Sequestration in Hybrid Poplar Plantations ($63K/$70K)

Objectives: (i) To assess carbon sequestration in hybrid poplar plantations. (ii) To develop management techniques for improved C fixation in hybrid poplar plantations.

Researchers: C. Prescott (UBC), D. Burgess (CFS)

Plan/Methods: Whole trees ranging in age from 4-12 years will be excavated to develop allometric regressions for predicting biomass. Tree growth ring samples will also be analyzed. Leaf and root mass, nutrient content, leaf area and litter production will be determined as will nutrient content estimates for whole trees. Ion exchange resins and soil samples will be analyzed to assess on-site nutrient availability. The efficacy of fertilization to improve the efficiency of biomass production and C sequestration will be examined in several existing trials in B.C. from annual height and diameter measurements. The effect of fertilization on the distribution of C in trees will be assessed by sampling above and belowground biomass at three times during a plantation rotation. New fertilization trials will be established on a variety of site types and soil C sequestration will be monitored throughout the rotation. This information will be used to model above- and below-ground biomass accretion under various management scenarios.

Schedule/Milestones: 04/00-03/01: detailed planning with partners, site selection and characterization, sampling of soil and plant tissues. **04/01-03/03**: sampling of soil and plant tissues, nutrient analyses, model development, establish new fertilization trials. **04/03-03/04**: data analyses, model refinement and testing.

Proj. 1J Modeling and National C Budget Calculation ($38K/428K)

Objectives: To validate large-scale ecosystem models using tower flux data and calculate national carbon budgets using remote sensing, climate, and forest inventory data.

Researchers: J. Cihlar (CCRS), J.M. Chen (CCRS); D.T. Price (CFS); W. Chen (CCRS); K. Higuchi (AES); R. Grant (UA)

Plan/Methods: Two large-scale process models will be used in this project. One is the Integrated Terrestrial C-Budget model (InTEC) developed at CCRS. This model integrates the Farquhar photosynthesis model with the Century soil carbon and nitrogen model using new spatial and temporal scaling algorithms. InTEC calculates the influence of climatic variation on annual C and N cycling processes and then combines the information with carbon release data from disturbance processes. A national forest carbon balance is obtained through combined use of the model with satellite, climate, and historical disturbance data. The second model is Foley's Integrated BIosphere Simulator (IBIS). IBIS is a dynamic vegetation model, which simulates the distribution and successional development of vegetation. It uses the Farquhar photosynthesis model and a built-in soil biogeochemistry model, coupled with algorithms to represent competition among different vegetation types. The two models describe biological and physical processes in vegetation and soil using similar principles, but InTEC uses biophysical parameters measured by remote sensing while IBIS simulates them from plant functional characteristics and surface observations of climate and soil conditions. These independent approaches will be compared and differences analyzed. Both models will be further validated using new tower flux data from the eddy covariance network. The EcoSys will be used to investigate detailed C and nutrient dynamics in soil and vegetation associated with stand age, and to help parameterize InTEC and IBIS applied at the national scale. A mesoscale model (AES) will be linked with InTEC to include boundary layer processes in diurnal, seasonal and annual carbon cycle simulations.

Schedule/Milestones: 04/00-03/02: Simulation of soil/vegetation biomass at different stand ages; validation of flux estimates at existing flux sites; analyze forest inventory data for biomass-age relationships; fine-tune InTEC and IBIS for simulating biomass-age relationship; map distribution of total soil C from NPP and stand age. **04/01-03/02**: Compare IBIS predictions of vegetation distribution with NRCan landcover maps; compile gridded climate data for period 1900-2000; calculate and map NPP for 1999-2000 using AVHRR and MODIS data; calculate and map soil respiration and NEP for 1999-2000. **04/02:** Fine-tune InTEC and IBIS using new tower flux data; publications; InTEC and IBIS comparisons for regional averages; finalize the 1999-2000 NPP and NEP maps. **04/03:** Summarize C source and sink statistics by region, latitude, species; publications.

2.3. Theme 2. Agriculture

Theme Leader

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Background

Emissions of GHGs from Canadian agricultural activities in 1996 were estimated to be 64 Mt of CO_2 equivalent, which represents 10% of total Canadian emissions (Environment Canada 1998). While agricultural soil C sinks are not yet included in the Kyoto Protocol, Article 3.4 requires that the Conference of the Parties decide as soon as practical how carbon removals (sinks) in agricultural soils and land-use change be taken into account. The inclusion of soil sinks is important for Canada because there is a large potential to reduce net GHG emissions from agriculture by promoting C sequestration in soils through adoption of conservation tillage and cropping practices, the establishment and maintenance of perennial grasslands, and the maintenance and restoration of prairie wetlands (Smith et al. 1997, Bruce et al. 1999).

Sources and sinks of CO_2 in agricultural soils are reasonably well known (Smith et al. 1997), except for those parts of the agricultural landscape that do not produce commodities, such as wetlands and native grasslands. However, while potential C sequestration by wetlands and grasslands is large, too little is known of the factors regulating C and GHG fluxes in these habitats to reach confident conclusions about their net C sequestration capability or role in GHG mitigation. This information is important because if agricultural soils are included in the Kyoto Protocol, the whole agriculture landscape, including localized wetlands and native grasslands, must be considered in estimates of their C storage capacity.

This project proposes to provide a comprehensive and integrated assessment of the C storage potential of the complete agricultural landscape. It is intended to compliment research that is currently focused on the production lands, such as the Prairie Soil Carbon Balance Project, a large study designed to develop a scientifically credible tool for measuring soil C sequestration for the major annual and perennial cropping systems. Here, we broaden the scope of the Prairie Soil Carbon Balance Project by providing data on the potential of wetlands and native rangelands as C sinks, and the role of carbonates in permanent soil C sequestration. The result of this project will be a landscape approach to C sequestration which integrates research from all land uses within the prairie ecosystem. Specifically, we will produce information on C fluxes for non-cropped soils, integrate University and Governmental research initiatives, and provide flexible and reliable policy options to ensure environmentally and economically-viable stewardship of the prairie environment while meeting our international obligations.

Project Overview

A) Terrestrial. The production of agricultural crops is associated with emissions of all of the major greenhouse gases. In 1996, these emissions included 1.7Mt of CO_2, 23 Mt of CH_4, and 40 Mt of N_2O (as CO_2 equivalents), estimates based on IPCC guidelines for GHG emissions from agriculture (Environment Canada 1998). In general, CO_2 emissions from agriculture were related to net soil loss and the use of fossil fuels, whereas methane emissions were mainly from livestock, while both livestock and crop production activities emitted N_2O. Therefore, optimal GHG management strategies to increase C storage and reduce GHG emissions must consider land-use practises which impact on each of these activities.

The conversion of native Prairie grassland to crop production has resulted in the loss of about 25% of the soil organic C (Monreal and Janzen,1993). The largest losses occur within the first decade of cultivation, after which losses of organic matter gradually diminish until the soil reaches a new equilibrium characteristic of the crop production system (Tiessen et al. 1982, Pennock et al. 1994). Soil organic carbon is lost because cultivation increases the rate of organic matter decomposition, reduces organic carbon and nutrient inputs, shatters soil aggregates which exposes soil organic matter to microbial activity, and increases soil erosion (Pennock and Anderson 1992, Pennock et al. 1994). Improved agricultural practices can reverse that trend. Reduced tillage, adequate fertilization, and elimination of summer fallow can sequester soil C at estimated rates of 0.2 tC ha^{-1} yr^{-1} during the first 20-30 yr of implementation (Bruce et al. 1999) and gradually declining as the system reaches a new equilibrium after about 50 yr (Parton et al. 1999). To sequester C at maximal rates, biomass production must be maintained at high levels; in cropping systems this generally requires nutrient inputs, especially nitrogen (Barrett and Burke 1999). However, N fertilization increases the potential for N_2O emissions (Walsh et al. 1999, Riley et al. 1999) and the transfer of available N from croplands to wetlands. Buffer strips of native grasses and riparian plants at the wetland can take up the N, thereby reducing agricultural N_2O emissions and increasing C sequestration, but such buffer vegetation can saturate at maturity (5-10 yr) and may require periodic harvesting to maintain effectiveness (Mulitsch et al. 1999).

Native grasslands account for a vast area of land within the prairie biome (ecozone) of western Canada. Of the 48 x 10^6 ha in this ecozone, about 33 x 10^6 ha are used to produce annual crops and, to a lesser extent, as perennial pasture and forage. The remaining 15 x 10^6 ha of prairie is composed of a mixture of native and exotic grasses, but has largely been neglected as a potential contributor to GHG exchange and C sequestration. These regions may constitute a significant C sink, as recent research has shown that soil C content is 25% lower under introduced species than native grasses, equivalent to 3.3-4.8 x 10^8 tC in North America (Christian and Wilson, 1999). Similar results are known from other prairie regions (Burke et al. 1995, Dormaar et al. 1995) and appear to result from differences in vegetation species composition rather than land-use history (Christian and Wilson 1999). Unfortunately, little is known of grassland response to stresses such as climatic change, elevated atmospheric CO_2, increased N deposition, and invasion by exotic species, hence it is difficult to determine whether this C sequestration potential can be achieved.

The sequestration of biogenic C as soil $CaCO_3$ (pedogenic carbonate) represents another potential C sink that has not yet been integrated into estimates of soil C sequestration. Inorganic C content exceeds that of organic C in many soils, and at 800-900 Pg globally (Schlesinger, 1995), is at least as large as the C storage potential of the biota. For example, Saskatchewan grassland soils store up to 120 Mg ha^{-1} as pedogenic carbonates, a value equal to that of soil organic C. Pedogenic carbonates can be differentiated from carbonates of geologic origin (parent materials) by their distinctive $\delta^{13}C$ content (Wang and Anderson 1998). While, annual fluxes into the pedogenic C store are small in comparison to organic inputs, carbonates continue to accumulate long after the organic C store is at equilibrium, and may represent an important permanent sink. Recent work on wooded calcareous soils in Saskatchewan suggests that inputs to the pedogenic carbonate store from the biocycling of gypsum by *Populus sp* may be up to two orders of magnitude greater than those observed in other arid regions (5 kg ha^{-1}) and nearly equal to organic C storage (Fuller et al. 1999).

B) Aquatic Lakes, wetlands and reservoirs play a potentially important role in reducing net C flux from the Canadian prairies. For example, permanent lakes and wetlands account for 7.1% of agricultural land-area in Saskatchewan alone (1.7x10^6 ha), despite loss of ~0.5x10^6 ha of wetlands since ca. 1880 AD (Saskatchewan Wetlands 1993). Prairie lakes are predominantly alkaline (pH>8.5) and productive (Chlorophyll >30 μg l^{-1}), hence may exhibit significantly elevated rates of C sequestration when compared to unproductive boreal lakes. For example, Dean and Gorham (1998) calculate that, on a global basis, small lakes bury 0.73 tonnes C (tC) ha^{-1} yr^{-1}, assuming mean organic (12%) and inorganic (2%) C contents and linear accumulation rates of 0.75 mm yr^{-1} and 3 mm yr^{-1} before and after the onset of traditional farming activities, respectively. In contrast, Hall et al. (1999) demonstrate that prairie lakes can accumulate sediments at twice the rate of boreal lakes (1.5 mm yr^{-1} pre-1880, 6 mm yr^{-1} post-1930). As well, surveys of >360 prairie lakes show that sedimentary carbonate content is often unusually high relative to soft-water systems (mean 27.2% of dry mass; Last 1989; Last and Slezak 1988), consistent with high rates of biological decalcification by naturally high algal production. Together, these preliminary data suggest that prairie lakes may sequester $\geq$2 tC ha^{-1} yr^{-1}, assuming similar chemical and biological characteristics across the Prairies. To date, no study has evaluated the potential of wetlands and lakes to balance GHG emissions from agricultural activities.

The magnitude of C storage by prairie aquatic ecosystems will depend critically on land-management practises. Fertilization of agricultural lands was uncommon in western Canada prior to 1960, but is now a major control of aquatic productivity (Hall et al. 1999). In the Canadian prairies, this N causes large algal blooms and chemical changes that greatly enhance permanent deposition of both inorganic and organic C (Hall et al. 1999). Because lakes and wetlands encompass ~10% of prairie-wide agricultural lands, permanently bury C at 2-3x the rate of soils, and have been reduced by 27% as a result of agricultural activities since 1900, management of land-water interactions can play a pivotal role in determining net GHG flux from the prairie ecoregion. Additionally, because past agricultural practises have eliminated over $1.2x10^6$ ha of prairie wetlands since 1880 (Saskatchewan Government 1993), re-establishment of former wetlands on marginal cropland may be one management option which enables individual farms to be carbon-neutral, yet economically robust.

Future climatic conditions will likely affect interactions between terrestrial and aquatic C sinks. As shown by spring flooding in 1999, the aerial extent of prairie wetlands and associated agricultural activity is sensitive to changes in precipitation, hence C sequestration by smaller water bodies will depend on changes in temperature and precipitation. These ephemeral wetlands can account for 50% of standing water in the prairies during wet years (Saskatchewan Government 1993), yet little is known of the magnitude or direction of their C or GHG exchange with the atmosphere or surrounding agricultural landscape. Similarly, the ionic composition, biological productivity and magnitude of inorganic C burial in lakes are also regulated by precipitation deficits (Laird et al. 1996; Vinebrooke et al. 1998), and may be expected to vary in complex manners in response to GHG-induced global warming.

