climate change
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Forecasting Carbon Storage and Carbon Offsets for Southern Ontario Afforestation Projects: The 50 Million Tree Planting Program

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Introduction

Human activities and the combustion of fossil fuels have significantly increased the atmospheric concentration of carbon dioxide (CO_2) and other greenhouse gases (GHG) over pre-industrial levels (IPCC 2007). The accumulation of GHG is now accepted as the most likely primary cause of recent warming and projected climatic change that is predicted to have a profound, largely negative influence on the social, economic, and ecological health of Canada (Lemmen et al. 2008). Forests store large amounts of carbon (C) in living and dead biomass and soil through the processes of photosynthesis, respiration, and decomposition. International efforts aimed at addressing climate change recognize land use, land use change, and forestry as relatively low cost options to enhance terrestrial C storage, slow the rate of atmospheric CO_2 accumulation, and mitigate the adverse effects of climate change (Sedjo et al. 1995, IPCC 2000). Within this context, afforestation can be defined as a land use change since it involves deliberately establishing new forests (and increasing the amount of biomass C) on lands that have not contained forests since 1990 (White and Kurz 2005). Generally, these trees are established on marginal or fallow agricultural land where the climate is suitable for their growth.

In August 2007, the Ontario government released its plan to address climate change and achieve meaningful reductions in provincial GHG emissions (Government of Ontario 2007). A suite of actions are proposed to reduce future provincial emissions by 6, 15, and 80% of 1990 levels by 2014, 2020, and 2050, respectively. Current and future initiatives to create new forests are key features of provincial efforts to mitigate climate change by increasing forest C storage. Since almost 75% of the approximately 1.26 million ha of land available for afforestation in Ontario is located in the south and is privately owned (Parker et al. 2000, OMNR 2002, Bird and Boysen 2007), the scale and contribution of afforestation to meeting the emissions reduction targets will depend in part on incentives to landowners to commit their land to growing plantations (Cherry 2001, ArborVitae Environmental Services Ltd. 2004, Bird and Boysen 2007, Gleeson et al. 2009).

As a component of Ontario's *Action Plan on Climate Change*, the province announced a long-term commitment to plant 50 million trees on about 25,000 ha in southern Ontario by 2020 (Government of Ontario 2007). In this note, we provide estimates of the range of C storage possible through afforestation programs in Ontario, using the 50 million tree planting program as a test case scenario. Red pine (*Pinus resinosa* Ait.) and white spruce (*Picea glauca* (Moench.) Voss) are commonly planted in southern Ontario (Taylor and Jones 1986) and were selected as the focal tree species for this exercise. Red pine has historically been a popular choice for planting across its natural range due to its ability to establish on water- and nutrient-limited sites, relatively high growth rate, and suitability for intensive management for timber production (Rudolph 1990, Ouimet et al. 2007, Parker et al. 2008). White spruce has a lower relative growth rate than red pine, but is a preferred species for timber production and

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afforestation in Canada and in Ontario on finer textured, more productive soils (White and Kurz 2005, Tremblay et al. 2006). As well, sufficient growth and yield information relevant to Ontario and adequate for this exercise, much of which is derived from plantations established on degraded forest and marginal agricultural land, is available for both species.

Materials and methods

Carbon storage forecasts were generated using several stem wood volume (inside bark)–stand age relationships relevant to southern Ontario (Table 1). With few exceptions, yield curves were for unthinned plantations with minimal management. In some cases, separate yield curves were derived for general classes of site productivity, or *site index* (SI) (height (m) at age 50). Because these yield curves were produced from data collected from many stands occurring on a range of sites, it is assumed that they provide estimates of average stem volume growth rates for an aggregation of individual plantations varying in site conditions and stand establishment activity within a larger, regional afforestation program (Figure 1).

Table 1. Geographic location, number of sampling plots (N), age, site index[1] (SI), and data source for the red pine (a) and white spruce (b) stem wood volume-stand age yield curves used for the C storage projections.

