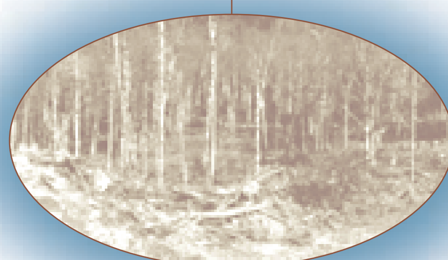
Silvicultural Systems for the Production of Energy Biomass in Conventional Operations in Atlantic Canada



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Task XII: Biomass Production, Harvesting, and Supply

Forest Management Activity

Review Study

Silvicultural Systems for the Production of Energy Biomass in Conventional Operations in Atlantic Canada

P.E. Zundel, A.J. Hovingh, L. Wuest, D. MacElveney, and T.D. Needham

Applied Stand Dynamics and Management Group
Faculty of Forestry and Environmental Management
University of New Brunswick, Fredericton, New Brunswick

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Cover: *Photos by Pierre Zundel, showing (top to bottom) full-tree harvesting and chipping, a harvested mixedwood stand, and full-tree extraction in Atlantic Canada.*

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Foreword

The Forest Management Activity of Task XII of the International Energy Agency Bioenergy Agreement (IEA Bioenergy) aims to improve the economies of biomass production from forests, increase understanding of the silvicultural processes involved, and develop the means to bring forward increased quantities of forest biomass to the market-place as cost-effectively as possible. This goal has been pursued through a series of workshops, field study tours, and review studies in Canada and northern Europe.

The review studies of the Forest Management Activity are undertaken to develop definitive information on silvicultural systems that can potentially be used for the production of wood for energy (and for traditional forest products) in conventional forestry. The studies focus on specific regions and describe the stand conditions, silvicultural treatments, potential for forest-energy production, and economic considerations of each system. Information developed from one particular region or country can be used by other regions or countries to help develop strategies to increase their use of forest bioenergy.

This publication presents the findings of a review study conducted in Atlantic Canada of silvicultural systems that may increase the production of wood for energy from conventional forestry. Atlantic Canada is defined as the four easternmost provinces—New Brunswick, Nova Scotia, Prince Edward Island, and Newfoundland. Forest production in Atlantic Canada is based on management of natural stands of coniferous, broadleaved, and mixed conifer-broadleaved species, with forest renewal dependent largely on natural regeneration. Forest biomass is already a significant source of energy in the region, but opportunities exist to increase the recovery of energy biomass from conventional forestry. Information from Atlantic Canada can be applied to a large number of other situations in the boreal forest region in Europe and North America.

The findings of the Atlantic Canada study were presented in summary form at the joint meeting of IEA Bioenergy Task XII Activities held in Jyväskylä, Finland, in September 1996. An abbreviated version of the study report was published in the proceedings of that workshop.[1] The complete study report contained considerably more information and data, and merits this separate publication.

[1] P. Hakkila, M. Heino, and E. Puranen (Editors). 1997. *Forest management for energy*. Proceedings of a joint meeting of [IEA] Activities 1.1, 1.2 and 4.2 of Task XII in Jyväskylä, Finland, September 9 and 10, 1996. Finnish Forest Research Institute Research Paper 640. 237 p.

Avant-propos

L'activité « Aménagement forestier » au titre de la tâche XII de l'Accord sur la bioénergie de l'Agence internationale de l'énergie (AIE/Bioénergie) vise à accroître les économies liées à la production de biomasse forestière, à mieux comprendre les procédés de sylviculture s'y rapportant et à élaborer des moyens de mettre sur le marché davantage de biomasse forestière, au meilleur rapport coût-efficacité possible. À cette fin, des études récapitulatives, des voyages d'étude et des ateliers ont été organisés au Canada et dans le nord de l'Europe.

Les études récapitulatives ont été entreprises en vue de produire une documentation complète sur les modes de régénération convenant à la production de bois-énergie (et de produits forestiers traditionnels) dans le contexte de l'exploitation forestière classique. Axées sur certaines régions, les études décrivent, pour chaque mode de régénération, l'état des peuplements, les traitements sylvicoles, le potentiel de production de bois-énergie et les conditions économiques qui s'y appliquent. L'information obtenue pour une région ou un pays particulier pourrait servir à élaborer des stratégies de valorisation de la bioénergie forestière dans d'autres régions ou pays.

