A retrospective and lessons learned from Natural Resources Canada's Forest 2020 afforestation initiative

by S.W.J. Dominy[1,2], R. Gilsenan[3], D.W. McKenney[1], D.J. Allen[1], T. Hatton[3], A. Koven[4], J. Cary[4], D. Yemshanov[1] and D. Sidders[5]

ABSTRACT

Canada is seeking cost-effective means to mitigate anthropogenic greenhouse gas emissions, particularly CO_2, that have been linked to global climate change. In 2003 the Government of Canada launched the Forest 2020 Plantation Development and Assessment Initiative to assess the potential for fast-growing woody crops to sequester carbon from the atmosphere. Across the country 6000 ha of plantations were established and monitored on nonforested lands (afforestation) using a variety of methods. Economic analyses assessed the investment attractiveness of this mitigation measure for a range of species and suitable lands, taking into account such factors as growth rates, agricultural opportunity costs and a range of possible carbon values. Analyses illustrated that at current trading prices for carbon and for much of the available lands and expanding markets for forest bioproducts, expected rates of return on investment for afforestation were relatively low. However, higher future carbon prices, combined with monetary values for environmental benefits, could dramatically change the economics of afforestation in the future.

Key words: afforestation, carbon sequestration, forest carbon offset project, climate change mitigation, policy analysis, risk analysis, forest investment analysis, hybrids, hybrid poplar, fast-growing trees

RÉSUMÉ

Le Canada est à la recherche de moyens pour réduire les émissions de gaz à effets de serre issues de l'activité humaine, notamment le CO_2, qui ont été reliées aux changements climatiques de l'ensemble de la planète. En 2003, le Gouvernement du Canada a lancé le Programme d'évaluation et de démonstration de plantation de Forêt 2020 dans le but d'évaluer le potentiel d'utilisation des plantations d'arbres à croissance rapide pour piéger le carbone contenu dans l'atmosphère. Dans l'ensemble du pays, 6 000 ha de plantations sur des terrains non boisés (boisement) ont été créés et ont fait l'objet de suivis selon différentes méthodes. Des études économiques ont permis d'évaluer les incitatifs financiers rattachés à cette mesure de réduction des gaz dans le cas de différentes espèces et de divers terrains propices au boisement, en prenant en considération des facteurs comme le taux de croissance, les coûts d'opportunité agricole et un ensemble de valeurs possibles du carbone. Les études ont indiqué que selon les valeurs actuelles de transaction du carbone, de la plupart des terres disponibles et des marchés en progression des bioproduits forestiers, les taux attendus de retour sur l'investissement dans le cas de boisement étaient relativement faibles. Cependant, des valeurs plus importantes du carbone dans l'avenir associées à la valeur monétaire des bénéfices environnementaux, pourraient modifier de façon importante l'aspect économique du boisement.

Mots clés : boisement, piégeage du carbone, projet forestier de piégeage du carbone, mesure d'atténuation des changements climatiques, étude des politiques, analyse du risque, analyse des investissements forestiers, hybrides, peuplier hybride, arbres à croissance rapide

Introduction

Global climate change is one of the most important environmental, social and political challenges facing society today. Anthropogenic disturbances to the global carbon cycle—particularly the burning of fossil fuels—have led to increased concentrations of greenhouse gases in the atmosphere. Scientists predict that these increases will lead to significant regional and global changes in climate and climate-related parameters such as temperature, precipitation, drought, soil moisture, and sea level (Houghton *et al.* 2002).

Forests cycle carbon dioxide (CO_2), an important greenhouse gas (GHG), through the processes of photosynthesis, respiration, decomposition, and emissions associated with disturbances such as fire, insects, and timber harvesting. The carbon sequestration potential of forests was recognized in the Kyoto Protocol, thus allowing forestry activities such as afforestation to contribute to Canada's efforts to achieve Kyoto targets.

With continually increasing demands on the forest to supply non-timber benefits, meeting future societal demands for wood fibre will require deriving higher yields from the relatively small area of land available for plantations. One means to achieve this goal is to establish and intensively manage fast-growing tree plantations on currently unforested, underutilized agricultural lands (i.e., afforestation) capable of producing wood more quickly than natural forests. Internationally,

[1]Natural Resources Canada, Canadian Forest Service, 1219 Queen St., Sault Ste. Marie, Ontario P6A 2E5.
[2]Author to whom correspondence should be addressed.
[3]Natural Resources Canada, Canadian Forest Service, 580 Booth St., Ottawa, Ontario K1A 0E4.
[4]Trees Ontario, 200 Consumers Road, Suite 701, Toronto, Ontario M2J 4R4.
[5]Natural Resources Canada, Canadian Forest Service, 5320 – 122 Street, Edmonton, Alberta T6H 3S5.

plantations are becoming an important source of wood. The UN Food and Agriculture Organisation (FAO) forecasts that production of roundwood and fuelwood from plantations could triple in the coming four decades (Brown 2000).

On August 12, 2003, the Government of Canada announced the details of an investment of over $1 billion towards the implementation of a Climate Change Plan for Canada. As part of this investment, Natural Resources Canada's Canadian Forest Service (CFS) received funding for four years to demonstrate and assess the potential role of fast-growing plantations to sequester carbon and hence help Canada's efforts to mitigate climate change.

To this end the CFS implemented a four-year initiative, the Forest 2020 Plantation Demonstration and Assessment Initiative (F2020). F2020 established a series of plantation sites and analyses to test and improve the biological and economic information base, to demonstrate that fast-growing trees can help offset GHG emissions, and to create an alternative source of wood fibre. Twenty-year growth targets for the $20 million initiative were up to eight times the national average forest yield of 1.7 m^3 ha^{-1} yr^{-1}.