Location	N	Age (yr)	SI	Source
(a) red pine				
ON	34	36-74	24, 18	Woods and Penner 2000
ON	na[2]	na		Plonski 1981
QC	280	4-53		Ouimet et al. 2007
PEI	na	6-50		Greene 2002
WI, US	54	15-31	20, 17	Wilde et al. 1965
(b) white spruce				
ON	46	12-60	24, 21, 18, 15	Berry 1987
PEI	na	10-50		Greene 2002
WI, US	37	<30	20, 17	Wilde et al. 1965

1/ Site index is a measure of site productivity expressed as average height (m) attained by dominant trees at age 50.
2/ Not available in data source.
Note: ON: Ontario, QC: Quebec, PEI: Prince Edward Island, Canada. WI, US: Wisconsin, United States.

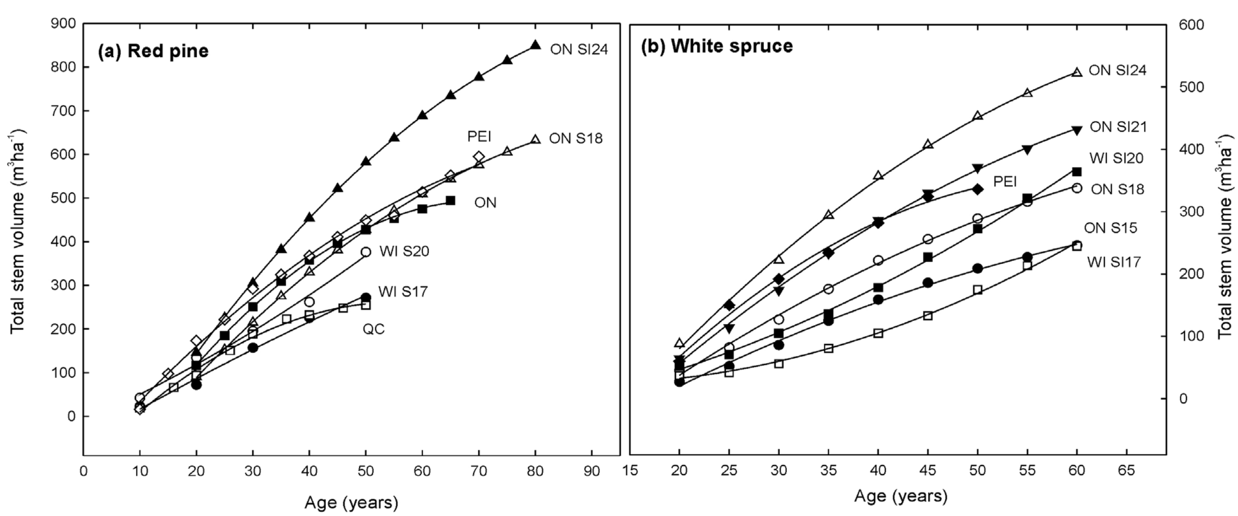

Figure 1. Relationship of stem wood volume and stand age for red pine (a) and white spruce (b) plantations growing in several geographic locations. Curves are labelled to indicate geographic source of data and (where applicable) site index (SI) (see Table 1). Note difference in scale of y axes between species.

Regression was used to generate a single quadratic equation for data pooled for the seven yield curves for each species. Regression was confined to a shared pooled data range for yield curves (red pine, 10 to 50 years old; white spruce, 20 to 50 years old). This quadratic equation is assumed to define the relationship between average stem volume per hectare and stand age for southern Ontario. From this regression analysis, the 95% prediction interval associated with this yield curve also was generated, allowing calculation of the statistical variation in mean volume yield projections (Figure 2).