BIOCAP Deliverables. Optimal strategies to reduce GHG emissions, maximize C sequestration and sustain economic health in the prairies will require an integrated management strategy that includes both terrestrial and aquatic habitats. BIOCAP Theme 2 will provide the agricultural industry, government and people of Canada with management options to meet Kyoto GHG commitments which are scientifically credible, economically sensitive and socially responsible. Research will quantify and compare the magnitude of carbon sequestration in both terrestrial and aquatic habitats under a variety of present and projected land-use strategies (BIOCAP Objective 1). In particular, projects will provide the first direct estimates of permanent carbon storage by prairie lakes and wetlands, inorganic C sequestration by soils, and the relative impacts of native and exotic grasses on soil C storage in order to develop a full suite of reliable management options. Critically, this theme evaluates the interaction and consequences of these actions at a variety of scales (farm to Prairie) by using a combination of exhaustive survey, direct experimentation and predictive models (BIOCAP Objective 2). The research will allow farmers to select the best combination of agricultural and land-management practises to achieve carbon neutrality, thereby adding value to land and product. Models will be customized for each climatic region to predict the impacts of land-use changes, evaluate risks due to climate warming, and predict the societal and economic impacts of specific strategy options. Further, the Theme II projects will collaborate with on-going comprehensive regional, national and international agricultural research programs to maximize scientific efficiency and product delivery.

Project Descriptions

Further details about each of the Theme 2 Projects are provided below. The name(s) of the Project Leader(s) is (are) underlined. The dollar values associated with each title are the average annual NCE request for each of the next 4 years / total annual NCE + Non-NCE budget.

Proj. 2A C Sequestration in Prairie Lakes: Impacts of Agricultural Practises and Climate Change ($89K/$233K)

Objectives: (i) Produce the first comprehensive estimate of C sequestration by prairie lakes; (ii) Quantify variations in C sequestration in response to modern gradients of climate and land-use; (iii) Measure how aquatic C sequestration has varied as a function of land use and climate during 1850-2000 AD; (iv) determine whether improved land management diminishes C sequestration by lakes.

Project Team: Leader: P. Leavitt (UR-organic C sequestration); B. Cumming (QU-radiometry); D. Gauthier (UR-GIS lake database); W. Last (UM-inorganic C sequestration).

Methods and Research Plan: Though prairie lakes encompass ~$1.7x10^6$ ha and may sequester over 2 tC ha^{-1} yr^{-1}, little is known of how aquatic C storage varies with climate and land-use practises. Potentially, improved land management will reduce lake fertility, half aquatic C sequestration, and eliminate net C credits for the prairie agro-ecosystem. Modern rates of organic and inorganic C burial will be measured in ~75 lakes organized within a stratified-random sampling design according to wetland size, land use, and regional precipitation. Gamma radiometry (^{210}Pb, ^{137}Cs) will be used to establish sediment chronology, whereas mineralogical, organic geochemical and isotopic techniques will quantify the amount and providence of C accumulation. Modern lake and drainage characteristics (e.g., chemistry, drainage basin, morphometry, production, climate, land-use) will be measured, combined with existing governmental data sets (EC, PFRA), and used to develop predictive models of C sequestration (cf., Rowan et al. 1992) for use in adaptation, management and policy planning. Cores encompassing 150 yr will be obtained from all survey lakes, analyzed to quantify historical changes in C sequestration, and subject to variance partitioning analysis to identify the relative importance of climatic and land-use change as controls of past C sequestration (cf. Hall et al. 1999). Comparison of aquatic and concomitant terrestrial C sequestration under different land management practises will be used to identify the optimal strategy to minimize net-GHG emissions from the prairie biome.

Schedule and Milestones: 04/00: Survey & core lakes; Begin chem. & sediment anal.; Commence lake database (GIS); Install radiochronology facility. **04/01:** Complete chemical and radiometric analyses; Continue sedimentary analyses. **04/02:** Complete sedimentary analyses; Complete GIS data base; Develop models of C sequestration. **04/03:** May 2004 Complete C sequestration estimates and predictive models of C sequestration; Quantify relative importance of climate and land-use as controls of aquatic C storage; Compare aquatic and terrestrial C sequestration.

Proj. 2B Impacts of Global Warming on Aquatic C Sequestration: Risk Assessment using Paleoclimatic Analyses. ($125K/$157K)

Objectives: (i) Reconstruct prairie climate over the past 2000 yr; (ii) Quantify the impacts of sustained climatic aridity on C sequestration in lakes; (iii) Develop risk assessment models for impacts of climate warming on aquatic C sequestration.

Project Team: Leader: B. Cumming (QU-diatoms, radiometry, climate reconstruction); P. Leavitt (UR-pigments, organic C sequestration, stable isotopes); W. Last (UM-mineralogy, inorganic C sequestration); G. Chen (UR-time series models, risk forecasts).

Methods and Research Plan: Development of effective mid-term (~30 yr) C sequestration strategies requires accurate predictions of ecosystem response to global climate change, in particular to the increased prairie aridity predicted from GHG-forced GCMs (Lemmen et al. 1997). Little is known of how the controls and magnitude of aquatic carbon storage will vary under sustained aridity. We will address this issue by measuring historical changes in carbon sequestration in climatically-sensitive prairie lakes under a variety of arid and humid climates. Of particular interest is the observation that the prairies were perpetually arid prior to 1200 AD (Laird et al. 1996) and that instrumental records do not encompass the full range of natural climatic variation (Woodhouse and Overpeck 1998). Six climatically-sensitive lakes identified from *Project 2A* will be chosen to maximize regional representation, climatic gradients, and coherence with eddy covariance measurements and parallel C sequestration studies. Multi-disciplinary paleolimnology (biological, mineralogical, isotopic) will be used to measure circum-decadal changes in organic and inorganic C storage in response to climatic variability over the past 2000 years, a time frame which encompasses both the arid 'Medieval Warm Period' (and the relatively humid 'Little Ice Age'. Climatic reconstructions will be based on standard fossil diatom and isotopic analyses (Laird et al. 1996), anchored in radiometric determinations of sediment chronology (^{14}C-AMS, ^{210}Pb). C content will be determined by elemental and mineralogical analyses (Last 1989), as well as direct estimates of lake production using fossil pigments (Leavitt 1993). High resolution (1-3 yr) reconstructions from three sites will be subject to standard and novel time-series analyses (spectral, point-process, non-parametric, Weibull) to provide quantitative forecasts of impacts of future climatic aridity on C sequestration rates.

Schedule and Milestones: 04/00: Collect and process 10-15 cores; Evaluate site suitability for climatic reconstructions; Commence radiometric, mineralogical and elemental analyses; Develop predictive time series models. **04/01:** Complete high-resolution analysis of Lake 1; Complete radiometry (all sites). **04/02:** Complete high-resolution analysis of Lake 2; Complete time series models; Complete sequestration estimates for all cores. **04/03:** Complete high-resolution analysis of Lake 3; Complete climatic forecasts.

Proj. 2C Carbon cycling in rangeland on the Canadian Prairies. ($30K/$97K)

Objectives: (i) Estimate the quantity of C stored in Canadian Prairie rangeland on a regional basis; (ii) Estimate the above- and below-ground annual net primary productivity of rangeland communities in contrasting ecoregions; (iii) Evaluate the potential for increasing C storage in native rangelands; (iv) Compare C storage on native rangelands with previously cultivated grasslands with introduced grasses; (v) Assess the relative contribution of above- and below-ground plant C to ecosystem C storage.

Project Team: Leader: BH Ellert (AC-biogeochemistry); EW Bork (UA-rangeland management), JF Cahill (UA-grassland ecology), WD Willms (AC-rangeland ecology).

Methods and Research Plan: Native grasslands have been largely neglected as a potential contributor to the exchange of GHGs, despite the observation that C storage in soils varies as a function of prairie vegetation characteristics (e.g., species, history; Dormaar et al. 1995, Christian and Wilson 1999). Researchers will investigate the regulation of C cycling in grasslands and the potential of different vegetation types as C sinks. C and N storage in plant and soil components will be quantified along transects across native, seeded, abandoned, and forage grasslands to estimate distribution. Estimates of C and N storage will be compared with annual net primary production in contrasting plant communities to estimate rates of elemental recycling and the scope for increased C storage under different land management strategies. Results will be scaled up regionally using ongoing AAFC research and historical data from crop insurance and land managers. Impacts of exotic plant species on elemental cycling and net C storage will be quantified using paired experiments and surveys of native and introduced grasslands under differing land management histories (cultivation, graizing intensity and season). The fate of plant C in soils will be assessed using stable isotope technologies in communities that have shifted from dominantly C4 to C3 photosynthetic pathways (Boutton 1997). Field plot measures of soil C on abandoned farmlands will be compared with soil C measures from ongoing AAFC experiments established along a climatic and production gradient from arid grasslands (Onefour AB) to foothill grasslands (Stavely AB) to assess the roles of vegetation composition on root:shoot C partitioning, resource competition, organic matter decomposition, and C sequestration in litter and soils.

Schedule and Milestones: 04/00: Establish field plot experiments on abandoned farmland; Begin above- and below-ground production and decomposition estimates; Install soil and plant sample processing equipment. **04/01:** Survey and sample representative grasslands; Complete soil and plant analyses; Start monitoring C cycling and below-ground productivity in the experimental plots. Initiate compilation of historical rangeland productivity data. **04/02:** Continue grasslands surveys; Measure soil C sequestration and stable C isotope ratios under native and introduced species; Analyze soil and root samples from experimental plots. **04/03:** Estimate regional soil C storage and isotopic shifts; Develop C and N budgets for representative grasslands; Synthesize impacts of management and environmental change on C storage in rangeland.

Proj. 2D Inorganic & Organic C in Soils: Role of Mass Transfer in Regulating GHG Emissions from Prairie Ecosystems ($86K/$172K)

Objectives: (i) Quantify the magnitude of C and N transfer between croplands, flooded lowlands and permanent wetlands; (ii) Determine the magnitude and direction of GHG flux from ephemeral wetlands; (iii) Evaluate the importance of inorganic soil C in landscape GHG emissions; (iv) Compare experimental and eddy covariance estimates of GHG emissions under contrasting prairie land uses.

Project Team: Leader: D. Anderson (US-carbon mass flux, models); E. de Jong (US-magnetic susceptibility); D. Pennock (US-^{137}Cs, GHG flux); J. Hendry (US-stable isotopes; hydrology; GHG flux);); R. Robarts (NWRI/EC-management; aquatic C sequestration); G. Van der Kamp (NWRI/EC; hydrology).

Methods and Research Plan: The magnitude and variance of GHG emissions from agricultural lowlands is poorly known largely because of complex interactions between hydrologic, edaphic and land-use controls. The hydrologcial cycle of the prairie landscape, with a time-frame of decades, is another source of variability in the C sequestration potential of wetlands. Field-based measures of C storage must be interpreted with reference to current conditions within the overall cycle, as sequestration potential will increase and decrease as hydrologic conditions cycle over time.

Redistribution of soils from uplands increases crop production and soil C in lowland sites; however, mineralization of organic matter to CO_2 and CH_4 and denitrification emissions of N_2O may greatly exceed C sequetration when lowlands are flooded (i.e., spring smowmelt) (Gregorich and Anderson 1985; Pennock, 1999). Our assessment of C storage in wetlands will include assessment of C sequestration as pedogenic carbonate under different land uses, based on natural C cycle processes and the magnitude of annual fluxes. The role of inundated agricultural lowlands in the prairie C balance will be measured at three at the St. Denis Wildlife Area, SK, where three decades of landuse and aquatic research have been done by EC and CWS. The sites will represent (i) ephemeral wetlands within an uncultivated landscape, (ii) wetlands within a cultivated landscape, and (iii) an infilled (former) wetland within a cultivated landscape. Soil erosion and the mass flux of C into lowlands will be measured using ^{137}Cs and magnetic susceptibility technologies (de Jong et al. 1998). Seasonal estimates of GHG emissions based on chamber measurements will be taken throughout the year. Stable isotopic analyses (∂^{13}C, ∂^{15}N) will be used to determine the relative importance of organic and inorganic materials in soil C fluxes and GHG emissions (Wang and Anderson, 1998). Comparison of C storage capabilities of lowlands with those of croplands, grasslands (***2C***) and lakes (***2A***) will be used to determine the best hydrologic strategy (flood, dewater, maintain) to optimize C sequestration in ephemeral wetlands. Companion sites, studied at less detail, will be selected in the Brown and Black soil zones, mainly for studies of pedogenic carbonate, and cultivation effects on soil, C and nutrient transfers to wetlands.

Measures of the GHG flux, net organic C sequestration, and inorganic carbon sequestration will be interpreted relative to the long-term variations of wetland water levels. A preliminary hydrologic model has been developed by U of S and EC from long-term site data to simulate the long-term relationship between the climatic variations, land-use and wetland water levels (Su et al. 1999). The hydrologic model, together with long-term data on changes of wetland vegetation, will be used as a basis for estimation of net C sequestration over the full cycle of wetland conditions. The model will allow field based measures from short-term studies to be interpreted with reference to the longer-term of decades.

Schedule and Milestones: 04/00: Establish sites; Commence measures of GHG flux, soil erosion and deposition, nutrient and carbon transfers, and hydrologic model development. **04/01:** Continue GHG monitoring at main site; initiate work on pedogenic carbonate; establish site in Brown soil zone. **04/02:** Continue as in 2002; add site in Black soil zone. **04/03:** Complete field studies; data analyses and modeling; Interpret field results with reference to the hydrologic model.

Proj. 2E Impacts of Land Use, Climate Change and Policy on Agriculture and its Carbon Sequestration Potential. ($29K/$61K)

Objectives: (i) Adapt the Farming Systems Model (FSM) to include wetland and grassland C budgets; (ii) Apply the FSM model to select prairie ecodistricts under contrasting climate change and economic policy scenarios; (iii) Quantify interactions between economic, climatic and biological constraints on C sequestration potential for the Prairies.