In this paper we provide a brief retrospective of various aspects and policy lessons learned from the F2020 program, primarily emphasizing the analysis of fast-growing plantations with a particular focus on hybrid poplar as it was the most widely planted across the country. The F2020 initiative resulted in a broad spectrum of valuable knowledge related to afforestation in Canada. Information was obtained through surveys, literature reviews, detailed economic analyses, technical sessions and direct field trials. This information has been presented in seminars and workshops, various publications posted on the F2020 website (CFS 2008a) and in peer-reviewed journals/publications (e.g., McKenney *et al.* 2004, McKenney *et al.* 2006, Yemshanov *et al.* 2005, Yemshanov and McKenney 2008). F2020 research also evaluated the investment prospects of joint projects that combine benefits of wood fibre and carbon sequestration offsets and tried to address the key policy question, "Under what circumstances would the combined values of afforestation provide sufficient incentive for establishing fast-growing plantations on a large scale in Canada?"

Background

F2020 had two interrelated components. The first was to establish 6000 hectares of fast-growing demonstration plantations across the country to test a variety of approaches and, the second was a policy objective aimed at assessing and understanding the spatial variation in investment opportunities for both wood production and carbon sequestration. Taking advantage of combined benefits was critical to the economic evaluation given the emergence of a market value for carbon sequestration offsets.

F2020 was structured to permit the integration of data and information from a diverse group of stakeholders who are or could be involved in afforestation activities. Rural Canadian landowners, provincial and municipal governments, forest product and nursery industries, environmental organizations, large institutional investors, scientists and economists combined their data, information and modelling capabilities to a single cause. Many small private and large industrial landowners also helped establish demonstration sites across Canada. These demonstrations were spread out across the country to garner national participation and to represent Canada's diverse range of ecological areas and bioclimatic zones. Plantation demonstration sites were coordinated through the CFS regional offices, which were able to use existing networks and established organizations to liaise with participating landowners and other partners. On the whole, lands selected for afforestation were underutilized fields, and did not supplant productive agricultural use. To derive a complete spectrum of growth data, it was necessary to include some higher quality lands, particularly in the Prairie region.

Operational Outcomes

Each of the five CFS regional centres developed delivery arrangements specific to their individual regions. Collaborators typically included provincial and municipal government departments, forestry and environmental associations, forest industry, research and educational institutions, silvicultural contractors, First Nations, and private landowners. A total of 5960 ha were planted under F2020 across Canada in 2004 and 2005 (Fig. 1).

Case study: F2020 delivery in Ontario

Trees Ontario (TO) was formed in 1994 and is now responsible for fundraising, supporting and coordinating many private sector tree planting activities in Ontario. Early on in the F2020 program TO was commissioned by the CFS regional centre in Sault Ste. Marie to organize a workshop of national experts from the science, genetics, seed, nursery production and plantation establishment fields. The objective was to identify, discuss, and confirm the state of knowledge of fast-growing native tree species. Based on the results of the workshop, TO immediately formed partnerships with Conservation Authorities and silvicultural associations and began working closely with private nursery growers to secure supply contracts based on stock availability. Partners developed and promoted a program across the province that attracted landowners who together embodied a wide range of land management objectives and species preferences. In some regions third-party consultants were engaged to deliver the program. In total, TO coordinated the establishment and reporting of over 90% of the provincial F2020 target area, involving 22 tree species.

Trees Ontario's challenge was to minimize administrative costs while developing: site selection criteria; agreements with delivery agencies and between landowners and delivery agencies; protocols for enlisting eligible sites; systems to track site information and allocation of resources; and templates for site plans, post-plant reports, planning quality assessments and survival assessments. These operational tools are posted online at http://www.treesontario.on.ca. To best manage the limited budget and meet the target total area across over 200 relatively small plantations, TO required landowner contributions of 25%, financial or in-kind, for each hectare planted.

Trees Ontario was so successful that in August 2005 the Ontario government announced a $2 million grant to TO and a further $2.1 million grant in spring 2006 to support tree planting on private lands. Today, TO continues to build upon the legacy of its F2020 experience in working with partners to build tree seed collection and nursery production capacity in support of a renewed afforestation effort in Ontario and is now the Ontario government's delivery agent for its 50-Million-Tree Program.

Case Study: F2020 Delivery in the Prairie Provinces

The CFS regional centre in Edmonton used its expertise and extensive partner network across Alberta, Saskatchewan and Manitoba to deliver the F2020 initiative. CFS staff negotiated agreements with private landowners, forest and afforestation companies, woodlot and forestry associations, First Nations, government and non-government forestry agencies. Guidelines were developed that outlined recommended site conditions and best practices for establishing tree plantations. Moderate- to high-quality land was identified using a map-based land suitability classification system (Joss *et al.* 2007).

Due to the long history of hybrid poplar breeding and planting across the Prairies, hybrid poplar was well suited to the F2020 high-yield objective, and consequently was the dominant tree planted in that region. CFS staff, using in-house greenhouse research facilities, produced site-suitable hybrid poplar container stock under 20-week growing regimes and passed them on to commercial nursery growers as a means of quickly meeting the program requirements. Additional site-suitable hybrid poplar cuttings and softwood seedlings came from private nurseries. Under F2020, several hybrid poplar plantations were established in a configuration to assess different clones and weed control regimes, and the results were used to refine best practice guidelines. Baseline carbon levels, growth and yield, and monitored plantation performance data were also collected, much of which is now available in the National Afforestation Inventory.

There were two significant results from the experience gained and partnerships formed under F2020 in the Prairie Provinces. The Manitoba government initiated a five-year, $5M Trees for Tomorrow program to plant 5 million trees (primarily hybrid poplar) on agricultural land to contribute to climate change mitigation. The Alberta Forest Research Institute invested $3.6M in a Centre for the Development of Best Short-rotation Woody Crop Practices to promote community stability through carbon sequestration, green energy and bioproducts.

F2020 objectives demanded that the selected species be relatively fast-growing. Additional factors that were considered in selecting species included resistance to disease, availability of stock, potential harvested wood products, and landowner preferences. Some regions were required to integrate some slower-growing species into their plantations because availability of fast-growing nursery stock was limited and because of the desire to assess "value", not just "volume" growth. Table 1 provides a summary of area and species planted and success rates after two or three growing seasons. The average plantation size was just over 10 ha, ranging from the largest (13.9 ha) established in the Prairies, to the smallest (2.2 ha) in Quebec. The size of individual plantations was partially affected by regional patterns of private land ownership. The widest array of species was planted in Ontario. In general, survival was best in Quebec and poorest in British Columbia, although data were not available to explain this difference.