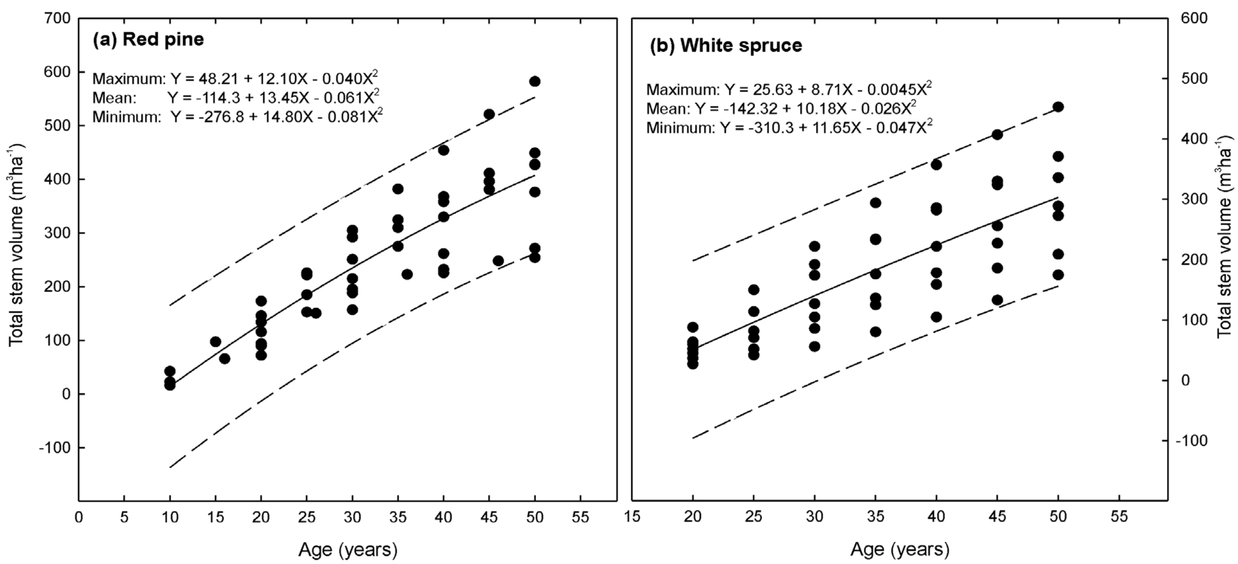

Figure 2. Relationship between total stem volume and stand age for red pine (a) and white spruce (b) yield curve data pooled for all geographic locations. Shown are regression lines, 95% confidence limits, and quadratic equations for the mean, maximum, and minimum predicted volume.

Protocols for quantifying C storage in living trees rely on the use of known allometric relationships and biomass expansion factors, based on measures of stem size, to estimate biomass and C contained in the stem wood, bark, branches, and coarse roots of living trees (Jenkins et al. 2003, Lambert et al. 2005). Accounting for changes in C in standing dead trees, forest floor, and mineral soil is not mandatory in afforestation protocols (e.g., Alberta Environment 2007) and these factors were not considered in this analysis. We used the mean volume yield equation to estimate total CO_2 removal, or CO_2 equivalents (CO_2e), using species-specific allometric relationships and biomass expansion factors as follows. Mean stem wood volume estimates (m^3 ha^{-1}) for any selected stand age were converted to stem wood biomass (t ha^{-1}) by multiplying volume by the mean wood specific gravity (0.39 t m^{-3} for red pine and 0.35 t m^{-3} for white spruce as per Mullins and McKnight 1981). Stem wood biomass was then converted to total aboveground biomass using allometric relationships and biomass equations. The average proportion of total aboveground biomass contained in stem wood bark and branches for trees ranging from 5 to 30 cm in diameter at breast height (dbh) (the dbh range documented for pine and spruce 10 to 50 years old) were estimated using the biomass equations of Lambert et al. (2005). Coarse root biomass was assumed to be 0.20 of total aboveground biomass, a somewhat conservative estimate based on values published for upland conifers (Cairns et al. 1997, Li et al. 2003). Total living tree biomass was converted to total C by multiplying by 0.50, which is the average proportion of C in dry plant biomass (i.e., 50% of wood dry mass is C). Total CO_2 sequestration (i.e., CO_2e contained in living biomass C) was estimated by multiplying total C by 3.667 (i.e., 1 kg biomass C equals uptake of 3.667 kg CO_2).

If 50 million trees are to be planted between 2008 and 2020, an average of 3,846,154 trees must be planted in each of the 13 years of this period. Assuming a planting density of 1,830 trees per hectare,[5] about 2,102 ha will be afforested annually from 2008 to 2020. Trees planted from 2008 through 2020 will be 42 to 29 years old, respectively, in 2050. The mean stem volume yield curve, the area planted in a given year, and the approach outlined above was used to estimate total C stored or CO_2 removed by red pine and white spruce plantations for selected future time periods. A mixed 4:1 white spruce:red pine planting scenario was also examined, based on the relative proportion of these two species in the 235,000 trees planted on 125 ha in the Credit Valley and South Nation River Conservation Authorities of Ontario between 2006 and 2008 (Gleeson et al. 2009). A quadratic equation was fit to the upper and lower 95% confidence limits for mean stem volume for each species to estimate the maximum and minimum projected total C or CO_2 stored, respectively, for this same time period and area planted.