Project Team: Leader: M. Boehm (US- soil quality, farming systems, GHG emissions); K. Belcher (US - agricultural and ecological economics, wetland research).

Methods and Research Plan: The Farming System Model (FSM), developed within the Centre for Studies in Agriculture, Law, and the Environment at US, is a computer simulation model that dynamically integrates the biophysical and economic components of prairie farming systems. Applications include evaluation of climate change, and transportation policy impacts on the economic and environmental sustainability of conventional and alternative farming systems (Boehm and Belcher, 1998; Belcher and Boehm, 1999). Research will improve the FSM model by the addition of grassland and aquatic components.. The spatial foundation of the FSM is the ecodistrict, which delineates a relatively homogeneous bio-physical environment. Ecodistricts will be selected to represent a range of landscapes and farming systems for the Prairie region and carbon sequestration will be modelled, utilizing information from existing literature and data from *Projects 2A*, *2B*, and *2D*. Simulations representing current climatic and economic conditions will be run to provide baseline land use and carbon sequestration results. Possible future scenarios of climate change and agricultural policy will be developed, parameterized within the model, and simulated for assessment relative to the baseline results. Scenarios will be evaluated for each agricultural landscape on the basis of relative differences in carbon sequestration, land use, farming system economic viability, and environmental benefit (i.e., soil quality, wildlife habitat, wetland and crop productivity, and production risk). Policy options / climate change combinations that maximize carbon sequestration, minimize GHG emissions and foster sustainable farming systems will be identified.

Schedule and Milestones: 04/00: Integrate data from on-going C sequestration initiatives; Select ecodistricts and farming systems; Develop baseline parameters, climate change and policy scenarios. **04/01:** Develop and integrate grassland component of FSM; Commence wetland module. **04/02:** Develop wetland C sequestration model; Complete baseline simulations. **04/03:** Complete scenario simulation; Assess relative potentials for cropland and wetland C sequestration; Identify optimal strategies.

2.4. Theme 3. Plant Science

Theme Leader

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Background

To effectively exploit the biosphere management opportunity provided by Canada's large landbase/population ratio, we need to maximize the carbon capture capacity of our landscapes while ensuring that we derive the greatest possible economic benefit from the accumulating biomass. Carbon retention in the Canadian biosphere can be influenced by many ecological and anthropogenic factors, several of which will be explored within Objectives 1 and 2. However, it is also clear that large increases in fixed carbon can potentially be attained on a 10 - 70 year rotation by deployment of intensive plantings of fast-growing trees. Such a large-scale afforestation program is an attractive option for a country in which at least 8 million hectares of previously cleared marginal farmland exist, largely in western Canada (Nagle, 1990). With appropriate policies and economic incentives in place, much of this marginal land could be rapidly converted to plantations of aspen and hybrid poplar. Intensive management of such plantations is capable of increasing wood production (and carbon sequestration) by 500 - 1000% compared to native stands (Guy and Benowicz, 1998). *Populus* spp. are the most promising candidates for such an enterprise for the following reasons:

- they display impressive growth rates (up to 50 m^3/ha/yr) in north temperate climates (DeBell and Harrington, 1997), and have been cultivated for over 30 years in central Europe,
- they can be grown in most parts of Canada,
- they provide solid wood, fibre and other lignocellulosic feedstocks for an established industry infrastructure,
- considerable research expertise in poplar culture and utilization exists in Canada, particularly in Quebec, Ontario, Alberta and B.C.
- the genus is well-suited for application of the tools of biotechnology and molecular breeding.

Unlike crops, forest trees have never been domesticated, and breeding for tree improvement is still in its infancy. Nevertheless, a high degree of genetic diversity exists within tree species, which offers great potential for systematic genetic gain. Earlier breeding and selection efforts will therefore be extended through molecular breeding, to build a rapid germplasm improvement program. Adding further value to plantation biomass can potentially be achieved through genetic engineering, with a particular focus on genes that shift the carbon allocation within poplar wood. Genetic constructs to be tested should be capable of reducing lignin accumulation while favouring cellulose synthesis (Hu et al, 1999), or of modifying the structure of lignin to make it more easily extracted (lower energy costs) and of greater industrial value.

The efficiency of plants as carbon sequestration sinks is ultimately controlled within the photosynthetic machinery, and plants are presently adapted to a low CO_2 environment (Stitt, 1991). We propose to identify the genetic controls that limit carbon fixation in the higher CO_2 atmosphere that is developing as a result of GHG build-up.. For this purpose, we will exploit the power of *Arabidopsis* genetics, the most highly developed model plant system available in modern biology. The ability of plant genes to work effectively across species boundaries means that knowledge and tools gained in *A. thaliana* can then be readily deployed in poplar.

Finally, Canadian farmers already fix enormous amounts of carbon each year in the form of both traditional and transgenic annual field crops grown on ca. 40 million ha of arable land.. This activity offers many opportunities for genetic improvements affecting either carbon management or biomass quality. Several of these will be explored in trial studies to learn which offer the greatest potential economic and environmental benefits and thus justify in-depth development .

Project Overview.

The superior biomass productivity of hybrid poplar and aspen has been clearly demonstrated in both Europe and North America, but most of the currently available varieties are adapted to warmer climates than we experience in Canada. For deployment in western Canada we need to evaluate and select genotypes that can demonstrate excellent productivity and quality across the relevant biogeoclimatic zones. A broadly representative collection of poplar genotypes will therefore be field-tested on both warm and cold climate sites in **Project 3A1**, and breeding populations initiated from desirable parents. Breeding cycles in slowly reproducing species such as trees can be dramatically shortened through the use of molecular markers. Therefore, in **Project 3A2** we will exploit the progeny populations from the existing poplar breeding program in the Poplar Molecular Genetics Cooperative in Washington to identify genetic loci controlling broadly heritable traits (QTL) of importance to Canadian conditions and markets. Beyond the existing genetic diversity within Populus lies a vast potential for altering plant carbon biology through genetic engineering of metabolism. This can be pursued from a number of directions, starting with the fundamental process of photosynthesis. Homeostatic mechanisms that have evolved within existing plants appear to limit their ability to take full advantage of higher CO_2 atmospheres. The molecular control points behind those mechanisms can often be revealed through mutational analysis, and in **Project 3B1** populations of insertionally-mutagenized *Arabidopsis* will be screened for new phenotypes that are responsive to high CO_2 atmospheres. These will be physiologically characterized and, if promising, the tagged genes will be isolated for transfer to other test species, including poplar. DNA microarray technology will also be used, in **Project 3B2**, to detect gene expression patterns associated with biomass accumulation under high CO_2, and the interplay between CO_2-responsive genes will be identified for future exploitation. An alternative approach will be explored in **Project 3D1**, where a novel chemical treatment will be used to trigger increased photosynthesis. The responding genes will be characterized and compared with those identified through Projects 3B1 and 3B2.

It will not suffice to increase C-sequestration through afforestation without simultaneously creating added value in that new biomass. The commercial value in lignocellulosic biomass currently resides in the glucan component, and genotypes with an improved cellulose:lignin ratio have immediate preference in both the pulping and fermentation industries. In **Projects 3C1** and **3C3**, we will demonstrate the potential for directly altering this ratio in transgenic poplar by deploying specific transgenes that suppress lignin accumulation, increase cellulose synthesis and/or create more easily extractable lignin. As successfully modified genotypes are developed, these will be evaluated by the researchers in Theme 4, whose close collaboration will help guide future engineering efforts. At a more fundamental level, we will use insertional mutagenesis in Arabidopsis to identify the genes that control the formation of lignified cell walls in plants (**Project 3C2**), in order to design the next generation of molecular tools for manipulating the content of woody tissues.

A range of opportunities can be identified for addressing carbon management issues with transgenic technology within Canadian crop systems. In **Project 3D6**, these options will be extended and subjected to a rigorous, user-oriented economic analysis. Several projects with clear potential will, however, be initiated immediately. The first (**Project 3D2**) involves the development of a self-retting flax genotype that would enable oil-seed flax straw, millions of tonnes of which is currently burned each year on the Canadian prairies, to serve as a cost-effective feed-stock for the fibre industry. In **Project 3D5**, we examine the impact of expressing novel fatty acid hydroxylase genes in oil-seed flax in order to convert linseed oil to a high-value industrial feedstock for the chemical industry. The recent availability of a multi-generation progeny population in flax gives us a unique opportunity in **Project 3D3** to map the flax genome and thus identify the genetic basis of numerous valuable traits in this crop, including fibre properties, oil quality, yield and hardiness. Finally, in **Project 3D4**, we will explore the potential for sequestering additional carbon in crop root systems, and hence in the soil, by specifically engineering increased root lignification, using canola as the test system.

Project Descriptions

Further details about each of the Theme 3 Projects are provided below. The name(s) of the Project Leader(s) is (are) underlined. The dollar values associated with each title are the average annual NCE request for each of the 4 years / total annual NCE + Non-NCE budget.

Proj. 3A1. Selection of optimal poplar genotypes for afforestation in western Canada. ($86K/$162K)

Objective*:* To develop high-yielding *Populus* genotypes suited to the full range of major planting sites across western Canada.

Researchers: Rob Guy (UBC), S. Aitken (UBC; R.P. Pharis FRSC (UC); S.B. Rood (UL)

Approach: We will obtain promising germplasm from the wild and from existing collections in North America to establish base breeding populations of *Populus trichocarpa*, *P. balsamifera*, and *P. deltoides*, as well as representative standard hybrids (approx. 225 accessions). Replicated raised bed trials will be conducted at two sites (Lower Mainland and Prince Goerge area) representing climatic extremes, with a primary focus on assessment of genetic variation and environmental response in biomass accumulation. Specific traits to be assessed include photosynthetic capacity, C-allocation, phytohormone profiles, crown form, drought resistance, nutrient uptake capacity, resource use efficiencies, wood quality and frost hardiness. Promising parental material will be selected for controlled crosses, and progeny populations will be evaluated for a similar suite of traits.

Timelines: 04/00-09/00: trial gardens built and planted, **01/01-12/03:** physiological and field performance data collected

Proj. 3A2. Molecular tools for poplar improvement. **($54K/$98K)**

Objective: To establish the molecular basis of superior growth and quality traits in poplar.

Researchers: Carl Douglas (UBC), Peter Constabel (U.Alberta)

Approach: In cooperation with Project 3A1, and with P. Watson and S. Potter (Paprican), QTL mapping within existing pedigrees (Poplar Molecular Genetics Cooperative, Washington) will allow us to establish the heritability of physiological and structural traits of interest. Placement of microsatellite markers, in cooperation with T. Bradshaw, U. of Washington, will generate molecular probes that can be used for early-progeny testing in the breeding program. The availability of a poplar BAC library (obtained by UBC from Texas A&M University) will enable us to anchor the most promising QTLs to BAC contigs and move toward direct identification of the relevant genes.

Timelines: **04/00-04/01:** high density mapping near QTL of interest, **04/00-11/02:** complete BAC map near QTL, **11/02-12/03:** sequence target region and identify genes

Proj. 3B1. CO_2-response gene mutants in *Arabidopsis* ($100K/$189K)

Objectives: To create a saturated mutant population of Arabidopsis and locate phenotypes with altered physiological responses to high CO_2

Researchers: George Haughn (UBC), P. McCourt (UT), , J. Coleman, (UT), R. Sage (UT)

Approach: Mutational analysis in *Arabidopsis* has proven to be a powerful approach to establishing the genetic basis of physiological traits in plants, and when combined with insertional mutagenesis, also allows direct isolation and identification of the relevant genes. This approach will be exploited to identify genes that control key regulatory steps in carbon assimilation and partitioning pathways. A full genome coverage (50,000) T-DNA-tagged collection of *Arabidopsis* lines will be developed and carried through to the T3 progeny level. These will be screened for aberrant growth capacity under elevated CO_2 conditions, relative to wild-type plants. Confirmed mutants will be characterized with respect to source-sink relationships, photosynthetic capacity and developmental timing. The tagged gene(s) will be isolated and identified, and their function confimed by mutant complementation and/or phenocopying in transgenic plants.

Timelines: **04/00-03/02:** transformation and selection of new T1 population, **10/00-07/02:** generation of new T3 amplified lines. **04/00-07/03:** gene i.d. and isolation from existing lines. **10/02-10/03:** gene i.d. and isolation from new lines

Proj. 3B2. Patterns of CO_2 response gene expression ($46K/$65K)

Objective: To identify, by DNA microarray analysis, the array of genes differentially expressed during adaptation to higher CO_2 environments

Researchers: Peter McCourt (UT), John Coleman (UT)

Approach: Differential gene expression technologies, including classical mRNA differential display, will be exploited to detect more complex gene expression patterns that are specifically associated with growth of *Arabidopsis* under low and high CO_2 regimes. Genes whose expression is clearly correlated with adaptation to elevated CO_2 will be isolated and identified. At a later date, DNA microchip array analysis will be employed, using a custom 2000 gene array, to map the global patterns of gene expression associated with physiological adaptation to higher CO_2. In the long term, gene constructs that are potentially capable of improving photosynthetic carbon fixation in higher CO_2 environments will be tested in transgenic *Arabidopsis* and the most promising constructs will then be expressed in transgenic poplar (and selected crop species) for detailed evaluation

Timelines: **04/02-06/03:** differential display analysis completed, **01/03-12/03:** PCR amplification of 2000 genes

Proj. 3C1. Modification of lignin quantity and quality ($83K/103K)

Objective: To develop transgenic strategies for reducing the relative amount of lignin, particularly guaiacyl lignin, in plant secondary walls.