Under F2020, landowners were asked to make a long-term commitment to look after the plantations in exchange for support for site preparation and purchasing and planting the trees. Ontario, Quebec and Prairie regions each produced comprehensive guides to assist landowners meet program requirements by providing information for plantation establishment and subsequent maintenance (Sidders and Keddy 2003, Ménétrier *et al.* 2005, White *et al.* 2005).

Investment Attractiveness Analyses

One of the key areas of economic analysis completed under the policy component was an examination of the economic returns from fast-growing plantations and the associated potential options for attracting large-scale investments into future Canadian plantations. Proponents of afforestation projects may have the opportunity in the future to obtain value for the carbon sequestration resulting from their project, in addition to benefits from wood fibre and other environmental services. The possibility of generating revenues from carbon offsets could therefore have a significant impact on the economic feasibility of afforestation projects by creating an income flow over the project lifetime. Ways to further facilitate private investment into fast-growing tree plantations were also explored.

Initial work included the analysis of international approaches to afforestation, including: Australia's joint venture arrangements; the Danish Forestry Extension Programme; institutional investment (TIMOs and FMOs[6]); Coillte's Farm Forestry Partnership Scheme in Ireland; Japan's Fiscal Investment and Loan Program, and Co-operative Financing Agreements; Norway's Forest Trust Fund; United States Forestry Incentives Program; and World Bank Carbon Finance Funds (CFS 2008b).

As part of F2020 the CFS organized a Plantation Investment Experts' Forum in March 2005 that included national and international experts in the plantation investment business (e.g., timberland investment firms, insurance companies, foreign governments, environmental commodity brokers, forest industry and researchers). These experts presented information on the policy drivers and motivation behind plantation investments. A key insight was the expected rates of return from afforestation projects. The forum also raised several other issues affecting the investment attractiveness of afforestation. These issues are: be clear about what the afforestation project will accomplish; make afforestation competitive (including 8%–14% rates of return to excite the private sector); clarify the rules for carbon offset trading; address liability and non-permanence issues; and, ideally, create mechanisms to generate annual cash flows from afforestation.

In support of discussions at the Forum, the results of preliminary cost–benefit modelling with the Canadian Forest Service Afforestation Feasibility Model (CFS-AFM) were presented; results suggested opportunities for afforestation in certain parts of the country. The CFS-AFM and its later version, Forest Bioeconomic Model (FBM) were developed by CFS to help assess the viability of afforestation and gain insights into the possible availability of land for afforestation in Canada given various financial incentives (CFS 2008c). The models are spatially explicit, and make use of climate data, operational costs, productivity information for various species, and land-use opportunity cost data. They include a carbon tracking module that is based on the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS2) principles (Kurz and Apps 1999) and allows carbon values to be included in the investment analyses. Both CFS-AFM and -FBM make use of a national Land Suitability Model (CFS

[6]Timber Investment Management Organization and Forest Management Organization, respectively.

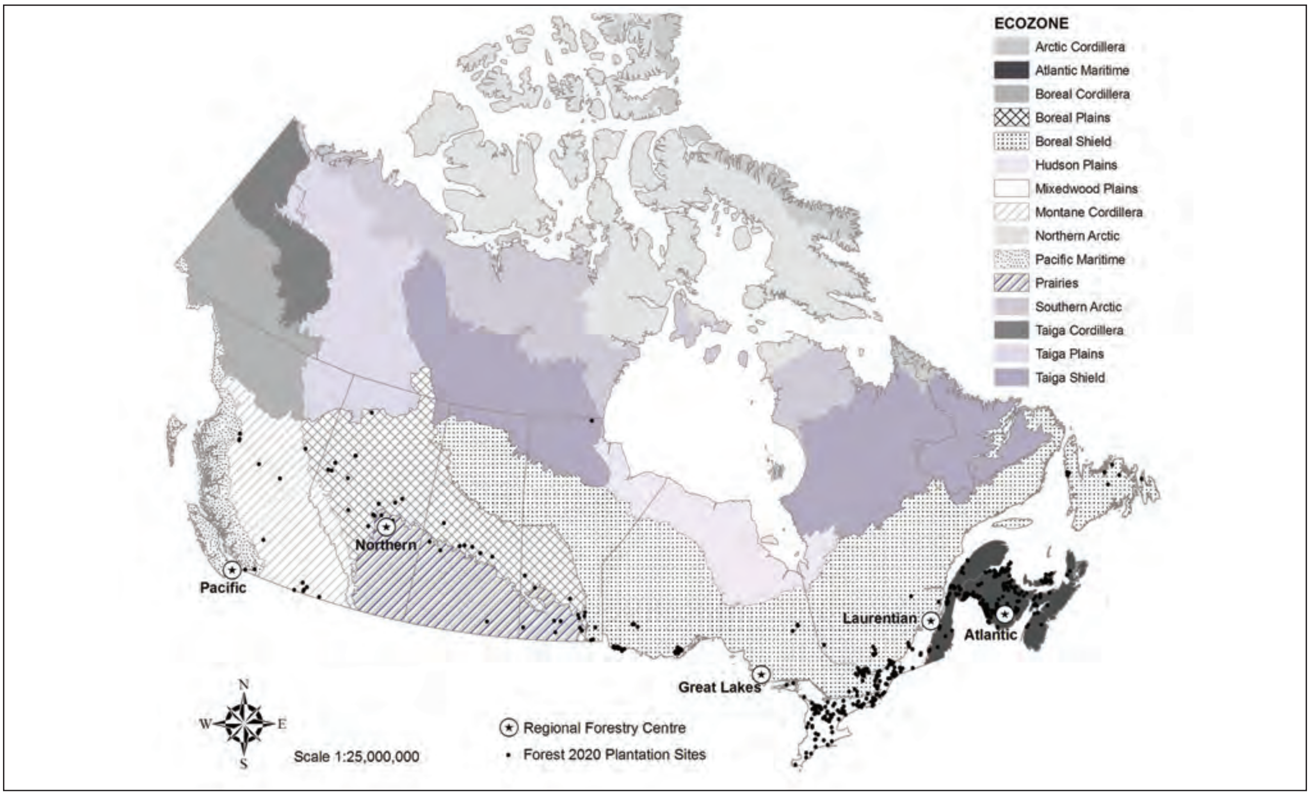

Fig. 1. Distribution of F2020 sites in Canada with reference to broad ecological regions.