Results and discussion

Planting 50 million trees in southern Ontario from 2008 to 2020 at an average planting density of 1,830 trees ha^{-1} on 2,102 ha each year will result in 27,326 ha of new forested land. If this land were planted exclusively to red pine that exhibited growth approximated by the derived average volume–age relationships, by the year 2050 total C stored in living tree biomass would range from 1.3 to 3.6 megatonnes (Mt) and average about 2.5 Mt (Figure 3a). The total CO_2e removed from the atmosphere and stored in living biomass by 2050 in these pine plantations would average 9.1 Mt and range from 4.8 to 13.3 Mt (Figure 3b). In comparison, if this land were planted to the relatively slower growing white spruce, about 30% less C would be stored in living tree biomass. In 2050, total C would range from 0.5 to 2.8 Mt and average about 1.7 Mt (Figure 3c), while total CO_2e in spruce plantations would average 6.0 Mt and range from 1.7 to 10.4 Mt (Figure 3d). As expected, mixed plantings favouring white spruce over the faster-growing red pine yield total C (mean 1.8 Mt) and CO_2e (mean 6.6 Mt) slightly above that for pure white spruce populations in 2050 (Figure 3e, f).

The rate and amount of C stored by planting red pine and/or white spruce per unit land area also depends on the influence of site, soil, and climatic factors on tree survival and growth, and the level of management activities directed towards cultivation and protection of these trees (Freedman et al. 1992, Parker et al. 2000, Yemshanov et al. 2005). In this example, we suggest that careful planting of seedlings certified as healthy through the provincial stock testing program (Sampson et al. 1997), coupled with investment in management to improve early establishment and growth (i.e., site preparation, weeding), will yield C storage between the estimated mean and maximum values shown in figures 2 and 3. Conversely, environmental and operational factors that reduce tree survival and growth rate will reduce C storage to below average, and significant C storage may not result for several decades. Regardless of potential growth rates, if plantations are not protected from fire or insects, large total losses of stored C are possible.

Recent afforestation efforts in Canada have focused mainly on planting conifer species, primarily spruce and pine (White and Kurz 2005). Were different species planted in this case study, C storage could be somewhat higher than the estimates provided here. For example, the growth rates (and C storage potential) of tree species commonly planted in southern Ontario are generally ranked as: European larch, aspen, red maple > red pine, white pine, larch > white spruce, eastern white cedar, white birch (Freedman et al. 2009). Afforestation in Canada using fast-growing hybrid poplar can result in much higher estimated C storage and mitigation potential than native tree species (van Kooten et al. 2000, Yemshanov et al. 2005). Regardless of the species mixture planted, forecasts of C stored by afforestation are only as credible as the availability and quality of the regionally relevant growth and yield data on which they are based. Unfortunately, for many of the species being planted in southern Ontario, growth and yield data specific to plantations is limited, precluding a more rigorous, quantitative evaluation of potential C storage by afforestation.

[5] Average planting density of recent southern Ontario afforestation projects sponsored by Trees Ontario.