Researchers: C. Douglas (UBC), B. Ellis (UBC), Doug Kilburn (UBC)

Approach: 4-Coumarate CoA ligase (4CL) catalyzes a crucial step that allows hydroxycinnamyl-CoA substrates to be directed toward lignin synthesis. Recent results in transgenic poplar and Arabidopsis have suggested that suppression of 4CL activity can alter both the quantity and type of lignin formed. We plan to probe the poplar genome for further members of this gene family, and then manipulate the ability of transgenic plants to express each of the 4CL isoforms, using gene-specific antisense strategies. In collaboration with J. Noel (Scripps Institue) we are working toward the crystal structure of 4CL. If this proves successful, we will use protein engineering (site-directed mutagenesis) to alter the affinity of 4CL for specific hydroxycinnamic acid substrates, and test the impact of these mutant forms in over-expressor transgenic plants. Other gene constructs to be tested in transgenic poplar plants will be apoplastic expression of cellulose binding domains (CBD), which have been reported to increase cellulose biomass accumulation in preliminary experiments (collaboration with O. Shoseyov, Hebrew University), and over-expression of sucrose synthase (SuSy), the major substrate supplier for cellulose synthesis (collaboration with D. Ellis, Silvagen Ltd.).

Timelines: **0400-12/01:** generate full array of AS-4CL, CBD and SuSy transgenics. **10/01-12/03:** analyze transgenes and phenotypes. **01/02-12/03:** model 4CL active site; create and evaluate novel mutant structures.

Proj. 3C2. Tagging genes that control secondary wall formation. ($63K/$90K)

Objective: To isolate and characterize Arabidopsis genes essential for deposition of secondary walls.polysaccharides and lignin.

Researchers: George Haughn (UBC)

Approach: An initial screen has detected several Arabidopsis mutants that are altered in their ability to undergo normal seed coat differentiation.. One of these (*mum4*) fails to form the massive secondary walls so characteristic of crucifer seed coats. We will extend these observations through an exhaustive screen of T-DNA tagged *Arabidopsis* mutants (using existing collections, as well as the new array to be generated in Project 3B1). The mutants will be characterized with respect to defects in secondary wall formation, and the corresponding genes will be isolated, characterized and tested for the effects of ectopic expression in either sense or anti-sense orientation. The most promising genes will be further tested in poplar, as a means of establishing overall control of wood deposition rates.

Timelines: **04/00-08/02:** complete mutant screening. **01/01-04/03:** characterize new mutants; clone and express new genes. **04/00 - 08/02:** clone, analyze and express *MUM4*

Proj. 3C3. Delivering functional proteins to the cell wall for added biomass value. ($53,000)

Objective: To develop transgene cassettes that drive synthesis of heterologous proteins, coupled with secretion and retention in the apoplastic compartment.

Researchers: Brian Ellis (UBC), Carl Douglas (UBC), Doug Kilburn (UBC)

The plant cell wall represents a major storage region in growing plants, with great potential for ectopic expression of useful proteins. We will develop expression cassettes that combine efficient apoplastic protein secretion signals with model reporter proteins (GFP; GUS) to fully define the secretion path. We will include novel N- or C-terminal motifs (CBD; polyY) designed to anchor the secreted protein in the wall. The effectiveness of these constructs for driving accumulation of industrially useful proteins in the wall, and thus creating inexpensive immobilized enzyme matrices, will be evaluated. The potential for incorporating wall-modifying enzymes into the apoplast and thus creating more readily harvestable biomass, will also be tested using fungal lignin peroxidase as an example..

Timelines: 04/00-12/00 Prepare transformation constructs; **12/00-08/02** Produce and evaluate primary transgenics; **06/02-12/03** Analyze protein expression phenotypes (wall content, stability, activity)

Proj. 3D1. Genes controlling rates of photosynthesis ($20K/$25K)

Objective: To measure gene expression patterns related to chemically-induced changes in plant photosynthetic rates and thus identify genes regulating the rate of photosynthesis.

Researchers: Donald Smith (McGill), Marc Fortin (McGill).

Approach: We have observed that photosynthetic rates in corn and soybean can be dramatically up- or down-regulated by treatment with lipo-oligosaccarhides (LCOs), salicylate or sucrose injections. The effects of LCOs, SA and injected sucrose will be verified in *Arabidopsis* and canola. Data will be collected on photosynthetic rates, stomatal aperture, leaf internal CO_2 levels, plant growth rates (based on dry weight), and time to developmental stages. mRNAs will be collected from treated plants at different times to monitor gene expression levels. Expression patterns associated with imposition of treatments, and with the onset of homeostatic corrections will be identified. A collection of 200 ESTs representing genes that may be involved in homeostatic regulation of photosynthesis, as well as 200 ESTs of unknown function will be arrayed. ESTs that appear be responsive will be fully sequenced. In parallel, we will use quantitative AFLP to monitor other treatment-related changes in gene expression outside the 400 ESTs used above.

Timelines: 04/00-09/00 Verification of physiological responses in *Arabidopsis* and canola; **09/00-03/01** Preparation of the arrays; **03/01-09/01** Analysis of expression patterns; **06/01-03/02** Cloning and characterization of relevant genes; quantitative AFLP analyse

Proj. 3D2. Self-retting flax. ($20K/$30K)

Objective: To create a transgenic oilseed flax genotype whose cellulose fibres can be isolated from post-harvest straw without the need for traditional field-retting.

Researchers: Graham Scoles (US), Ron Wilen (US)

Approach: Retting of flax straw allows microbial hydrolases to break down the tough pectic matrix in which the bast fibres are embedded. We propose to by-pass this step by inducing ectopic expression of a plant polygalacturonase at a point when the mature stem tissue is becoming dehydrated. To do this we will employ an Arabidopsis abscission zone polygalacturonase gene (AtPG1), provided by Dr. Michael Tucker (USDA - Beltsville, MD), and clone this behind a barley dehydrin promoter, obtained from Dr. Tim Close (UC Riverside). This fusion product will be cloned into a Ti transformation vector (pSH737) which, in host strain GV3850, enables efficient transformation of oilseed flax.

Confirmed transgenic lines will be grown to maturity in the greenhouse and then subjected to controlled water withdrawal. Expression of the transgene will be monitored by northern blots, and extractable polygalacturonase activity will be assayed. Dessicated plant material will then be subjected to mini-pulping tests in collaboration with Biolin Research Ltd. (Sask) to determine the correlation between PG transgene expression and ease of fibre recovery.

Timelines: **04/00-03/01:** production of primary transgenics. **04/01-03/02** complete replicated dessication trials

Proj. 3D3. Flax genomics ($43K/$63K)

Objective: To understand the genetic basis for the partitioning of sequestered carbon in a major Canadian crop by mapping quantitative trait loci (QTL) in the flax genome.

Researchers: Diane Mather (MU), Thomas Bureau (MU).

Approach: Molecular markers will mapped in flax and QTL affecting the partitioning of sequestered carbon (fibre vs. oil; lignin vs. structural carbohydrates) will be mapped. A mapping population consisting of 175 recombinant inbred (RI) lines has already been developed by Steven Knapp (Oregon State Univ.) from a cross between a fibre flax cultivar and an oilseed flax line. This material exhibits a wide range of intraspecific variation in how it partitions sequestered carbon. To develop a saturated marker map, we will screen the parents for genetic polymorphism, using a novel transposon-based marker system (MITE) recently developed in T. Bureau's lab. Using these markers, RI lines will be genotyped and a linkage map constructed, incorporating MITE loci as well as AFLP and SSR loci from the other labs (Oregeon, Saskatoon) as data become available. We will increase seed of the RI lines, and evaluate agronomic traits and biomass partitioning traits (lignin, structural carbohydrates, oil) on replicated populations grown in Ste-Anne-de-Bellevue, Oregon and Saskatoon. Data on marker genotypes and trait phenotypes will be analyzed to estimate genomic positions and effects of QTLs.

Timelines: **04/00-12/02:** MITE genotyping of RI lines. **04/00-03/03:** complete phenotyping of replicated RI lines. **04/02-03/03:** preliminary genetic map constructed.

Proj. 3D4. High-lignin root systems for carbon sequestration ($30K/$45K)

Objective: To produce and evaluate a crop genotype with selectively increased levels of lignin accumulation in the roots.

Researchers: Brian Ellis (UBC), Wilf Keller (NRC-PBI)

Approach: To enable us to evaluate the potential for sequestering additional carbon within agricultural soils through development of higher lignin root systems, we will create isogenic lines of canola in which different degrees of root lignification have been established by genetic manipulation of the lignin biosynthetic pathway. Woud Boerjan, University of Ghent, has recently found that over-expression in transgenic poplar of a specific isoform of anionic peroxidase (aPRX) results in higher levels of lignification (pers. comm.). Dr. Boerjan has agreed to provide us with this cDNA clone for testing in canola. Dr. R.

Datla (NRC-PBI, Saskatoon) will make available a promoter that provides a high uniform pattern of expression in crucifer roots. Transformation of *Brassica carinata* will be carried out at PBI by Dr. W. Keller. Regenerated transgenics will be assessed for transgene copy number, expression of the transgene, extractable and wall-bound aPRX activity, tissue specificity of expression, and level and distribution of lignin deposition. Transgenic lines (25) differing in their root lignin content will be compared to control lines in greenhouse trials, measuring their agronomic performance and root development pattern. A major change in lignin deposition may be limited by the flux through the biosynthetic pathway that supplies substrates. We will therefore isolate and test *Brassica* homologues of genes (e.g. AtMYB308) that appear to exert an influence on the overall activity of the phenylpropanoid pathway.

Timelines: 04/01-03/02: production of primary aPRX over-expression transgenics. **10/01-06/02:** complete analysis of aPRX transgenes. **04/01-03/02:** complete phenotypic analysis of transgenic plants. **04/01-12/01:** screen *Brassica* genome for regulatory gene homologues. **01/01-03/02**test cloned genes for regulatory in transgenic plants.

Proj. 3D5. Manipulation of flax oil composition for new industrial applications ($45K/$89K)

Objective: To develop transgenic flax varieties accumulating high levels of specific hydroxy fatty acids in their seed oil. Hydroxy fatty acids have a wide range of uses as industrial feedstocks for lubricants, waxes, polishes and polymers.

Researchers: Ljerka Kunst (UBC)

Approach: Flax oil is high in polyunsaturated fatty acids and relatively low (10-15%) in monounsaturated oleic acid. However, a single mutation in the delta-12-desaturase gene will block polyunsaturated fatty acid synthesis and result in the accumulation of oleic acid. Oleic acid is the substrate of the fatty acid hydroxylases for the production of hydroxy fatty acids. We will EMS-mutagenize flax seed (M_1) and screen individual M_2 seeds by gas chromatography (GC) to identify those with high levels of oleic acid (Kunst et al. 1992). The seeds exhibiting major useful alterations in their seed fatty acid profiles will be grown out as M_3 seeds to test for stable inheritance and single mutations. Once a high-oleic flax line has been identified, it will be transformed with castor and *Lesquerella fendleri* hydroxylase cDNAs driven by strong seed-specific promoters. Expression of either one of these hydroxylases in transgenic *Arabidopsis* resulted in the production of hydroxy fatty acids in seeds (Broun and Somerville, 1997; Broun et al, 1998). Transgenic flax plants will be evaluated for the transgene copy number and expression of the transgenes, and the data correlated with the hydroxy fatty acid content in seeds. Crosses will be made between the selected transgenic lines to optimize hydroxylated fatty acid production.

Timelines: 04/01-03/02 Production of M_2 seed population; **10/01-09/02** Complete mutant screen for oil variants. **01/02-12/03-**Complete mutant characterization. **06/02-03/03:** Create hydroxylase transgenics. **04/03-03/04:** Evaluate transgenic lines.

Proj. 3D6. Crop Biomass Opportunity Analysis ($8K/$11K)

Objective: To assess the market potential for selected transgenic plant products developed in Canadian crop systems.

Researcher: Glenn Fox (UG)

Approach: We will conduct case studies of potential applications of genetically modified plants in Canadian agriculture. Specific transgenic products to be investigated will be identified though expert interviews with researchers, industry and producer groups and relevant government officials. Analysis will be conducted at the farm or enterprise level to determine conditions under which these production opportunities would be attractive to producers. In addition, we will evaluate potential market size. Regulatory and trade issues will be investigated as part of the overall assessment of the economic viability of the potential products. Recognized enterprise analysis and commodity market modeling techniques will be employed. The structure of the commodity market analysis component of the project will reflect the relevant parameters of the markets and policies for the product in question.

Timelines: 04/00-09/00 Review literature and carry out expert interviews; **09/00-12/00** Collect data and develop modelling frameworks **; 01/01-12/01** Calibrate enterprise budgets and market level models; complete analyses.

2.5. Theme 4. Microbiology and Chemical Engineering

Theme Leader

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Background

Theme 4 of BIOCAP is focused on the mitigation of GHG emissions through developments in biologically based industrial processes (*bioprocess engineering*). This will be achieved by taking advantage of the metabolic activities of microorganisms to:

- Convert low cost agriculture and forestry carbon substrate (lignocellulosic) waste into fuel or products of value. This waste would otherwise biodegrade, releasing CO_2 into the atmosphere with no added value.
- Convert biomass that has been specifically grown for the purpose into fuels and industrial feedstocks that will help to offset the continuing rise in our dependence on fossil fuels.

The importance of this strategy for Canada is made clear by the predictions of the Shell Planning Group (see Section 1.2). As the fossil fuel domination of the world's energy and material resources is challenged over the next 20-30 years, there will be increasing dependence on renewable energy sources such as wind, biomass, solar and geothermal. Given Canada's large land area (7% of the earth's land) and small population (0.5% of global population), and importance of the agricultural and forestry sectors, the biomass option will be of particular importance to this country. Success in the development and application of bioprocess engineering alternatives to fossil fuels will be dependent on sound engineering, microbiological and biotechnological principles.