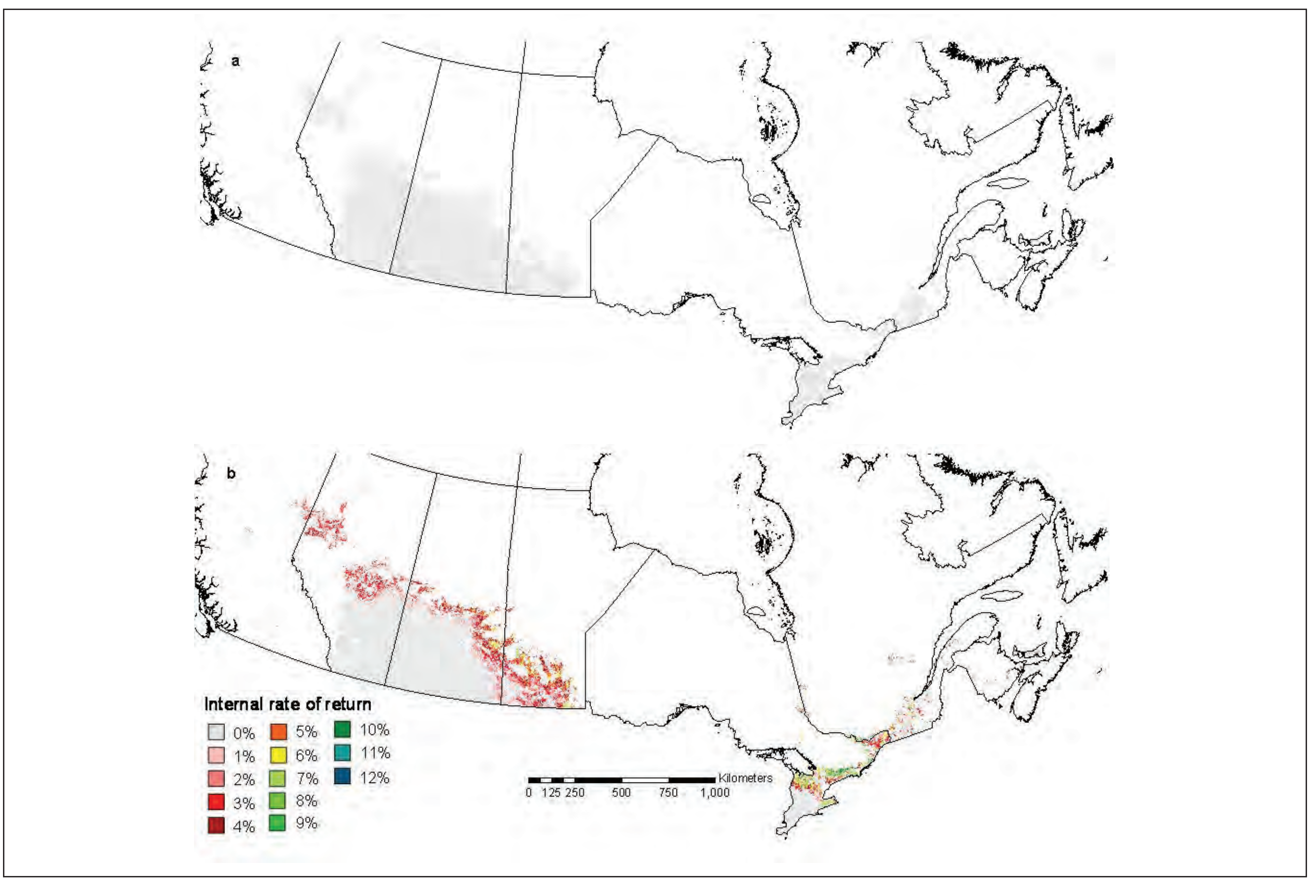

Fig. 2. Internal return on investment (ROI) for hybrid poplar shown spatially for Canada at two carbon prices: **a)** \$0 per tCO_2e and **b)** \$15 per tCO_2e.

Table 1. Details and performance of F2020 plantations, by region, after two to three growing seasons

Region	Area (ha)	Number of plantations	Average plantation area (ha)	Species[a]	Survival (%)
Atlantic	1643	283	5.8	HyP, Sn, Sw, Pr, Pw, Le, Fb	77
Quebec	147	66	2.2	By, HyP, Msu, Pr, Sn, Sw,	91
Ontario	1184	222	5.3	Ag, Aw, Cb, Hb, HyP, I, Le, Leu, Lj, Mr, Msi, Msu, Ob, Or, Ow, Pj, Pr, Pw, Sw, Sn, Tu, Wb	72
Prairies	1737	125	13.9	HyP, Ls, Ps, Pr, Sc, Sw	75
British Columbia	1246	100	12.5	Ar, Cwr, Cob, Fd, HyP, Ls, Pl, Pp, Sw	53
Total	5957	577	10.3		

[a]Full species names are listed in Appendix I.

2008d), which helped identify the potential productivity of agricultural lands for fast-growing hybrid poplar, hardwood and softwood species. More technical descriptions of the model and interpretations can be found in McKenney *et a*l. 2004, 2006; Yemshanov *et al.* 2005, 2007; Yemshanov and McKenney 2008.

Because of uncertainty in both the biological and economic aspects of this kind of analysis, the CFS-AFM and -FBM models were developed to portray a number of economic metrics such as internal rates of return, net present values and break-even unit prices for fibre and carbon offsets based on a range of different assumptions. These metrics can be useful because they provide a sense of what price carbon offsets would have to be for an investor to generate a profit. In fact, carbon markets are still evolving and although markets for carbon will likely persist and include important players like the United States, there remains much uncertainty about the actual path of future carbon prices.