Cette publication présente les conclusions d'une étude effectuée dans la région canadienne de l'Atlantique sur les modes de régénération qui pourraient accroître la production de bois-énergie dans le cadre d'une exploitation forestière classique. Le Canada atlantique est formé des quatres provinces du Canada les plus à l'est, soit le Nouveau-Brunswick, la Nouvelle-Écosse, l'Île-du-Prince-Édouard et Terre-Neuve. La production forestière repose principalement sur l'aménagement de peuplements naturels (conifères, feuillus, mixtes), renouvelés en grande partie par la régénération naturelle. La biomasse forestière représente déjà une source importante d'énergie dans la région, mais il serait possible d'accroître la biomasse récupérée dans le cadre d'opérations forestières classiques. L'information obtenue pour la région est applicable à un grand nombre d'autres situations dans la région forestière boréale, en Europe et en Amérique du Nord.

Les conclusions de l'étude sur le Canada atlantique ont été présentées sous forme de résumé à la réunion conjointe sur les activités de la tâche XII d'AIE/Bioénergie à

I offer my sincere appreciation to the authors for their work in conducting the study and preparing and presenting the findings. The professional help of Victor Spassov and staff of VSES Communications, Ottawa, is gratefully acknowledged for their work in the copy-editing, proofreading, design, and layout of the publication. Catherine Carmody, Francine Langevin, Danielle Monette, and Denis Rochon of Scientific and Technical Publications, Science Branch, Canadian Forest Service, provided invaluable assistance with translation, cover design, and production.

J. Richardson
Activity Leader
Forest Management Activity

Jyväskylä, en Finlande, en septembre 1996. Une version abrégée du rapport de l'étude a été publiée dans le compte rendu de cet atelier[1]. La présente publication du rapport complet se justifie par l'abondance d'information et de données qu'il contient.

Je tiens à exprimer ma grande appréciation pour le travail des auteurs qui ont réalisé cette étude et en ont préparé et présenté les conclusions. Il convient également de remercier Victor Spassov et le personnel de VSES Communications, à Ottawa, pour leur travail de révision, de correction d'épreuves, de conception graphique et de mise en page de la publication. Catherine Carmody, Francine Langevin, Danielle Monette et Denis Rochon, du service des publications scientifiques et techniques de la Direction des sciences du Service canadien des forêts, m'ont aussi apporté une aide précieuse pour la traduction, la conception de la couverture et la production.

J. Richardson
Responsable d'Activité
Activité « Aménagement forestier »

[1] P. Hakkila, M. Heino et E. Puranen (éd.). 1997. Forest management for energy. Proceedings of a joint meeting of [IEA] Activities 1.1, 1.2 and 4.2 of Task XII in Jyväskylä, Finland, September 9 and 10, 1996, Finnish Forest Research Institute, Research Paper 640, 237 p.

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The authors wish to thank cooperators in the three case study areas who provided a range of cost, yield, silviculture and policy data as well as suggestions on silvicultural interventions: in New Brunswick — Luc Ouellet, Gordon Whitmore, Gilles Couturier, and Chris Ouellet of Fraser Paper Inc., and Craig Frame of the New Brunswick Department of Natural Resources and Energy; in Newfoundland — Wayne Brown of Corner Brook Pulp and Paper Inc., Darrel Harris of the Newfoundland Forest Service, and Bill Buggie of Viking College; in Nova Scotia — Wade Prest of Forestex Ltd. and Fred Wellings of the Department of Natural Resources.

Several members of the Applied Stand Dynamics and Management Group were also involved in the research and production of this report, including John Kershaw, Paul Carter, Gordon Cross, Jennifer Johnston, and Julia Linke. Special thanks go to Gretta MacCready and Karin Zundel for extensive help with research, production, and proofreading of the report.

Abstract

This report presents an analysis of silvicultural systems designed to produce energy biomass from conventional forestry operations in Atlantic Canada. It also analyzes policy changes and incentives that might make biomass energy more attractive in the region. This report also serves as a model for other stand-level studies of this type to be carried out in Canada, and therefore methodological issues such as the appropriate scale and point of view from which to evaluate biomass energy are discussed.