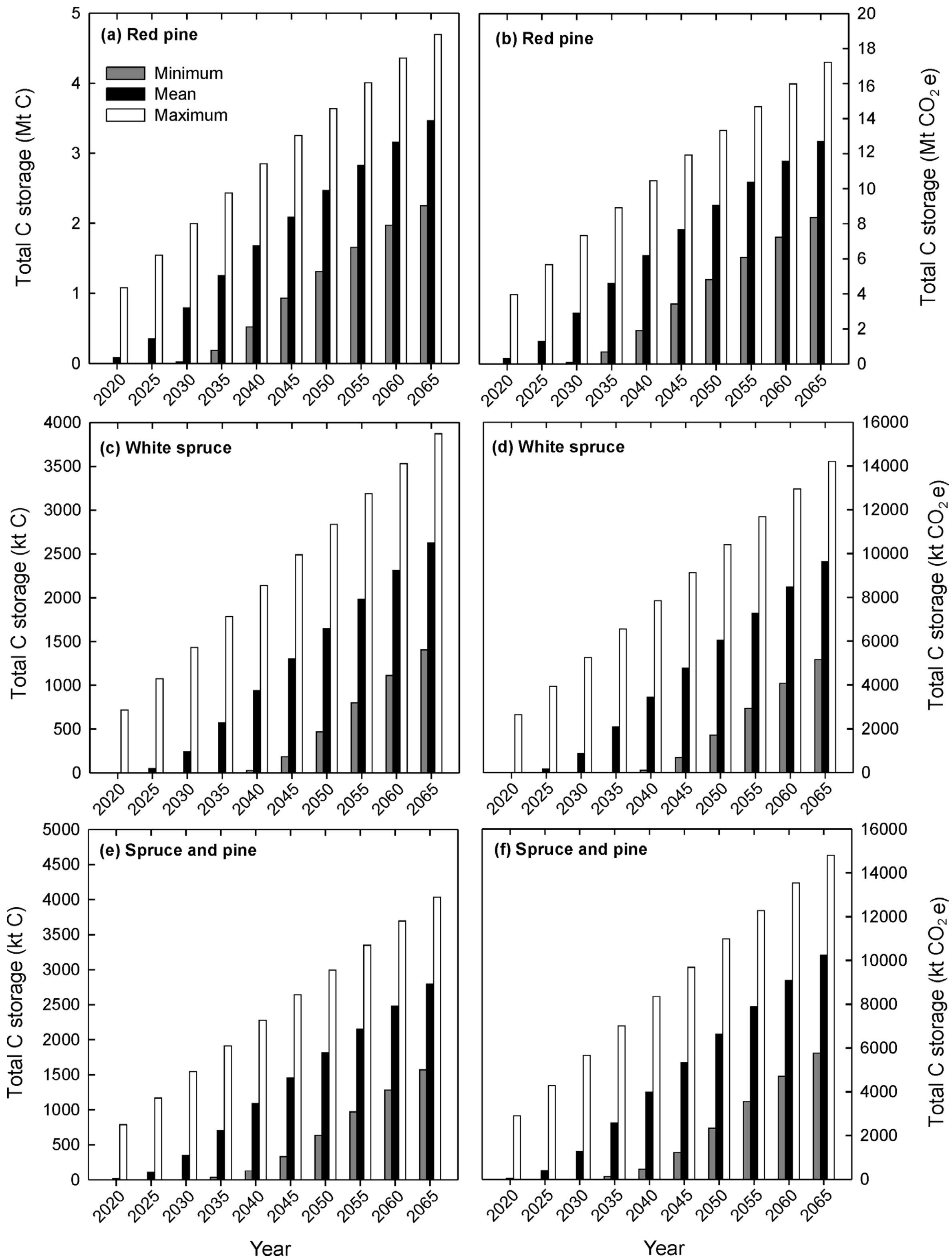

Figure 3. Temporal changes in mean, minimum, and maximum projected total carbon (C) (a, c, e) and total carbon dioxide equivalents (CO2e) (b, d, f) in living trees as a result of planting 50 million red pine (a, b), white spruce (c, d), and mixed white spruce-red pine (e, f) over 27,326 ha in southern Ontario between 2008 and 2020. Note difference in scale of y axes between species.

To put these estimates in context, using the projections for red pine, the average of 9.1 Mt CO_2e stored in tree biomass by 2050 is roughly equivalent to the amount of CO_2 emitted by the combustion of 3.86 billion litres of gasoline.[6] However, the 9.1 Mt CO_2e stored on 27,326 ha by this single afforestation program by 2050 is small relative to, for example, the 47 Mt CO_2e emitted by combustion of gasoline and diesel fuel in road transportation in Ontario and total provincial emissions of 190 Mt CO_2e in 2006 (Environment Canada 2008). If the 300,000 ha of private land that is potentially available for afforestation in southern Ontario (Bird and Boysen 2007) were planted with red pine or white spruce between 2008 and 2020, total storage by 2050 would average 99.0 and 66.4 Mt CO_2e, respectively, assuming equivalent area is planted annually. This suggests that, at best, planting a relatively large area over a very short period will sequester about 50% of a single year's total emissions (i.e., 190 Mt CO_2e in 2006).