The various analyses suggested that investment returns for, for example, hybrid poplar wood fibre values alone are close to zero. However, at an offset price of \$15/tonne of CO_2e[7], carbon can increase the rate of return to about 12.5% on some sites. The greatest potential appears to be in parts of the Prairies, parts of central Ontario and some locations in the Maritimes, with land opportunity cost being a key driver. While average growth rates of medium-growing hardwood and softwood plantations in Canada are about half those of hybrid poplar, some areas of the country are potentially attractive investments for afforestation using such slower-growing species, primarily because of much lower establishment costs (Yemshanov *et al.* 2005).

Fig. 2 portrays results, using hybrid poplar as the model, for two scenarios that use conservative silvicultural and management costs based on current contractor rates. These are meant to be illustrative since they do not include some project-level assumptions (such as transaction costs, leakage and non-permanence liability). The first map (Fig 2a) provides an outline of agricultural lands across the country and suggests that fibre benefits alone won't make poplar plantations financially attractive. The key model assumptions that influenced these results were up-front establishment costs (close to \$4000/ha over the first four years), low wood fibre prices, growth rates (15 m^3 ha^{-1} yr^{-1} on the best sites), and agricultural opportunity costs. Fig. 2b, however, shows that a significant portion of Canada's agricultural land-base can potentially generate an attractive return.

The only difference between Fig. 2a and Fig. 2b is the assumption of carbon sequestration benefits at the unit price \$15 per tCO_2e. These analyses did not monetize possible environmental co-benefits that may be associated with fast-growing plantations. Such benefits are often localized, difficult to price and often do not generate direct financial returns to a landowner. Some analyses were undertaken in the original F2020 work that identified what the break-even price for other non-wood and non-carbon values would have to be to generate positive returns. The numbers varied considerably; the highest break-even prices were near urban centres with highly priced agriculture lands, such as in southern Ontario (Ramlal *et al.* 2009).

The economic and financial modeling suggest that returns on investment of 8% to 12% are generally difficult to meet unless prices for carbon approach or exceed \$15/tCO_2e. Recent estimates in the United States and Canada predict that carbon prices could level out somewhere between \$16 to \$32 per tCO_2e by 2020, with realistic mean estimates being around \$25 per tCO_2e (EPA 2007; Congressional Budget Office 2009; EIA 2009a, b). Taken together these results illustrate some of the challenges faced by the forest community to make afforestation more financially attractive.

Since the completion of these analyses we have seen large fluctuations in the price of petroleum, and a growing sense of urgency for the need to cut GHG emissions, which has led to the introduction of low-carbon fuel standards around the world. This increased interest in the development of biofuels, along with advancements in technologies for converting wood biomass into biofuels and other high-value co-products, is now causing renewed interest in the economic modeling completed under F2020. Specifically, the potential for deriving extra value from forest residuals or from dedicated short-rotation plantations of hybrid willow or hybrid poplar is also affecting the potential value of investment into Canadian plantations. Using the research work and modeling capacity developed under F2020, these issues are being re-examined (e.g., Yemshanov and McKenney 2008, Ramlal *et al.* 2009).

[7]The CO_2e quantity of any greenhouse gas is the amount of carbon dioxide that would produce the equivalent global warming potential.

Operational Lessons Learned

Plantation establishment considerations

Establishing plantations in underutilized agricultural fields can be costly due to the number of steps involved, from site selection through establishment and maintenance. Afforestation also has to compete with agricultural land uses and usually requires far more intensive management practices than typical reforestation, and thus is more akin to farming, with the added challenge that the harvest revenue is deferred for several years, thus affecting net economic returns. Minimizing the up-front costs is especially important for deriving a positive financial return on investment if this is a principal landowner objective.

Experience from F2020 dictated that establishment costs can often be minimized by mechanizing as many aspects of the operation as possible, ensuring the best match of species to site type, using the lowest-cost planting stock that meets desired growth rate targets, choosing the optimal tree spacing, and selecting species for which end product market demand and price are more favourable. Protecting the initial investment through diligent weed control, particularly in the early plantation establishment phase, and in some cases pest management practices and irrigation, may become important.[8] Planting on relatively productive soils where land costs are low, and in areas relatively close to services and markets can often improve economic returns. Because of economies of scale, larger-scale afforestation projects can help lower per-unit costs of managing and harvesting tree plantations.

Hybrid poplar as a fast-growing afforestation choice for Canada

Hybrid poplar has been developed over many years through the trial-and-error crossing of genetic stock, commonly from various parts of North America and Europe, and provides an illustration of how such breeding can result in significant productivity gains. All regions of the country have experience with growing hybrid poplar, and planting stock for certain favoured clones are generally available across the country. Hybrid poplar is easy to establish using readily available cuttings that can be produced in large quantities within a relatively short time, has a known capacity to achieve the high yield targets set by F2020 (up to 13.6 m^3 ha^{-1} yr^{-1} over 20 years), and is adapted to various growing conditions experienced in many regions of the country. It is the most widely planted high-yield tree grown on a commercial scale in Canada. Thus, all regions of the country planted at least some hybrid poplar clones under F2020. Despite the advantages noted, certain hybrids, particularly when grown at close spacing in monoculture plantations, are predisposed to diseases that lower quality, yield and lifespan. There have been few field trials replicated across provinces with hybrid poplar; thus, there is still much to be learned about adapting clones to site and region to optimize yields. There is also a continual need to develop and refine clones to suit various biogeoclimatic conditions, work which is especially germane in light of a rapidly changing climate.

Examples of ongoing research efforts with hybrid poplar include Canada's 100-year-old Prairie Shelterbelt Program at the Prairie Farm Rehabilitation Administration in Saskatchewan (Agriculture and Agri-Food Canada 2007). The government of Quebec has been breeding and field testing poplar clones for 40 years. Other significant programs are underway in western Canada, including one led by Alberta-Pacific Ltd. in northern Alberta, and another by Scott Paper Ltd. in south-central British Columbia. These region-specific efforts have resulted in a significant increase in volume yields relative to native trees, and clones that can better tolerate harsher northern climates and poorer quality soils. With the work now underway to decipher the ecological function of individual genes (Tuscan *et al.* 2006) the future for attracting new investments in clonal poplar plantations looks especially promising.