Three case studies were conducted in Atlantic Canada to evaluate a range of silvicultural systems that could be used in a variety of stand types. They include a clearcut system in a balsam fir (*Abies balsamea*) stand type in Newfoundland; a shelterwood system in red spruce (*Picea rubens*) in Nova Scotia and a partial cutting system in shade-tolerant hardwoods (e.g., *Acer saccharum* and *Betula alleghaniensis*) in New Brunswick. Evaluation criteria included delivered cost, biomass yields per hectare (ha), as well as silvicultural and environmental implications. Delivered costs ranged between $20.39/oven-dried tonne (odt) and $35.38/odt. Yields varied between 10 and 48 odt/ha where the lower amount was for branch and top residue in a shelterwood cut and the higher was for a partial harvest that also recovered stems of unmerchantable species. Silvicultural impacts of biomass removal are likely to be positive in the kinds of stand types studied in New Brunswick and Nova Scotia. There is some uncertainty about the silvicultural impacts in Newfoundland, although existing evidence shows that long-term negative impacts are unlikely. Environmental impacts due to nutrient removal can be avoided by using compensatory fertilization. Prescriptions currently proposed to conserve coarse, woody debris for wildlife habitat are unlikely to affect yield significantly.

The systems presented were full-tree variants of classic silvicultural systems. They would be applicable in any stand type where their tree-length or shortwood variants could be used, except where the energy biomass would be needed for other purposes. The technology required to implement them is widely available in the Atlantic Region and a significant area is in stand types suitable for the systems described.

The main policy changes or incentives required to increase the use of biomass energy in the Atlantic region relate to market creation. This will require electrical utility corporations to pay the full avoided cost of power rather than the avoided fuel cost. Enactment of clean-air legislation that provides stringent guidelines for pollution control is likely to provide a comparative cost advantage for biomass over sulphur-rich fossil fuels.

Résumé

Ce rapport analyse des régimes sylvicoles axés sur la production de biomasse-énergie dans le cadre d’opérations forestières traditionnelles dans le Canada atlantique. Il examine également les modifications des politiques et les incitatifs qui pourraient rendre la production de ce type d’énergie, aussi appelée énergie verte, plus attrayante dans la région. Il sert également de modèle à d’autres études du même genre qui pourraient se réaliser ailleurs au Canada, au niveau de peuplements, et aborde donc des questions de méthodologie comme l’échelle et le point de vue qui conviennent à l’évaluation de la biomasse-énergie.

Trois études de cas ont été effectuées dans la région de l’Atlantique afin d’évaluer une gamme de régimes sylvicoles utilisables dans divers types de peuplement. Les régimes utilisés étaient les suivants : coupe à blanc dans un peuplement de sapins baumiers (*Abies balsamea*) de Terre-Neuve; coupes progressives dans un peuplement d’épinettes rouges (*Picea rubens*) de la Nouvelle-Écosse; et coupes partielles dans des peuplements de feuillus d’ombre (p. ex., *Acer saccharum* et *Betula alleghaniensis*) au Nouveau-Brunswick. Le prix à la livraison, les rendements en biomasse par hectare et les incidences sylvicoles et environnementales constituaient les critères d’évaluation. Le prix à la livraison oscillait entre 20,39 et 35,38 $/tonne anhydre. Les rendements variaient de 10 à 48 tonnes anhydres/hectare, le plus faible rendement provenant des branches et des résidus de cimes dans un parterre de coupe progressive, et le plus élevé, d’une coupe partielle où les tiges des espèces non marchandes ont également été récupérées. L’exploitation de la biomasse devrait avoir des effets sylvicoles positifs dans les types de peuplement étudiés au Nouveau-Brunswick et en Nouvelle-Écosse. Ses effets restent toutefois incertains à Terre-Neuve, bien qu’à long terme, ils ne devraient manifestement pas être négatifs. La fertilisation compensatoire peut remédier aux répercussions environnementales attribuables à l’élimination d’éléments nutritifs. Les prescriptions actuelles concernant la conservation des débris ligneux grossiers comme habitat pour la faune ne devraient pas affecter énormément les rendements.

Les régimes présentés utilisaient des variantes de l’exploitation traditionelle par arbres entiers. Ils seraient applicables à tout type de peuplement où des variantes de l’exploitation par arbres entiers et en bois courts peuvent être utilisées, excepté lorsque la biomasse-énergie est destinée à d’autres fins. La technologie nécessaire à leur mise en œuvre est largement accessible dans la région de l’Atlantique et les types de peuplement où les régimes décrits sont applicables en représentent une vaste superficie.

Biomass energy production will have many effects that are only felt at the forest level rather than the stand level, particularly in forests constrained to produce nondeclining yields. In addition, many of the advantages of biomass energy are felt at the socioeconomic level. As a result, silvicultural systems that produce biomass energy should be evaluated at both the stand level and the forest level, using socioeconomic and environmental criteria.