The main objective of BIOCAP Theme IV activities is to improve the cost competitiveness of the bioprocessing alternatives by increasing the range and efficiency of the bioprocesses. Activities are therefore directed at:

- Improving the yield of sugar substrate from hydrolysis of lignocellulosic biomass.
- Optimizing the utilization of the sugar substrate by the bioprocessing organisms.
- Optimizing specific product formation during growth on the sugar substrate.

In temperate zones, most biomass is in the form of cellulose or lignin. On hydrolysis, lignocellulosic substrates yield a mixture of monomeric hexoses (glucose, mannose and galactose) and pentoses (xylose and arabinose). Ideally, hemicelulose and cellulose components should all be converted to monomeric sugars (Gregg et al.1998). To achieve this it is necessary to develop pretreatment/fractionation protocols for the recovery of hemicellulose monomers, to develop enzymatic hydrolysis strategies to maximize cellulose hydrolysis, and to address the inhibitory influence of lignin on hydrolysis (Stenberg et al.. 1998).

To ensure the cost competitiveness of the bioprocesses, potential bioconversion microorganisms must be able to ferment both hexoses and pentoses efficiently into product. Many industrial production strains are unable to utilize pentose sugars as a carbon source. The discovery of pentose-fermenting yeasts in the early 1980s by Canadian (Schneider et al. 1981). and US researchers (Slininger et al. 1982) was a significant milestone in this regard. Numerous studies have been carried out in the past 18 years on various aspects of pentose bioconversion by these yeasts. In general, pentose fermentation is much slower as compared to glucose fermentation.

In addition, these yeasts suffer from glucose repression, low ethanol tolerance, and poor performance in the presence of lignin-derived inhibitors. Through metabolic engineering, several recombinant bacterial species (Lindsay et al. 1995) and recently a recombinant *Saccharomyces cerevisiae* strain (Ho et al. 1998) capable of fermenting glucose and xylose simultaneously have been constructed. These strains represent significant improvements over the existing non-recombinant strains. Despite these advances, the factors that regulate the rate and extent of production from mixed sugars remain unknown. Moreover, the key enzymes in the pentose metabolic pathway in both recombinant and non-recombinant strains have not been well studied. It will be necessary to fully characterize the pentose metabolic pathway to allow optimization of the rate and extent of pentose bioconversion.

Polyhydroxyalkanoate (PHA) deposits are accumulated by many different species of bacteria, and they act as carbon stores to aid the cells in surviving nutrient carbon starvation conditions (for recent review, see Madison and Huisman 1999). The structural diversity and range of physical properties of the known PHA polymers is very great, with >90 different constituent hydroxyalkanoic acids described to date (Steinbüchel and Valentin. 1995). While PHA polymers and co-polymers can substitute for many existing fossil fuel derived polymers such as polypropylene and polyethylene, and many PHA polymers have novel properties not matched by the existing plastics, the greatest impediment to wide scale production and marketing of PHA bioplastics is the high production cost in comparison to that of fossil fuel derived polymers. There is currently an approx. 5- to 10-fold disparity between the production costs of PHA by bacterial fermentation and the production costs of fossil fuel derived polymers (Ramsay et al. 1995). A substantial portion of the cost of PHA production by bacterial fermentation is due to substrate cost (Choi and Lee 1999). Efficient production of PHA using inexpensive and readily available lignocellulosic-derived substrate would significantly improve the economic competitiveness of biopolymer production vs. fossil fuel polymer production. Most of the PHA producing bacteria that have been investigated for industrial production are not able to efficiently metabolize the abundant pentose sugars in lignocellulosic hydrolysate. It will be necessary to develop strains that produce PHA with high yield on lignocellulosic hydrolysate.

Lignocellulosic-derived substrate can be potentially utilized to produce several other commodities and fine chemicals that are currently fossil-fuel derived.

Conversion of carbohydrates to useful products requires catalytically- and/or biocatalytically mediated chemical reactions as well as separation processes. Whereas technologies for catalytic conversions and separations involving fully-reduced hydrocarbons are well established, this is not the case for the oxychemicals characteristic of biomass-derived products. Furthermore, the fields of metabolic engineering and oxychemical catalysis are both in an early stage of development. There is thus much scope for research that will result in improvements in the conversion of biomass to useful products.

The United States of America has been particularly aggressive in pursuing strategies to shift to biobased industrial products and biofuels (Committee on Biobased Industrial Products, 1999). The National Sustainable Fuels and Chemicals Act (S.935) is currently being promulgated and is heavily supported by the US based Biotechnology Industry Organization. This authorization bill (6 years) will potentially secure funding for fundamental research and coordinate research efforts among national laboratories, universities and colleges, and the private sector. Approximately US$50M per year is being proposed to fund the National Sustainable Fuels and Chemicals Research Initiative, which will augment the US$200M that the US currently spends on biomass research. The President's Council of Advisors on Science and Technology has also recommended significant increases for support of research on biomass energy.

The activities of the BIOCAP Network directed towards the development of strong biologically based industrial technology will be important for Canada as it strives to enhance its global competitiveness, reduce its dependency on fossil fuels, and moves towards sustainable, environmentally acceptable and clean industrial practices.

Project Overview

Theme IV exploits the power of Biotechnology, through Molecular Biology, Microbiology and Chemical Engineering, to address the overall BIOCAP goals of reducing net GHG emissions. The objective is to develop the scientific understanding and novel technologies that can be implemented in the use of lignocellulosic biomass as industrial feedstock and for fuel production, thereby relieving some of the ever-increasing demand for fossil fuels and petrochemicals. Using gene-shuffling and metabolic engineering approaches, it is possible to uncouple biomass conversion from product synthesis; if lignocellulosic biomass can be efficiently metabolized by industrial production microorganisms, then this biomass can be converted to energy and material resource.

There have been recent developments in the hydrolysis of lignocellulosics, yielding mixtures of hexose and pentose sugars. **Project 4A** will focus on increasing the efficiency of product synthesis from lignocellulosic-derived fermentation substrate through developments in substrate pretreatment and fermentation technologies. Many microorganisms used in industrial fermentation are unable to efficiently metabolize pentose sugars;. **Project 4B** is focused on characterizing and improving pentose fermentation in industrial organisms. The other projects will target value-added production. The objective of **Project 4C** is to develop polyhydroxyalkanoate (PHA) biopolymer as a fully-recyclable replacement for fossil-fuel-derived plastics. Novel PHA synthesis and degradation genes will be isolated directly from the bacterial community and expressed in appropriate host strains. These genes will then be used for the engineering of organisms to efficiently produce PHA using lignocellulosic-derived sugars, and novel products using waste PHA as substrate. The goal of **Project 4D** is to utilize lignocellulosic C via novel bioprocesses to obtain commodity chemical feedstocks for the manufacture of synthetic polymers and plastics, and other value-added products such as fine chemicals. Product possibilities include succinic and lactic acids, acetic, propionic and butyric acids, ethylene, propanediol and butanediol, acetone and butanol, the higher alcohols, and adipic acid. A series of feasibility studies, including life cycle assessment, will be carried out over the first 12 months, in order to identify the most promising chemical feedstocks to target for biological production using lignocellulosic-derived substrate. Once the most promising chemical feedstocks are identified, research will be directed at these.

Theme IV research activities will aim to: (a.) improve lignocellulose hydrolysis to optimize yield of metabolizable substrate (b.) identify limiting factors in substrate utilization by existing bioprocessing strains (c.) engineer bioprocessing strains to improve substrate utilization (d.) identify limiting factors in product formation (e.) engineer bioprocessing strains to improve product formation (f.) isolate novel strains and genetic material to use in improvement of product formation (g.) identify limiting factors in product processing (h.) develop engineering solutions to improve product processing.

Anticipated deliverables after four years include: (a.) substantially improved lignocellulose pretreatment and fermentation technologies, (b.) improved understanding of pentose metabolism in industrial fermentation microorganisms, and development of microbial strains that are more efficient pentose fermenters, (c.) the development of microbial strains and technologies for the production of biopolymers using lignocellulosic-dervied substrate at a cost that is competitive with the production of similar fossil fuel derived polymers, and for the utilization of waste biopolymer as substrate for the production of commodity and fine chemicals. (d.) the identification of the best targets for development.

Project Descriptions

Further details about each of the Theme 4 Projects are provided below. The name(s) of the Project Leader(s) is (are) underlined. The dollar values associated with each title are the average annual NCE request for each of the next 4 years / total annual NCE + Non-NCE budget.

Proj. 4A Pretreatment and enzymatic hydrolysis for optimal recovery of all wood components. ($98K/$208K)

Objectives: (i) To define optimal bioconversion process steps that lead to maximum recovery of wood components with reasonable economic benefits. (ii) To reduce the detrimental effect of lignin on enzyme recycling. (iii) To evaluate the microbial strains developed in Project 4B.

Researchers: Jack Saddler (UBC), Wing Sung (NRC), Hung Lee (UG).

Approach: To achieve the project Objectives, four subprojects are envisaged:

4A1: Optimization of pretreatment conditions, using catalyzed steam explosion to maximize recovery of all wood components.

Techno-economic modeling has shown that we need to maximize the use of all wood components. This project will be directed towards finding pretreatment conditions that minimize sugar loss and fermentation inhibitor generation. Mass balances for the three major wood components, cellulose, hemicellulose and lignin, will be determined on aspen and genetically engineered poplar wood in collaboration with Theme III. Better recycling of sequestered carbon will be achieved through the development of genetically engineered lignocellulosics that contain a higher cellulose fraction, lower lignin and are easier to pretreat and convert to ethanol.

4A2: Comparing the efficiency of enzymatic hydrolysis and component fractionation under different pretreatment conditions.

The relative recalcitrance of (water insoluble)residue to enzymatic hydrolysis is the greatest impediment to optimization of pretreatment for recovery of all components. Nevertheless, enzymatic hydrolysis remains beneficial for the overall process because it produces a stream that does not contain fermentation inhibitors and hence is easily fermentable. There are also no further losses of sugars through degradation reactions. Research will evaluate existing and new strategies to increase enzymatic hydrolysis and fractionation of lignin and cellulose. By mixing different ratios of endo and exo-glucanases we anticipate better hydrolysis. Other strategies such as simultaneous milling and hydrolysis, enzyme recycle, and hydrolysis in organic phases will also be evaluated to enhance fast, efficient hydrolysis.

4A3: Understanding the role of lignin in enzyme recycling.

Along with enzyme engineering and improvement of enzyme producing microorganisms, enzyme recycling could allow substantial savings for the wood to ethanol bioconversion process. The lignin is thought to be one of the major obstacles to enzyme recycling in this process. The essential objective of the research work will be to elucidate the quantitative and qualitative aspects of enzyme adsorption on the lignin. Reversibility of cellulase component adsorption will be evaluated. Development of strategies to desorb the enzymes will be investigated. The best strategy will be technically and economically evaluated.

4A4: Evaluating the strains developed by Project 4B.

Researchers will evaluate the fermentability of the stream from the pretreatment (mainly hemicellulose sugars) and the combined pretreatment-hydrolysis streams using the microbial strains developed in Project 4B. Systematic growth and sequential utilization of the mixed sugar wood prehydrolysates will be evaluated during these fermentation runs. We will also test the susceptibility of these strains to the inhibitory compounds found the prehydrolysate streams. The most 'hardy' strains will be isolated for further genetic and metabolic investigations

Timelines: 04/00: Collection and characterization of available aspen residues, characterization of the soluble and insoluble material after steam explosion, definition of the best recoveries and pretreatment conditions that led to these recoveries. **04/01:** Pretreatment of genetically modified poplar, enzymatic hydrolysis of insoluble fraction resulting from steam explosion, mass balances on the combined recoveries from pretreatment and enzymatic hydrolysis, definition of wood sugar streams for fermentation. **04/02:** Evaluation of the effect of residual lignin on enzyme adsorption, development of post-explosion treatment to increase enzymatic hydrolysis, fermentability of the stream defined in second year using genetically modified strains from Project 4B, evaluation of mixed sugar utilization and ethanol yields. **04/03:** Desorption trials of enzymes from enzymatic hydrolysis residues, development of the best enzyme recycling strategies, adaptability of the genetically modified strains to the hydrolysate streams, isolation and evaluation of the stability of the 'hardiest' strains.

Proj. 4B Strain Development ($138K/$223K)

Objectives: (i) To understand the limiting factors in the bioconversion of both the hexoses and pentoses found in lignocellulosic carbohydrates (ii) To develop the microbial strains suitable for use in the bioconversion of lignocellulosic carbohydrates into fuel ethanol and other value-added products.

Researchers: Hung Lee (UG), Roger MacKenzie (NRC), Elke Lohmeier-Vogel, (UC), Les Tari (UC), Jack Trevors (UG), Hans J. Vogel, (UC), Peter Lau (NRC-BRI), Jack Saddler (UBC).

Approach: The research effort will involve two subprojects, as defined below:

4B1. Improve the metabolic pathway of pentose-fermenting microorganisms.

Research will be directed at identifying inefficient and rate-limiting steps in the pentose metabolic pathway. This will include characterization of xylose and arabinose transport, as well as subsequent enzymic steps of pentose utilization in both recombinant and non-recombinant microorganisms. Genes encoding some of the key enzymes in the pathway will be cloned and their respective products subjected to structure-function analysis to understand their action mechanism(s). Using protein engineering methods key enzymes will be modified with respect to their catalytic efficiency, cofactor preference, substrate range and affinity to improve their function(s) in the pathway. Genes encoding these enzymes will be subjected to DNA shuffling either individually or collectively to improve metabolite flow.