In recognition of a number of factors, including lower transportation costs for the wood and a secure fibre supply, some private enterprises have adopted the practice of purchasing or leasing underutilized agricultural lands relatively close to mills to grow hybrid poplar. Indeed, companies may be more inclined to invest heavily in the intensive forest management required to optimize yields of poplar when they own or lease private lands.

Assessing carbon sequestration potential

The quantification of carbon sequestered in a plantation is a prerequisite for society to benefit from the potential co-benefits of carbon offsets and wood fibre production. Many countries are engaged in developing standard and repeatable methodologies to document this information. The CFS contributed to this effort through preliminary work done under F2020. The Alberta government has developed a Quantification Protocol for Afforestation Projects (Government of Alberta 2009) that includes measuring baseline above- and below-ground carbon on the land prior to planting, and monitoring plantation yield (a surrogate measure for carbon sequestration) over time. The CFS developed standard laboratory protocols for use by each Regional Centre.

Created for F2020, the National Afforestation Inventory (NAI) was developed to facilitate the compilation and management of information on afforestation in Canada, including detailed information on each plantation. It is publicly accessible, but it is also used by the CFS to provide information to Canada's National Forest Carbon Monitoring, Accounting and Reporting System (NFCMARS) for United Nations Framework Convention on Climate Change reporting (Environment Canada 2009a). Inside the NFCMARS, information from the NAI is input into the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) (Kurz and Apps 2006, Kurz *et al.* 2009), which calculates carbon stocks associated with afforested lands in biomass and dead organic matter and estimates annual carbon stock changes. The NAI is an important legacy of F2020 and remains Canada's principal vehicle for gathering and managing information about afforestation.

Policy Lessons Learned

Attracting investment into Canadian forests

Fast-growing plantation forests could have an increasing role as sustainable suppliers of fibre, fuelwood, low-grade roundwood, non-timber forest products and other social and environmental values. Moreover, emerging opportunities for the production of bioenergy and a range of other bioproducts (e.g., biochemicals, nutraceuticals, pharmaceuticals, carbon fibres, etc.) have helped renew interest in Canadian forestry. Although Canada has in the past ranked in the top five coun-

[8]Full details of the operational outcomes are available in regional reports posted on the F2020 Web site (CFS 2008a).

tries most attractive to investors with regard to timber-related capital spending (Neilson and Manners 1997), financial returns on fast-growing plantations have not yet been proven or secured on a large scale. Research on attracting investment into Canadian plantations and incentives and barriers to such investments is therefore expected to inform policy-makers on policies designed to create an enabling environment for increasing the establishment of fast-growing plantations.

For the most part, afforestation occurs on privately owned lands, which presents a unique set of challenges. Landowners tend to be cautious about planting trees and thus significant shifts in landowner actions will likely occur only when substantial, tangible evidence of the costs and benefits is demonstrated to them (CFS 2008e). Indeed, markets and prices for hybrid poplar and many other wood-based products are continuing to evolve and cause uncertainty in the decision-making process. In some isolated cases, certain hybrids have been successfully grown to sufficient size and quality to be converted to veneer used in plywood and furniture production in Canada, but in general the potential for hybrid poplar to become furnish for other higher-value products is largely unknown.

The relatively irreversible nature of forest plantation investments is an important factor in the landowners' decisions. Agriculture offers more alternatives every year than plantation forestry, which essentially locks up land use for a considerably longer period and does not generate significant income until the final harvest[9]. The significance of the opportunity to delay irreversible investments has long been recognized in the economic literature (Black and Scholes 1973, Merton 1973), but requires further investigation in the afforestation case.

The expected emergence of new markets for wood biomass for conversion to energy (e.g., wood-based biofuels, heat and power, and wood pellets) and the potential for such bioenergy plantations to generate additional revenue from the sale of carbon offsets, changes the economic picture. The presence of third-party investors who rent or lease private lands for growing woody crops also changes this analysis, as the risk is then shifted away from the landowner.

Afforestation and carbon sequestration

Carbon sequestration strategies for forests also have long-term policy implications. At first glance, carbon credits may provide a sustainable way of financing plantation enterprises. A leading example of action in carbon credit trading is the Chicago Climate Exchange, which opened in 2003 as the first North America-wide greenhouse gas emissions allowance trading system, under which afforestation-based carbon offsets are eligible. In Canada, the Alberta government has established the Alberta Offset System, which also recognizes forestry projects for carbon offset credits. Similarly, the Ontario and Quebec governments are considering cap-and-trade systems that aim to lower greenhouse gas emissions by putting a price on carbon; afforestation/reforestation projects are being proposed for inclusion in these systems. At the federal level, Canada's Offset System for GHG (Environment Canada 2009b) is under development, and recognizes afforestation as a voluntary emissions reduction measure. Such forest-based mitigation measures are likely to have to comply with an international framework such as the United Nations Framework Convention on Climate Change (UNFCCC), and thus would have to meet the criteria of additionality, permanence and leakage. These criteria present unique challenges for afforestation projects, not least of which is the risk associated with potential natural disturbance and harvesting that may result in unexpected and unavoidable emissions (Ristea and Maness 2009).

Afforestation can be used as a temporary storage system for carbon and can help a country advance towards its GHG reduction targets and thus buy more time until more advanced technologies for permanent carbon storage become available. The use of bioenergy and bioproducts made from forest biomass can replace higher-emitting petroleum-based products and high energy-intensity building materials such as concrete and steel. While there are not enough lands available in this country to fully offset Canada's emissions through tree planting and the use of biomass, afforestation is an option in the suite of possible mitigation measures for addressing GHG emissions targets.

Research completed under F2020 has enhanced our knowledge of forest management practices to maximize carbon, as well as methods for measuring and monitoring carbon sequestration rates. Minimizing the costs of quantifying carbon sequestration is expected to be a key factor in reducing the transaction costs associated with participation in an offset trading system. Approaches developed under F2020 can be used to inform policies and practices around this issue.