It is recommended that a model socioeconomic study of biomass energy production in Canada be carried to demonstrate the kind of analysis required. A compendium of the literature on the long-term growth effects of full-tree harvesting, including a comparison of full-tree harvesting against natural disturbances such as wildfire, should be carried out. Finally, a state-of-the-art report on compensatory forest fertilization with wood ash and other fertilizers in a full range of stand development stages should be prepared.

Keywords: energy, fertilization, forest biomass, harvesting, logging residues, nutrients, silviculture, socioeconomic impacts, soil, wildlife, reforestation, wood ash.

Les principaux changements ou les incitatifs à apporter aux politiques nécessaires à une utilisation accrue de la biomasse-énergie ont trait au développement de marchés. Il faudrait que les services publics d’électricité assument le coût total de l’énergie économisée plutôt que celui du combustible économisé. L’adoption d’une législation pour la pollution atmosphérique qui prescrive des directives plus sévères sur la lutte contre la pollution devrait rendre le coût de la biomasse comparativement plus avantageux que celui des combustibles fossiles à teneur élevée en soufre.

La production de biomasse-énergie aura de nombreux effets qui se feront sentir sur l’ensemble de la forêt, plutôt que sur le peuplement, notamment dans les forêts vouées à la production de rendements soutenus. En outre, nombre d’avantages de la biomasse-énergie seront d’ordre socio-économique. Il faudrait, par conséquent, évaluer les régimes sylvicoles axés sur la production de biomasse-énergie au niveau de la forêt et au niveau du peuplement à l’aide de critères socio-économiques et environnementaux.

Il est recommandé de réaliser un modèle d’étude socio-économique de la production de biomasse-énergie au Canada afin de déterminer le type d’analyse nécessaire. Il faudrait préparer un abrégé de la documentation sur les effets à long terme de l’exploitation par arbres entiers, en comparant ses effets à ceux des perturbations naturelles, comme les feux de forêt. Enfin, il faudrait rédiger un rapport sur l’état actuel des activités de fertilisation compensatoire à l’aide de cendre de bois et d’autres engrais dans les divers stades de développement des peuplements.

Mots-clés : énergie, fertilisation, biomasse forestière, récolte, résidus d’exploitation, éléments nutritifs, sylviculture, incidences socio-économiques, sol, faune, reboisement, cendre de bois.

Introduction

The International Energy Agency Bioenergy Agreement (IEA), in its Task XII group (Activity 1.1), aims to "improve the economies of biomass production of forests, increase the understanding of the silvicultural processes involved and develop the means to bring forward increased quantities of forest biomass to the market place as cost-effectively as possible." One of the activities undertaken toward this aim is to carry out a study of silvicultural systems that can be used to produce both energy biomass and traditional products in conventional forestry operations. The study presented in this report would form a model that could be used to analyze silvicultural systems in other regions of Canada and serve as a companion to a similar study being carried out in Denmark. This report presents the results of the Atlantic Canada study.

Forest biomass is already one of the major sources of energy in Atlantic Canada, providing 16% of total energy needs (National Energy Board 1988). Sources for this biomass range from industrial waste to harvesting primarily for domestic firewood. Growing biomass solely for energy production has not proved financially attractive at current energy prices. However, energy biomass recovery as a byproduct of conventional operations has the potential to be attractive. Only a modest proportion of the energy biomass available from conventional forestry operations is currently recovered. Considerably more could be obtained if practices were modified to facilitate biomass production. This report presents three case studies of Atlantic Canada silvicultural systems that could be used to increase the production of energy biomass from conventional operations.

Since the scale of the project does not permit a systematic analysis of all stand types and silvicultural systems in the region, the projects were chosen to reflect the rich variety of possibilities found in Atlantic Canada. The aim of each case study is to present one stand type and one silvicultural system combination representative of the biological or socioeconomic conditions in each of the different parts of the Atlantic region. Stand types were therefore chosen to be either typical of the region or demonstrate how conventional forestry could be modified to produce more biomass. Each case study presents the silvicultural system and its full list of interventions as well as a description of the stand type in which it could be used. The silvicultural, financial, and energy yield implications of each system are presented, and the potential use and contribution to the region's energy supply is described. The results of the three case studies are then synthesized to identify broader findings that would help guide future studies.

In addition to regional case studies, a number of issues affecting the potential of forest biomass production are discussed. These include the appropriate scale at which to analyze energy biomass issues and the impact of market and policy issues.