4B2. Strain improvement of fermenting microorganisms.

Studies will seek to (a) understand the biological mechanisms underlying ethanol tolerance, and (b) select for more ethanol-tolerant strains by random mutagenesis or by continuous culture selection. Research is expected to contribute to a better understanding of ethanol toxicity and tolerance. One of the likely biological mechanisms to be investigated will be the role of the plasma membrane Mg-ATPase in ethanol tolerance. We previously found in *P. tannophilus* an excellent correlation between this enzyme and growth in terms of their susceptibility to inhibition by alcohols of different chain length (Barbosa and Lee, 1991). Thehypothesis that ethanol tolerance in pentose-fermenting yeasts can be improved by expressing the Mg-ATPase gene from a more ethanol-tolerant yeast such as *S. cerevisiae* will be tested.

Other than ethanol toxicity and tolerance, research will be directed at understanding the biological mechanisms underlying glucose repression and chemical inhibition. A strain development program will be initiated to select for (a) glucose repression-resistant strains that can efficiently ferment both the hexoses and pentoses into fuels and chemicals; and (b) chemical inhibitor-resistant strains.

Timelines: 04/00-09/01: Cloning of genes encoding xylose metabolism enzymes. **01/01-07/02:** Over-expression and purification of gene products. **04/02-10/03:** Structure-function analysis. **07/02-01/04:** Protein engineering. **04/00-04/01:** Selection and isolation of ethanol tolerant strains. **10/00-04/02:** Characterization of ethanol tolerant strains. **04/00-04/02:** Investigation of the role of Mg-ATPase in ethanol tolerance. **07/01-01/04:** Investigation of the basis for glucose repression in production strains

Proj. 4C Bioplastics Production and Recycling ($175K/$234K)

Objectives: (i) To improve the economics of bacterial biopolymer production by optimizing the yield on lignocellulose-derived substrate, and by increasing the value of biopolymer, and (ii) To develop the capability for a fully recyclable system for biopolymer, whereby waste polymer is used as substrate for production of industrial chemicals, fuels, or depolymerized to provide optically pure specialty chemicals.

Researchers: Trevor Charles (UW), Juliana Ramsay (QU) , William J. Page (UA)

Approach: The research effort will involve two subprojects, as defined below. The industrial partner, Polyferm Canada, will provide analytical services, expertise in PHA production and characterization, and will pursue product development based on the Network supported research.

4C1. Isolation of novel PHA synthesis genes directly from the environment.

The nature of PHA produced during bacterial fermentation is partially determined by the genes in the PHA biosynthesis pathway, and there is considerable interest in the development of production systems for the more complex PHA with potentially useful properties. Currently, novel PHA synthesis pathway genes have been isolated from known, culturable organisms. However, it is generally accepted that >99% of the microorganisms in a given microbial community are not culturable. Many of these organisms might have the capacity to produce PHA of novel composition. We will take a bioprospecting approach, isolating genomic DNA directly from diverse Canadian environments, constructing gene libraries, and screening by both functional assay and DNA hybridization methods for PHA synthesis pathway genes. Novel genes will then be expressed in host production strains such as *Sinorhizobium meliloti*, *Agrobacterium* spp. & *Escherichia coli*, which are able to use pentose and hexose sugars as growth substrate, Particular attention will be paid to the production of PHA deposits of potentially higher value such as those of ultrahigh molecular weight [?] or composed of highly crystalline medium chain length monomers.

4C2. Waste biopolymer as substrate.

The GHG equation for biopolymer production would be even more favourable if some of the carbon substrate in PHA could support products synthesis, rather than being biodegraded without synthesis of useful products. This will require the availability of enzymes that can degrade more complex PHA. The genes that encode these enzymes might be isolated directly from the environmentby screening gene libraries for expression of the indicated activity in appropriate host organisms. Conceivably, many strains of *E. coli* and other engineeresd microorganisms could be further modified to utilize waste PHA as substrate. In addition, utilizing waste PHA as substrate might present unique opportunities for synthesis of compounds that are important chemical industry building blocks and are currently fossil-fuel derived. A major advantage of PHA-derived chemicals is that they would be optically pure.

Timelines: 04/00-09/00: Collection of environmental samples, isolation of DNA, construction of gene libraries. **10/00-09/01:** Isolation of PHA synthesis and degradation genes from the libraries by functional complementation. **07/01-06/02:** DNA sequence characterization of isolated genes. **07/01-06/02:** Characterization of polymer composition, investigation of the influence of growth substrate on polymer composition. **04/02-03/03:** Optimization of expression of PHA synthesis genes in host strains. **04/00-03/03:** Optimization of lignocellulosic-derived substrate utilization by host production strains. **04/01-03/03:** Optimization of fermentation conditions for polymer production by constructed strains. **10/02-03/03:** Metabolic engineering for production on waste biopolymer substrate. **04/02-03/03:** Conduct a life cycle inventory and economic analysis of the new production technology developed in this project and compare it to existing bacterial fermentation methods of PHA production and to fossil fuel derived polymer.

Proj. 4D Bioprocessing of Lignocellulosic C for the Production of Chemical Feedstocks ($83K/$158K)

Objectives: (i) Life-cycle analysis (LCA) of biomass-derived chemical feedstocks in relation to fossil fuel derived feedstocks (ii) identification of key products that have potential for being derived from available biomass (iii) Establishment of research priorities and programs that would establish the technical foundation for production of the identified chemical feed-stocks (iv) Prospecting for new microbial & genetic resources (v) Engineering metabolic pathways to increase product yields and facilitate product recovery.

Researchers: S N. Liss (RU), D.G Allen (UT), W A. Brown, (MU), T C. Charles (UW), B T. Driscoll (MU), D G. Cooper (MU), R A. Fraser (UW), B R. Glick (UW), Peter Lau (NRC-BRI), W J. Page (UA), J A. Ramsay (QU)

Approach: The research will involve three subprojects, as defined below.

4D1. Life-Cycle Analysis and identification of product focus.

An extensive review of the field for each chemical group identified in Table 2.2 will be conducted. These reviews will focus on identifying areas requiring technical improvements that will shape the direction of the research program. Advanced life-cycle analysis *(Relative-Mass-Energy-Economic method of system boundary selection, marginal sensitivity analysis, Monte Carlo Uncertainty analysis, and Uncertainty Reduction Analysis)* (Raynolds *et al*., 1999a and 1999b) will be employed to assess the identified chemicals. These analyses will be carried out by teams consisting of engineers and microbiologists, and R.A. Fraser will provide expertise and guidance in advanced life cycle analysis techniques.

Through the life cycle analyses, environmental performance and economic potential of each chemical feedstock will be determined with respect to production via bioprocesses and conventional technologies. The most promising chemical groups will be chosen for further development. Selections will be made in close consultation with the major industrial partners from the Canadian Chemicals industry.

4D-2. Bioprospecting for microorganisms with novel biocatalytic activites.

To ensure that the appropriate microbiological material is available to the research team, a series of bioprospecting exercises will be carried out. Unique habitats in Canada will be examined for the presence of new microbial strains that are able to generate products (particularly adipic acid, ethylene and propanediol) from single or mixed-sugar feedstocks, and under industrial conditions. Potentially useful organisms will be made available to the Canadian research community.

4D-3. Metabolic and process engineering.

The most promising product groups from 4D1 will be chosen for further development. Metabolic engineering will be carried out to improve yield on lignocellulosic hydrolysate, & bioprocess engineering will be carried out to optimize product recovery.

Timelines. 04/00-04/01: Life Cycle Analysis, **04/00-04/02:** Bioprospecting, **04/01-04/04:** Metabolic Engineering, **04/02-04/04:** Bioprocess Engineering.

Table 2.3. Product Focus and Lead Investigators for the Life Cycle Analysis subproject of Project 4D.

Product Focus	Lead Investigator & Expertise
Adipic Acid, Propanediol, Butanediol	S.N. Liss (Appl Microbiol., Microb Phys), W.A. Brown (Bioprocess, Chem Eng)
Acetic, Butyric and Propionic Acids	T.C. Charles (Microb Physiol, Microb Gen), D.G. Allen (Bioprocesss, Chem Eng)
Lactic and Succinic Acids	B.T. Driscoll (Microb Physiol Microb Gen), D.G. Cooper (Biochem Eng)
Ethylene	B.R. Glick (Molec Biol Plant-Microbe Inter'ns)
Acetone and Butanol	P. Lau (Bact Gen & Physiol)
Higher Alcohols (>C6)	W.J. Page (Microb Physiol, Biodegrad Polymers), J.A. Ramsay (Bioprocess, Chem Eng.)
Life-Cycle and Economic Anal. -*All Products*	R.A. Fraser (Life-Cycle Anal, Fuels & Energy)

2.6. Theme 5. Public Policy

Theme Leader

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Background

Policy responses to all issues related to global climate change have been proposed throughout the decade of the 1990s; but – given the magnitude and potential impacts of these issues – adequate responses are still far from being well-formulated. The policy domain is a complex and shifting mix of multiple, diverse factors: economics, resource law, federal/provincial relations, international negotiation factors, risk management and a robust public dialogue on all of the above. Theme 5 seeks to cover all of these factors and their interrelationships.

Economics: The management of terrestrial biomass in forests, grasslands and on agricultural land has important implications for carbon (C) flux and Canada's overall success at meeting CO_2-reduction targets. Carbon management strategies in forestry and agriculture may be economically competitive with strategies in other sectors of the economy for removing atmospheric CO_2 (van Kooten *et al.* 1993, 1999). However, it is necessary to examine the combined effects of producing / managing biomass in terrestrial ecosystems and of utilizing and processing biomass in manufacturing, energy and forest sectors. All of these strategies need to be evaluated in terms of their technical feasibility as well as their cost effectiveness, so that an optimal combination of these strategies, and their implications for the economy in terms of overall economic welfare and distribution of income, can be identified. For example, incentives may be provided to shift consumers toward long-lived products that store more C than substitute products do, or incentives given to grow and then utilize biomass as a fuel to offset fossil fuel emissions.

Law, Political Institutions & Intergovernmental Relations: Although attention to legal and institutional issues is of critical importance to the success of Canada's GHG strategy, there has been relatively little systematic analysis of these issues in the Canadian literature dealing with environmental law and policy and with legal aspects of resource management. The analysis that has appeared has focused primarily on emissions trading as opposed to integrated C management and tends to be confined to general descriptions of the constitutional division of powers and selected statutory regimes (Rolfe 1998). The 1998 Report of the Commissioner of the Environment and Sustainable Development reviewed the federal GHG strategy and concluded that "many of the key elements necessary to manage the implementation of Canada's response to climate change are missing or incomplete," notably the proper delineation of government roles that is essential for policy effectiveness, transparency and accountability (Canada 1998). This assessment underlines the pressing need for detailed legal and institutional analysis to support implementation of integrated carbon management.

The state of knowledge regarding the mechanisms of intergovernmental relations in the broad area of the environment has improved in recent years (Harrison 1996, Harrison & Fafard forthcoming). But there is little published work that shines light on the functioning of those mechanisms in relation to issues of carbon emissions and climate change. Given that the challenge of governance on climate change is far greater than on many other environmental issues, the absence of knowledge on ways of managing this larger issue, including its "horizontal" as well as its intergovernmental complexities, is a major concern.

International Negotiation: In the aftermath to the Kyoto Protocol on Climate Change, Canada must be better prepared for future meetings of the Conference of the Parties to the Framework Convention on Climate Change and its subsidiary bodies on implementation and scientific advice. This will take on greater importance if the U.S. should fail to ratify the Protocol. Issues that arise from the global strategy to reduce GHG emissions include: determining Canada's negotiating position and strategy as well as understanding obstacles to inter-state cooperation; the role of NGOs / the private sector in the implementation of international climate change agreements, and in fostering compliance with international obligations (Hurrell and Kingsbury 1992).

A Public Dialogue on Risk, Science, Policy and Global Models: Both the extraordinary complexity of the climate change phenomena, as a task for scientific understanding (represented in the various global models), and the high levels of uncertainties associated with predictions of future trends and effects, are great challenges to public understanding. Public support (a) for major scientific research programs in these areas; (b) for public policies which may be based in part on the provisional conclusions from international scientific research programs; and (c) for government actions based on these policies, which may have large economic, regional, and other impacts, must be based on adequate public understanding. Otherwise, those policies may not be able to be implemented, even if they are regarded by specialists as wise or prudent choices.

Project Overview

If carbon sequestration and biomass utilization strategies are employed there are likely to be significant costs and impacts on the Canadian economy. Is it worthwhile for Canadian people and industries to absorb these impacts? If there are significant costs, what C management and utilization strategies can and should be employed to minimize these impacts? If there are effective C management strategies available, how much of our scarce human, capital, material, and energy resources should be diverted to implementing these strategies? Part of the role of the Economics Project (5A) is to answer some of these questions utilizing the best available data in the short term and data generated by BIOCAP themes I to IV in the longer-term subprojects. Thus this project will provide input to the policy questions: *how much* biomass management and utilization should be done as well as *how to* implement these strategies? It is simply not enough to say we shall plant trees, use biotechnologies and biomass energy to reduce C fluxes because the net benefits to society are positive. Hence, a major component of project 5A to learn how incentive mechanisms should be structured to encourage the private and public sectors to reduce GHGs. Moreover, the various mechanisms (taxes, subsidies, contracting arrangements) must be evaluated in terms of their effectiveness in maximizing the net benefits to Canadian society and in ensuring that those bearing the costs of providing the incentives (e.g., Canadian taxpayers) are rewarded with lower net releases of greenhouse gases.