Conclusions

Working in partnership with provinces, forest industry, associations, rural landowners and others, CFS helped establish close to 6000 ha of fast-growing (primarily) plantation demonstration sites on private lands to test and improve biological information and demonstrate the various benefits, both economic and environmental, from plantation forests. Tools to measure and monitor carbon sequestration were developed and tested under the F2020 initiative. Many of these plantations continue to provide valuable information to researchers from both a carbon sequestration and alternative fibre use perspective. Researchers from the CFS are continuing their work on fast-growing plantations, examining various species for bioenergy and other products; F2020 hybrid poplar demonstration sites are proving valuable in these studies.

The economic analyses looked at hybrid poplar, in part because it was planted in all regions of the country and was known to have the highest average yield. The analyses indicated that while fast-growing forests can provide a range of timber supply and carbon benefits, their returns are generally not high enough (8%–14% rates of return) to induce large-scale private investments (at least with the price expectations examined). Additional public expenditures may be needed to attract significant private investment in fast-growing plantations. This investment could come in the form of partnerships, incentive programs, credits, and/or research that increases growth rates and/or drives down production costs. However, this conclusion comes with caveats. High carbon offset prices could change perspectives dramatically. Recent

[9]Short-rotation energy crops such as willow can generate income on a three- to four-year cycle, but once planted the crop could occupy the land for 20 years or more. Plantation commercial thinnings are recognized as another income-generating activity before final harvest, although the practice is presently uncommon in Canada.

predictions of carbon prices exceeding the $15 per tCO_2e level, and the establishment of cap and trade offset systems may bode well for investments in forestry carbon offset projects. Moreover, the potential for converting forest biomass to bioenergy and other bioproducts is expected to further increase the potential for higher returns in all regions of the country.

Overall, the F2020 program has enhanced our scientific knowledge base for fast-growing plantations in Canada. Research completed under F2020 is expected to provide long-term benefits for the Canadian forest sector by informing both forest managers and policy-makers on forest management strategies and policies related to plantation development.

Acknowledgements

The significant contributions of Ed Banfield, Gilles Chantal, Saul Fraleigh, John Henderson, Stephen Kull, Dean Mills, Art Robinson, Tim Keddy, and Trevor White are greatly appreciated.

References

Agriculture and Agri-Food Canada. 2007. Prairie Farm Rehabilitation Administration Shelterbelt Centre [online; modified 2007 Aug. 7] Available at http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1186517615847&lang=eng [Accessed 15 June 2009].

Black, F. and M. Scholes. 1973. The pricing of options and corporate liabilities. J. Political Economy 81: 637–659.

Brown, C. 2000. The global outlook for future wood supply from forest plantations. United Nations Food and Agriculture Organisation GFPOS Working Paper No. 3. 141 p.

[CFS] Canadian Forest Service. 2008a. Afforestation policy analysis [online; modified 2008 July 15]. Available at http://cfs.nrcan.gc.ca/subsite/afforestation [Accessed 2009 Dec. 18].

_____. 2008b. Investment option analysis [online; modified 2008 July 15]. Available at http://cfs.nrcan.gc.ca/subsite/afforestation/investmentanalysis#plantation [Accessed 2009 Dec. 18].

_____. 2008c. Economic analysis [online; modified 2008 Oct. 28]. Available at http://cfs.nrcan.gc.ca/subsite/afforestation/economic-analysis/#AFM [Accessed 2009 Dec. 18].

_____. 2008d. Land suitability [online; modified 2008 Oct. 28]. Available at http://cfs.nrcan.gc.ca/subsite/afforestation/landsuitability [Accessed 2009 Dec. 18].

_____. 2008e. Report summaries, Landowner Incentive Focus Sessions: "What Incentives are Required to get Trees in the Ground?" [online; modified 2008 Oct. 28]. Available at http://cfs.nrcan.gc.ca/subsite/afforestation/reportsummaries/#GLFC1 [Accessed 2009 Dec. 8].

Congressional Budget Office. 2009. The Economic Effects of Legislation to Reduce Greenhouse-Gas Emissions. Statement of Douglas W. Elmendorf Director before the Committee on Energy and Natural Resources, United States Senate. Available at http://www.cbo.gov/ftpdocs/105xx/doc10561/10-14-Greenhouse-GasEmissions.pdf [Accessed 2009 Nov. 15].

[EIA] Energy Information Administration. 2009a. Independent Statistics and Analysis, Figure ES-3. Allowance Prices in Main ACESA Cases, 2012-2030 [online; 2009 Aug. 4]. Available at http://www.eia.doe.gov/oiaf/servicerpt/hr2454/figurees3.html [Accessed 2009 Nov. 15].

_____. 2009b. Independent Statistics and Analysis, Energy Market and Economic Impacts of H.R. 2454, the American Clean Energy and Security Act of 2009 [online; 2009 Aug. 4]. Available at http://www.eia.doe.gov/oiaf/servicerpt/hr2454/index.html [Accessed 2009 Oct. 15].

Environment Canada. 2009a. National Inventory Report: Greenhouse Gas Sources and Sinks in Canada 1990–2007, Submission to the United Nations Framework Convention on Climate Change. Gatineau, QC.

_____. 2009b. Overview guide, draft for public comment [online; modified 2009 July 3]. Available at http://www.ec.gc.ca/creditscompensatoires-offsets/default.asp?lang=En&n=92CA76F4-1 [Accessed 2009 Nov. 15].

[EPA] Environmental Protection Agency. 2007. EPA Analysis of The Climate Stewardship and Innovation Act of 2007, S. 280 in 110th Congress. Available at http://www.epa.gov/climatechange/downloads/s280fullbrief.pdf [Accessed 2009 Nov. 15].

Government of Alberta. 2009. Approved Alberta Protocols – afforestation quantification protocol (draft) Available at http://carbonoffsetsolutions.climatechangecentral.com/offset-protocols/approved-alberta-protocols [Accessed 15 Nov. 2009].

Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden and D. Xiaosu (eds.). 2002. Climate Change 2001: The Scientific Basis. Cambridge University Press, Cambridge, UK. 83 p.