The role of afforestation in mitigation efforts is comparatively larger when examined in terms of its intended potential contribution to meeting provincial GHG emissions reductions targets. Ontario has committed to reducing total GHG emissions by 139.2 Mt CO_2e by 2050 (i.e., 80% below 1990 levels of 174 Mt CO_2e) (Government of Ontario 2007, Environment Canada 2008). The creation of new forests is one of many actions proposed to meet these targets. From 2045 to 2055, an average of 0.25 Mt CO_2e per year was stored in 27,326 ha of red pine planted from 2008-2020, or less than 0.2% of the reduction target for 2050. If over this same period 300,000 ha were planted to red pine, the average of 2.69 Mt CO_2e stored per year represents about 1.4% of the emissions reduction target.

Given the limited land available for afforestation in Ontario, these examples indicate that this activity can achieve a small but significant contribution to all mitigation efforts needed for meaningful reductions in provincial GHG emissions (Freedman and Keith 1996, Parker et al. 2000, White and Kurz 2005, Bird and Boysen 2007). Although not explicitly addressed in this report, the harvest and use of this biomass for wood products as substitutes for more energy-intensive materials (e.g., steel, aluminum) or as a bioenergy source can significantly increase the relative contribution of afforestation to climate change mitigation (van Kooten et al. 1999, Colombo et al. 2007). As well, the other economic and ecological benefits of afforestation are a desirable byproduct of tree planting programs and should not be overlooked. In addition to C storage, these forests can perform ecological functions such as protecting soil and water, providing habitat for wildlife and biodiversity, and eventually producing biomass for energy or material products (van Kooten et al. 1999, Freedman et al. 2009). Establishment of an accepted economic value for the ecological services provided by afforestation and other forestry activities has proven difficult but could increase the financial return from, and public participation in, these programs (Freedman et al. 2009).

*Using the assumptions and methods outlined in this note, planting 50 million trees on southern Ontario sites is expected to sequester **6.6 Mt $C0_2e$ by 2050.** Due to varying survival and growth rates, species selection, site productivity, and unknown future climate effects, actual $C0_2e$ sequestered can only be verified by field measurement and calculation in 2050.*

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[6] 1 litre of gasoline yields 2.322 kg CO_2e

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Prévoir la quantité de carbone qu'on pourrait stocker et de carbone qu'on pourrait retirer de l'atmosphère grâce à la plantation de 50 millions d'arbres dans le Sud de l'Ontario

Parmi les moyens mis en œuvre dans le monde pour s'attaquer au changement climatique, le reboisement est considéré comme une façon relativement peu coûteuse d'améliorer le stockage terrestre du carbone, de ralentir l'accumulation dans l'atmosphère de dioxyde de carbone (CO_2) et d'atténuer les effets nuisibles associés au changement climatique. La création de nouvelles forêts est un élément clé du plan d'action contre le changement climatique dont s'est doté le gouvernement de l'Ontario pour réduire les émissions provinciales de gaz à effet de serre. Le gouvernement de l'Ontario s'est engagé récemment à planter, entre 2008 et 2020, 50 millions d'arbres sur un territoire d'environ 25 000 hectares dans le Sud de la province. Il est prévu que la plantation de pins rouges ou d'épinettes blanches (ou des deux essences) dans le cadre de ce plan de reboisement pourrait stocker entre 0,5 et 3,6 mégatonnes de carbone dans la biomasse forestière et enlever de l'atmosphère entre 1,7 et 13,3 mégatonnes de CO_2 d'ici à 2050, selon les caractéristiques des terrains et des sols, et le degré d'aménagement forestier. Le reboisement sera centré sur des terrains privés dans la région sud de la province, où se trouvent la plupart des 1,26 million d'hectares de terres agricoles marginales ou en jachère qui pourraient être reboisées. En concevant des plans de reboisement qui incitent davantage les propriétaires de terrains privés à planter des arbres, il serait possible d'accroître la superficie totale qu'on pourrait reboiser, ainsi que la quantité de carbone qu'on pourrait stocker et la contribution que cela représenterait pour atteindre les objectifs provinciaux de réduction des émissions de gaz à effet de serre.

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