The Natural Resources Law and Policy Project (5B) will examine legal and institutional issues relating to the implementation of integrated C management as a GHG strategy. This set of issues will be focused on a portfolio of policy options generated within the BIOCAP NCE and will consider both the domestic and international contexts for implementation. Subprojects 5B-1 and 5B-2 will examine, respectively, domestic and international aspects of implementation of biosphere C management. 5B-3 will focus on forest management, and 5B-4 will investigate initiatives for voluntary compliance and non-regulatory approaches to compliance with national and international legal requirements concerning C management. Finally, subproject 5B-5 will describe and analyse the legal framework for joint implementation, focussing specifically on issues associated with biosphere C management.

The processes of the institutions of Canadian federalism will have a determining influence on the chances for the realization of the options for addressing climate change issues that emerge from the BIOCAP scientific research program. They planned studies in Project 5C will lay out alternatives to Canadian intergovernmental practice in the environmental and natural resource areas that may result from learning from the experience of sectors in the Canadian federation. We need to understand whether current governance structures have the resilience to cope with changes of the magnitude that are implied in dealing with climate change issues and, to the extent that they do not, what types of changes are needed for this purpose. Further, these studies will provide analysis of ways of achieving an appropriate relationship between the two orders of government and the various interest groups and other actors that seek to influence those governments. They will thus suggest an approach to managing the tension between executive federalism and democratic process.

Successful implementation of BIOCAP's proposed response to climate change requires attention to how scientific research affects domestic and foreign policy and, consequently, Canada's international negotiating positions. The first objective of the Project 5D is to facilitate the development of new foreign policy and negotiation positions arising from research conducted in other BIOCAP projects. Such positions would be in preparation for major regional and international negotiations on climate change issues. This work has relevance to the UN Framework Convention on Climate Change, its Kyoto Protocol, and the global strategy for GHG reductions, much of which remain to be negotiated. Second, Canadian-based companies, particularly in the energy and technology sectors, wish to develop business ventures and investment plans that take advantage of the opportunities offered by Clean Development Mechanism & Joint Implementation (Ad Hoc Int'l Working Group, 1998; Canada, DFAIT, 1998).

Finally, increasing public understanding of climate change issues in general, and those related to biosphere C management in particular, is a necessary part of a public policy agenda. An intensive effort is needed, in the context of the BIOCAP research program, to add new resources to those already in place to encourage public dialogue and understanding. Within the five subprojects of Project 5E there is a special focus on risk factors, risk management options, the integration of policy dimensions, the interplay between science and policy (Leiss 1999), and the nature of the large global models used by scientists to develop scenarios of climate factor interrelationships and predictions of possible future effects (Shackley *et al.* 1998).

Project Descriptions

The dollar values associated with each title are the average NCE request each of the first 4 years / total annual NCE + Non-NCE budget.

Project 5A: Economics of Biomass Management and Utilization ($213K/$354K)

Objectives: (i) To determine the costs and benefits of sequestering C through changes in agronomic practices, enhanced forest management, afforestation, changes in the management of forest and agricultural product pools, and utilization of biomass for energy and industrial products. These costs will be compared with costs of C management strategies in other sectors, seeing to what extent Canada's biosphere should be managed so as to sequester additional carbon, and to what extent industry can economically utilize biomass. (ii) To investigate incentives that can be used to encourage private landowners and firms to implement socially-desirable carbon management and utilization strategies.

Project Coordinators: Grant Hauer (UA), G. C van Kooten (UBC)

Approach: There are 6 subprojects associated with Project 5A. Each of these is presented separately.

5A-1: How Do Carbon Incentive Mechanisms Affect Forest Land Management and the Forest Products Industry?

Objectives: (i) Provide policy input as to how forest land management, forest products production, and biomass utilisation and storage by the forest products industry will and should change when carbon (C) uptake/release is taken into account; (ii) examine how incentives in other sectors impact forest management (e.g., changes in energy sector, C cap); (iii) examine how changes in ecosystem disturbance/transition affect C management strategies and land use; (iv) examine the welfare (net social benefits and distribution of net benefits) implications of C management strategies.

Project Team: Grant Hauer, (UA); Emina Krcmar-Nozic (UBC)

Approach: (i) Develop empirical economic models with explicit linkages to quantitative ecosystem, product life cycle and national carbon budget models; (ii) use the developed models to conduct regional and national policy and climate change impact simulations; and (iii) provide policy analysis and economic impact assessments based on model simulations. Economic models include (1) dynamic forest land management models that help determine "best" C management strategies and (2) economy-wide sector (dynamic partial equilibrium) models for predicting changes in land use, C sequestration and storage, biomass utilization, product and land prices, and supply of forest products in response to C incentives. The models will initially be developed using existing data and C budget models (Kurz, Apps, Beukema, Lekstrum 1995). Teams will draw on data, methods and models developed in Theme 1 and 2 to improve the calibration, and conduct policy analysis and forecasting simulations.

5A-2: How Do Carbon Incentive Mechanisms Affect Agricultural Land Use?

Objectives: (i) Provide policy input as to how agricultural land management will and should change when carbon (C) uptake/release is taken into account; (ii) examine how incentives in other sectors impact land management (e.g., changes in energy sector, C cap); (iii) examine the welfare (net social benefits and distribution of net benefits) implications of C management strategies.

Project Team: K. Klein (UL) P. Thomasin (MU)

Approach: (i) Develop empirical economic models with explicit linkages to quantitative ecosystem, product life cycle and carbon budget models; (ii) use the developed models to conduct policy and climate change impact simulations; and (iii) provide policy analysis and economic impact assessments based on model simulations. This project is closely linked to project 5A-1 as discussed in the description of that project.

5A-3: How Fast Should Society Adapt Land Management C Sequestration and Storage in Terrestrial Ecosystems?

Objectives/Approach: to examine the rates at which land use changes should take place; to explore the implications of sub-optimal land use change on economic well being; to determine how different incentive mechanisms of land tenure arrangements affect the best path/rate of land use change; to consider the impacts of discount rates and intergenerational considerations on land use; and to provide theoretical underpinnings to the empirical models of project 5A-1. Use analytical and mathematical methods to examine the implications of C values and management options (developed in Projects 5A-1 and 2) to land–use change and management.

Project Team: E. Wilman (UC), C. van Kooten, S. Shaikh (UBC)

5A-4: What Economic Instruments/Incentives are Required to Implement C Uptake in Terrestrial Ecosystems?

Project Team: C. van Kooten (UBC), Q. Grafton (UO), N. Olewiler (SFU)

Objectives: (i) To determine the types of incentive mechanisms / institutional arrangements needed to achieve C management objectives; (ii) to examine the welfare (efficiency) implications, transaction costs of various incentive mechanisms and institutional and property rights arrangements.

Approach: (i) review incentive mechanisms, institutional arrangements, transaction costs and principal-agent relations for its applicability for influencing land use changes associated with C management strategies; (ii) use the framework of the New Institutional Economics (contract arrangements, role of property rights, transaction costs, principal-agent problems) to determine the extent that landowners can be influenced to manage land for C sequestration and storage through various incentive schemes; (iii) examine linkages between emission reductions schemes (tradable CO_2 permits, C tax/subsidies) and C storage in the biosphere, at national and international levels; (iv) compare the efficiency of alternative methods of linking C emission reduction schemes to C sequestration schemes.

5A-5: The Effect of Carbon Incentives and Biomass Utilization on the Canadian Economy and International Trade

Objectives: To examine how incentives for storing carbon in biomass, use of biomass fuels, and carbon incentives such as taxes and permits affect: (i) various economic variables (contribution to GDP, employment, relative prices, welfare effects) in all sectors of the national economy (ii) economic performance of provincial economies; (iii) international trade in terms of changes in imports of foreign made products and exports of Canadian products.

Project Team: I.Vertinsky (UBC) P.Crabbé (UO)

Approach: (i) Develop multi-sector general equilibrium and international (trade) models with the ability to simulate the effect of policies that reduce carbon emissions from fossil fuels, increase the use of biomass fuels, and increase sequestration of C in biomass; (ii) use the models to simulate the economy wide impacts of C emission reduction and sequestration polices.

5A-6: Climate Change Impacts on Agriculture and Forestry Land Use Patterns: Developing and Applying an Integrated Economy-Ecosystem Response and Adaptation Impact Assessment Model.

Objectives: (i) Develop a spatial, dynamic, integrated assessment model for prediction of agriculture and forest land use changes over time in response to alternative climate change, ecosystem change and economic change scenarios; (ii) determine the range of possible effects of climate change and adaptation on land use patterns in the prairie provinces and on the distribution of ecosystem types; (iii) determine the range of possible impacts of climate change on land values; (iv) determine the effect specific adaptation measures and policies such as changes in forest protection and forest rotations have on land use values and patterns.

Project Team: David Price (CFS), Grant Hauer (UA), Tim Williamson (CFS).

Approach: (i) develop spatial econometric models of agricultural and marginal agricultural land values; (ii) analysis of production, cost and revenue structures of the forest industry to develop spatially explicit wood values; (iii) calibration of a dynamic ecosystem response model (IBIS) to Canadian vegetation types; (iv) development of a spatial dynamic partial equilibrium model of the Canadian forest sector and agriculture sectors with linkages to the IBIS model; (v) conduct impact analysis, policy simulations, and policy analysis.

Budget Note: No NCE funding required. Funded by the Climate Change Action Fund $98,500.

Project 5B: Natural Resources Law and Policy ($25K/$129K)

Abstract: Successful implementation of the BIOCAP approach requires close attention to the interface of science, law and public policy. The NRLP Project is designed to straddle this interface. One objective is to describe the legal and policy context for integrated C management. Natural and social scientists, government policy makers and other stakeholders will then have the information needed to develop proposals for action that, in addition to being scientifically sound, are attuned to the institutional constraints and opportunities relevant to implementation. The second objective is to identify and analyse the legal and institutional issues raised by a portfolio of policy options – generated throughout the BIOCAP Network – for reducing GHG emissions, maximizing C sequestration, promoting the use of biomass as a fuel and industrial feedstock, and adapting Canada's resource management regimes to a high CO_2 future. On this basis, specific legislative and policy initiatives will be proposed to implement these science-based options. The state of scientific knowledge will also be a key factor in designing workable legal mechanisms for verification and enforcement. The legal dimensions of C management include international environmental and trade law, Canada's constitutional division of powers, and the resource management laws that are in place – or will be needed – to ensure that human uses of the Canadian biosphere have the desired impacts on the C cycle. Institutional arrangements will be required for intergovernmental and interagency cooperation, both internationally and nationally. Resource disposition and regulatory processes will have to be adapted and coordinated to align the incentives facing individuals, corporations and governments with the requirements of a comprehensive and integrated C management strategy. Moving from scientific insight and technological breakthrough to implementation, verification and enforcement will require adjustments to law, policy and institutional arrangements. The NRLP Project will identify the legal constraints on this process and explore the most promising options for providing a solid legal, regulatory and institutional framework for using biosphere C management as a cornerstone of Canada's response to climate change.

Project Coordinator: Steven A. Kennett (UC)

Approach: All of the subprojects listed below will be carried out by researchers affiliated with the CI RL, University of Calgary.

5B-1: Context and Implementation Issues for Biosphere C Management in Canada

Project Team: Steven A. Kennett, Nigel D. Bankes, and Alastair R. Lucas (UC)

Approach: The project will: (1) examine the constitutional and statutory arrangements relevant to C management; and (2) apply legal and policy analysis to options generated by the BIOCAP research program in order to identify issues and propose legislative and institutional mechanisms for the implementation, verification and enforcement of integrated C management, including the role of voluntary non-regulatory instruments as alternatives to formal legal and regulatory C management requirements.

5B-2: International Context and Implementation Issues for Biosphere C Management

Project Team: J.O. Saunders, N.D . Bankes (UC)

Approach: The project will (1) examine the extent to which the international legal and policy framework both constrains and enhances the prospects for effective C management, drawing on such sources as international trade obligations and "soft law" principles related to environmental protection; (2) examine alternative approaches to the Kyoto Protocol to for C management; and (3) with respect to the Joint Implementation, propose a legal framework necessary to implement Article 6 of the Kyoto Protocol, especially with respect to enhancement of removals by sinks (issues include domestic and international mechanisms for project approval, domestic authorization of projects by non-state legal entities, verification and reporting).

5B-3: Forest Management and Biosphere C Management

Project Leader: Monique M. Ross (UC)

Approach: The project will: (1) review the legal and policy framework for forest management; (2) identify incentives and disincentives relevant to the role of forestry in biosphere C management; (3) propose legal and institutional arrangements supportive of biosphere C management options.

Project 5C: Federalism and Intergovernmental Relations ($81K/$106K)

Abstract: Managing climate change issues, requires a governance system that takes account of the interplay between three factors: policy goals, democratic institutions and processes, and federalism principles. Any approach to federation management that does not seek to maximize these three variables will be, at best, sub-optimal and, at worst, dysfunctional from the perspective BIOCAP and the broader public interest.

The set of studies outlined below will shine light on the current institutions and processes of Canadian federalism as they may affect BIOCAP. They will also lay out alternatives to Canadian intergovernmental practice in the environmental and natural resource areas that may result from learning from the experience of sectors in the Canadian federation. Further, these studies will provide analysis of ways of achieving an appropriate relationship between the two orders of government and the various interest groups and other actors that seek to influence those governments. They will thus suggest an approach to managing the tension between executive federalism and democratic process. As such, the studies will help us to hone in on a model of federal-provincial and democratic governance that may be most functional for the BIOCAP initiative.