Joss, B.N., R.J. Hall, D.M. Sidders and T.J. Keddy. 2007. Fuzzy-logic modeling of land suitability for hybrid poplar across the Prairie Provinces of Alberta. Environmental Monitoring and Assessment 141: 79–96.

Kurz, W.A. and M.J. Apps 1999. A 70-year retrospective analysis of carbon fluxes in the Canadian forest sector. Ecological Applications 9: 526–547.

Kurz, W.A. and M.J. Apps. 2006. Developing Canada's national forest carbon monitoring, accounting and reporting system to meet the reporting requirements of the Kyoto Protocol. Mitigation and Adaptation Strategies for Global Change 11: 33–43.

Kurz, W.A *et al*. 2009. CBM-CFS3: a model of carbon-dynamics in forestry and land-use change implementing IPCC standards. Ecological Modelling 220 (4): 480–504.

McKenney, D.W., D. Yemshanov, G. Fox and E. Ramlal. 2004. Cost estimates for carbon sequestration from fast-growing poplar plantations in Canada. For. Policy Econ. 6: 345–358.

McKenney, D.W., D. Yemshanov, G. Fox and E. Ramlal. 2006. Using bioeconomic models to assess research priorities: a case study on afforestation as a carbon sequestration tool. Can. J. For. Res. 36: 886–900.

Ménétrier, J, M. Perron, G. Daoust and G. Sirois. 2005. Afforestation of wildlands: a practical guide. [also available in French under the title Forêt 2020: Guide pratique sur le boisement des friches]. Gouv. Québec, Ministère des Ressources naturelles et de la Faune, Direction de la recherche forestière and Natural Resources Canada, Canadian Forest Service, Laurentian Forestry Centre, Ste. Foy, Quebec. 27 p. Available at http://www.mrnf.gouv.qc.ca/publications/forets/connaissances/recherche/Menetrier-Jean/Forest-2020-Afforestation.pdf (in English) and http://www.mrnf.gouv.qc.ca/publications/forets/connaissances/recherche/Menetrier-Jean/Foret-2020-Boisement-friche.pdf (in French).

Merton, R.C. 1973. Theory of rational option pricing. Bell J. Econ. Manage. Sci. 4: 141–183.

Neilson, D.A. and G. Manners. 1997. The tree farm and managed forest industry. DANA Publishing, Rotorua, New Zealand. 329 p.

Ramlal, E, D. Yemshanov, G. Fox and D. McKenney. 2009. A bioeconomic model of afforestation in southern Ontario: integration of fiber, carbon and municipal biosolids values. J. Environ. Manage. 90: 1833–1843.

Ristea, C. and T.C. Maness. 2009. Opportunities, challenges and markets for forest carbon offset projects. For. Chron. 85(5): 715–719.

Sidders, D. and T. Keddy. 2003. Afforestation guidelines for the Prairie Provinces. Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta. 4 p.

Tuscan, G.A. *et al*. 2006. The genome of black cottonwood, *Populus trichocarpa* (Torr. & Gray). Science 313: 1596–1604.

White, T.J.R., S.W.J. Dominy and D.J. Allen. 2005. Review of best practices for tree planting on marginal lands in Ontario [online]. [also available in French under the title Examen des meilleures pratiques pour la plantation d'arbres sur les terres cultivables marginales en Ontario]. Natural Resources Canada, Canadian Forest Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON.
Available at http://cfs.nrcan.gc.ca/subsite/glfc-tree-planting/intro (in English) and http://scf.rncan.gc.ca/soussite/glfc-tree-planting/introduction (in French).

Yemshanov, D. and D.W. McKenney. 2008. Fast-growing poplar plantations as a bioenergy supply source for Canada. Biomass and Bioenergy 32: 185–197.

Yemshanov, D., D.W. McKenney, S. Fraleigh and S. D'Eon. 2007. An integrated spatial assessment of the investment potential of three species in southern Ontario, Canada inclusive of carbon benefits. For. Policy Econ. 10: 48–59.

Yemshanov, D., D.W. McKenney, T. Hatton and G. Fox. 2005. Investment attractiveness of afforestation in Canada inclusive of carbon sequestration benefits. Can. J. Agric. Economics 53: 307–323.

Appendix I. Species abbreviations and full names.

Abbreviation	Scientific name	Common name
Ag	*Fraxinus pennsylvanica*	Green Ash
Ar	*Alnus rubra*	Red Alder
Aw	*Fraxinus americana*	White Ash
By	*Betula alleghaniensis*	Yellow Birch
Cb	*Prunus serotina*	Black Cherry
Cwr	*Thuja plicata*	Western Red Cedar
Cob	*Populus trichocarpa*	Black Cottonwood
Fb	*Abies balsamea*	Balsam Fir
Fd	*Pseudotsuga menziesii*	Douglas-Fir
Hb	*Carya cordiformis*	Bitternut Hickory
HyP	*Populus* spp.	Hybrid Poplar
I	*Ostrya virginiana*	Ironwood
Le	*Larix laricina*	Eastern Larch
Leu	*Larix decidua*	European Larch
Lj	*Larix leptolepis*	Japanese Larch
Ls	*Larix sibirica*	Siberian Larch
Mr	*Acer rubrum*	Red Maple
Msi	*Acer saccharinum*	Silver Maple
Msu	*Acer saccharum*	Sugar Maple
Ob	*Quercus macrocarpa*	Bur Oak
Or	*Quercus rubra*	Red Oak
Ow	*Quercus alba*	White Oak
Pj	*Pinus banksiana*	Jack Pine
Pl	*Pinus contorta*	Lodgepole Pine
Pp	*Pinus ponderosa*	Ponderosa Pine
Pr	*Pinus resinosa*	Red Pine
Ps	*Pinus sylvestris*	Scots Pine
Pw	*Pinus strobus*	White Pine
Sc	*Picea pungens*	Colorado Spruce
Sn	*Picea abies*	Norway Spruce
Sw	*Picea glauca*	White Spruce
Tu	*Liriodendron tulipifera*	Tulip-Tree
Wb	*Juglans nigra*	Black Walnut