While Canada will obviously seek to influence the content of that international legal and policy framework, given Canada's modest geo-political power, Canada is more likely to be a "policy taker" more than a "policy maker" within the sphere of international governance. This adds to the challenge in determining the most appropriate system of domestic governance, as it requires the above-mentioned domestic governance model to be sensitive to, and linked to, the pressures from the international arena. And as the nature of these pressures is somewhat unpredictable, the domestic governance system must be supple enough to accommodate a range of possibilities. The project will deal with the international uncertainty through the use of a scenario methodology.

The literature regarding economic growth and efficiency is increasingly recognizing the importance of efficient governance as a necessary pre-condition for successfully implementing effective economic and social policy. This project thus should contribute to these additional goals as well as the project-specific objectives.

Project Coordinator: Harvey Lazar (QU)

5C-1: Analysis of federal-provincial governance structures for managing climate change, with models for effective federalism

Approach: (1) To analyze the current existing Federal-Provincial Ministerial Committee for Managing Climate Change Issues, as well as the effectiveness of the Climate Change Secretariat with a view to establishing a baseline from which to assess governance options for BIOCAP; to investigate effective working relationships between both orders of government. (2) To develop alternative models of domestic governance, involving both federal-provincial and democratic elements, that would best maximize the BIOCAP, democratic and federalism elements referred to above. Since there is likely to be more than one model as contender for "best", to provide criteria for choosing among the contenders.

Project Team: Harvey Lazar, Doug Brown (QU)

5C-2: Assessing the impact of alternative international governance regime/rules on BIOCAP and the adequacy of federal-provincial arrangements.

Approach: This will require the development of different international governance scenarios and an assessment of how each scenario will impact on domestic federal –provincial governance.

Project Leader: Doug Russell, (Global Change Strategies International, Inc.)

Project 5D: International Negotiation ($70K/$115K)

Abstract: Successful responses to climate change issues requires attention to how scientific research affects domestic and foreign policy and, consequently, Canada's international negotiating positions. The first objective of the proposed project is to facilitate the development of new foreign policy and negotiation positions arising from research conducted in other BIOCAP projects. Such positions would be in preparation for major regional and international negotiations on climate change issues. This work has relevance to the UN Framework Convention on Climate Change, its Kyoto Protocol, and the global strategy for greenhouse gas emissions reductions, much of which remain to be negotiated (Subsidiary Body for Implementation 1999; Canada (NNI) 1999).

The prominence of biotechnology on the agendas of many international governance bodies underscores the close link between biotechnology and international politics (Cottier 1996, James 1999). Biotechnology-related diplomacy is practised through a variety of channels, including the traditional mechanisms of inter-governmental affairs, the boards of multinational enterprises, international non-governmental groups, and the colloquia of scientific communities. A host of multilateral organizations is involved in policy-making, harmonization of national regulations, and the administration of a wide range of legal instruments, including binding conventions, recommendations, codes of conduct, and best practices. Governance of biotechnology straddles across a number of international regimes. In many instances, tensions between these regimes exist especially between the global trade system and environmental safeguards. In addition to the protracted trade issues, the promises and pitfalls of biotechnology are closely tied to the current discussions about access to genetic resources and the sharing of benefits arising from their use.

Finally, if properly designed, Kyoto's Clean Development Mechanism / Joint Implementation can provide significant opportunities for increased private-sector activity between Canada and the United States on the one hand and Mexico on the other, primarily in the industrial sector. It is unclear, at this point in time, how these flexible mechanisms will be governed and implemented. Nonetheless, companies will be able to begin accumulating reductions credits by January 2000. These mechanisms are seen as a means of encouraging developing states to participate in the global GHG emissions reduction strategy, energy industries to invest in developing countries, and technology transfer.

Project Team: G. Smith and D. Wolfish (UV)

Three subprojects have been identified:

5D-1: Negotiating Climate Change.

Objectives/Approach: To develop foreign policy and negotiation positions that are based on the research conducted in other BIOCAP projects and that maximise Canada's comparative advantage in preparation for major regional (e.g., NAFTA) and global negotiations on climate change issues. The project will provide perspective on Canada's national interests and determine our international comparative advantage; develop a set of policy options and their corresponding foreign policy positions that will be grounded in the BIOCAP science findings; develop recommendations to generate international negotiating positions.

5D-2: Negotiating Biotechnology.

Objectives/Approach: To develop negotiation positions that deal adequately with the scientific, environmental, and ethical concerns about biotechnology products and processes. The current international regime for bioengineered products and processes has developed largely in the context of trade-related international issues (within OECD, World Intellectual Property Organization, and the World Trade Organisation), and in the very different context of the UN Convention on Biodiversity. The strengths and weaknesses of the positions adopted to date will be evaluated in the light of the need to include biotechnology applications in responses to climate change issues.

5D-3: Using the Kyoto Mechanisms to advance the Cleaner Production agenda.

Objectives/Approach: (1) to help prepare Canada as it enters negotiations on clean industrial processes and products; to assess the implications for Canada of agreements that will be reached; (2) to develop with key stakeholders business proposals that are scientifically sound and attuned to institutional constrains and opportunities; (3) to understand how global GHG reduction strategies affect trade and investment patterns in regions governed by free trade agreements.

Project 5E: Risk Dialogue and Risk Management ($224K/$249K)

Abstract: The objective of a "risk dialogue" is to establish and maintain a public resource for authoritative, fair, disinterested, comprehensive information about, and for, the exchange of views on, specific risk issue domains. A "risk issue domain" is defined as a discrete set of concerns over risks and risk management strategies associated with a natural hazard, an industrial technology or product, a personal activity, or some combination of sources of risk factors. Global climate change and GHG emissions is an excellent example of a combined-source risk domain; it may very well be the most complex risk issue citizens will ever confront and as a result the most difficult risk management problem also for governments.

A major part of Risk Dialogue projects is to provide resources for citizens to become better able to evaluate the conflicting information they may encounter in a risk issue domain, including:

- a timely, credible, critical, and complete running account of relevant scientific research results, including methodological aspects;
- an interactive forum for the discussion of the risk factors, public policy implications, and interpretive matters;
- communications products for the dissemination of results to different audiences.

Good risk management decisions are those that allocate the available pool of risk reduction resources in a way that is adequate to the nature of the problem, taking into account the magnitude of these risks relative to others that are being managed, and recognizing that such resources are always limited. Risk factors therefore must be correctly characterized and estimated from a scientific standpoint, including the uncertainties.

Democratic societies also require a broad public understanding of the risk issues and public confidence in risk management decision making.

In addition to specific tasks (such as facilitating a public dialogue), this project has the task of integrating all of the Theme 5 projects, first into an overall public policy perspective (including both domestic and international settings) and, second, within a general risk management framework. This framework will be designed to show how all of the decision parameters, representing scientific, technological, and public policy perspectives, can come together to form an acceptable Canadian response to both the expert analyses and the citizen perceptions of global climate change issues.

Project Coordinator: William Leiss (UC)

5E-1 CO_2-Com: A Public Risk Dialogue Project on Global Climate Change Issues.

Approach: Using a dedicated internet website as a delivery mechanism, the project will: (1) "translate" into understandable terms, for the non-expert public, the key consensus findings of scientific research on the risk factors associated with global climate change; (2) translate for the non-expert public the nature of the biosphere option, including the new technology options for C management; (3) describe the policy options and instruments available for responding to these challenges; (4) encourage dialogue among all interested parties about the integration of all of the above into an adequate risk management framework, using decision support software.

Project Team: William Leiss (UC), Greg Paoli (Decisionalysis Risk Consultants, Ottawa), Douglas Powell (UG)

5E-2: An Integrated Public Policy Perspective (Domestic Policy).

Approach: The development of domestic policy instruments oriented to the feasibility of the biosphere option for Canada will be occurring within a larger context of competing public policy perspectives being developed by other institutions in Canada as well as in other nations, particularly the United States and Europe. What is required is a clear sense of the strengths and weaknesses of domestic policy in the context of competing policies and perspectives originating both in Canada and elsewhere in the world. This subproject will supply a component of the integrated risk management framework.

Project Leader: Robert Boardman (DU)

5E-3: An Integrated Public Policy Perspective (International Policy).

Approach: A clear sense will be developed of the interplay between Canada's available policy options and instruments, in particular those based on the "comparative advantage" of its biosphere, and the choices made by other relevant nations, especially those which may constrain Canada's options (U.S., Europe, and others).

Project Leader: Robert Paehlke (TU)

5E-4: Guide to the Understanding of "Global Models."

Approach: A comparison of climate change models with other types of global models (e.g., ones developed for upper-atmosphere ozone depletion and population growth / resource demand interactions), including a close analysis of underlying strengths and weaknesses, can assist public understanding of the variety of models now being used in the climate change debate. The public needs to be aware of the nature, strengths, and limitations of these models in order to understand the risks associated with climate change. In addition, there has been a loud and protracted controversy over various assessments of climate models in the last decade. Since these models are exceedingly complex in their construction, a dedicated project is needed to provide guidance and assistance in this regard.

Project Leader: Stephen Haller (UWin)

5E-5: An Integrated Risk Management Framework.

Approach: Over the past twenty years risk managers in many different countries have developed flow-chart diagrams showing the nature and interconnections among the decision inputs for risk management issues. These decision processes are required to integrate scientific estimated of risk factors with a multiplicity of socio-economic factors. There is an ongoing re-evaluation and development of new process diagrams, most recently in the U.S. (1997). This project will integrate the decision inputs most relevant to the climate change debate within a decision process framework on an ongoing basis, as new information and policy considerations become apparent.

Project Leader: Daniel Krewski (UO)

Project 5F: Theme 5 Contribution to Case Study Integration Papers `($38K/$63K)

Objectives: To explore the science:policy interface in the various BIOCAP projects and prepare integration papers outlining policy options and identifying critical areas of science or technological needs.

Project Team: All Theme 5 Project Coordinators, with the assistance of Project Leaders from Project 5E1-5E6.

Approach: A graduate student and postdoctoral fellow will work full time on the integration of aspects of the science policy interface, especially as it relates to the four reports generated by the Case Study Working Groups. Also, once a year from year 2 to year 4, there will be a annual workshop to bring together a broader community and discuss ideas and recommendations.

2.7. New Initiatives Program:

New Initiatives Program Lead:

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Background:

Only after the Kyoto conference of Dec. 1997 did Canada accept a mandate to reduce its GHG emissions. Consequently, the nation has lacked a multidisciplinary, coordinated research effort in the management of its biosphere C emissions. Even though university and government labs have considerable research expertise relevant to this challenge, much of it is not directed to specific deliverables in this area. The BIOCAP Network will play a major role in attracting Canada's top researchers to this important research effort. To achieve this, BIOCAP's Administrative and Research Budget include a capacity to fund new research projects. In this way, we will have the opportunity to balance the many advantages of a collegial, network approach with the benefits of infusing fresh talent into BIOCAP on an annual basis.

Approach: In years 2 to 4, new investment dollars (Yr. 2-4, $150K; Yr. 3-4, $100K; Yr. 4, $50K; total: $700K) are requested to supplement (a) those resources that will become available when projects are phased out or cancelled by the Research Planning Committee during the funding period, and (b) new industrial and government partnerships. By approval of the BIOCAP Board, the Research Planning Committee will have the discretion to issue 'Calls for Proposals' for these new funding opportunities (typically between 5 and 15% of the annual NCE research budget) which will be peer-reviewed by the Research Planning Committee and its subcommittees. An annual administrative budget for this program of $25K/year is included in budget sheet E6.

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2.9. Abbreviations

Canadian Universities

DU	Dalhousie University
MU	McGill University
TU	Trent University
QU	Queen’s University
RPU	Ryerson Polytechnic University
SFU	Simon Fraser University
UA	University of Alberta
UBC	University of British Columbia
UC	University of Calgary
UG	University of Guelph
UL	University of Lethbridge
ULA	Université Laval
UM	University of Manitoba
UNB	University of New Brunswick
UO	University of Ottawa
UR	University of Regina
US	University of Saskatchewan
UT	University of Toronto
UV	University of Victoria
UW	University of Waterloo
UWin	University of Windsor
UWO	University of Western Ontario

Government Deparments & Research Groups

AAFC	Agriculture and Agrifood Canada
AES	Atmospheric Environment Service (EC)
BCMF	BC Ministry of Forests
BRI	Biotechnology Research Institute (NRC)
CCAF	Climate Change Action Fund
CCRS	Canadian Centre for Remote Sensing
CCRL	Carbon Cycle Research Lab., AES, EC
CCS	Climate Change Secretariat
CFS	Canadian Forest Service
CWS	Canadian Wildlife Service
DFAIT	Dept. Foreign Affairs & Internat. Trade
EC	Environment Canada
IBS	Institute for Biological Science (NRC)
ICPET	Institute for Chemical Process and Environmental Technology (NRC)
MRNQ	Min. des ressources naturelles du Québec
NRC	National Research Council
NRCan	Natural Resources Canada
OMNR	Ontario Ministry of Natural Resources
PBI	Plant Biotechnology Institute

Research Organizations and Models

Ameriflux	US Eddy Covariance Network
CGCP	Canadian Global Change Program
CGS	Centre for Global Studies, UV
CIRL	Canadian Institute of Resources Law
ECOLEAP	Extended Collaboration for Linking Ecophysiology & Forest Productivity
NWRI	Nat’l Water Research Instit. (Sask)
PFRA	Prairie Farm Rehabilitation Admin.

Other

BOREAS	The Boreal Ecosystem
GCSI	Global Change Strategies Int’l
GCM	General circulation model
GHG	greenhouse gas
GIS	Geographic Information System
N	Nitrogen
C	Carbon
CO_2	Carbon Dioxide
T C	tonne C (metric)
MT C	megatonne C (10^6 metric tonne C)