We end the report with conclusions about the kinds of silvicultural systems likely to succeed in achieving the aims of the IEA in the Atlantic Region, and recommendations for actions and further studies to fill knowledge gaps.

Study Methods

The central focus of the study is the individual silvicultural system case studies designed to produce biomass energy from conventional forestry operations. A secondary part of the study deals with policy changes and incentives that could increase energy biomass production. Case study development involved four main activities:

- stand type and operational context selection;
- silvicultural system design for the stand types selected;
- parameter selection for evaluating each silvicultural system and stand type combination; and
- synthesis of case study results to draw conclusions about the various silvicultural system and stand type combinations and their potential to increase biomass production.

The analysis of policy changes and incentives that might help make forest biomass energy production from conventional operations more attractive involved three main activities:

- definition of the advantages and disadvantages of energy biomass production in terms of its economic, social, and environmental sustainability;
- summary of key issues; and
- suggestion of some policy changes or incentives that might help make biomass energy production from conventional operations more attractive.

The main activities involved in the case studies are described in the following sections.

Selection of Stand Types and Operational Context

Selection of the stand type and operational context (geographic location, demographics, industry structure) was largely guided by three principles:

- capture the range of stand types found in the Atlantic Region;
- deal with stand types likely to be important in conventional operations over the analysis period; and
- focus on stand types for which there is little information about appropriate silviculture for energy biomass production (e.g., partial cutting in hardwoods).

Principles of Silvicultural System Design

Silvicultural system design was driven by five main principles. The silvicultural systems had to:

- be indicative of the practices likely to be commonly used over the analysis period (5-10 years);
- capitalize on equipment types already available in the area (to foster implementability);
- compensate for the undesirable characteristics of energy biomass, such as dispersion and low bulk density;
- recognize the key silvicultural issues involved (nutrient demand, reforestation success, intervention objectives such as wildlife habitat enhancement or protection, stand improvement, and regeneration); and
- recognize financial issues associated with integrated production of energy biomass and conventional products (machine productivity, low value of biomass, and high costs of handling biomass).

Evaluating Stand Type/Silvicultural System Combinations

Three parameters to be evaluated for each combination of stand type and silviculture system were identified in the study terms of reference. These included energy biomass yield, costs of production, and silvicultural implications. A number of other parameters were also included to reflect the environmental issues likely to have an impact on biomass harvesting over the analysis period. These included nutrient removals and silvicultural implications.

The effects of some of the assumptions used in preparing scenarios were also evaluated. Parameters for analysis were chosen to deal with sources of uncertainty and to provide the reader with some sense of the robustness of the conclusions reached in the study.

General Assumptions in the Case Studies

Four general assumptions were made for all three case studies presented in this report to facilitate calculations and comparisons. They were used consistently in all three case studies.

Silvicultural Prescriptions

It was assumed that the silvicultural prescriptions suggested by the foresters we contacted in each of the case study areas were an acceptable basis for our design of silvicultural systems that could be used to recover biomass energy in conventional operations. As a result, no attempt was made to determine whether the specific elements of each silvicultural prescription were in fact the optimal approach for achieving specific objectives. For example, the Nova Scotia shelterwood harvesting prescription assumes a 40% basal area removal target in the initial harvest. Such targets are compromises between financial feasibility, development or protection of regeneration, and stability of the residual stand to windthrow. The optimal compromise between these various factors is likely to change considerably according to specific market and stand conditions. It is assumed here that the target provided by our cooperators was a reasonable one for their context. All three cooperators are foresters with considerable experience in their own areas.

Incremental Costing

This study focuses on the recovery of biomass from conventional forest operations. As a result, it is assumed that any costs over and above those that would have been incurred in conventional operations if energy biomass had not been recovered should be charged against the energy biomass. For example, if the amount of merchantable softwood is reduced in each skidder load when birch destined for energy production is also skidded, the cost per unit of merchantable wood will increase. This increase would be the cost of delivering the birch to roadside. Appendix 1 describes how the calculations were carried out.

Adjustments for Inflation

Recent historical information has been used to estimate costs in certain case studies. These costs have been adjusted using the forest industry *Machinery and Equipment Price Indices* published by Statistics Canada (1995). It should be noted that inflation in forest industry equipment has been lower than the Consumer Price Index, which is the Canadian index of general inflation.

Biomass Moisture Content

For the purpose of this report, tree component moisture content has been assumed to be 45% on a wet basis (i.e., 45% of the green weight of trees is water). Although moisture content may vary between species and as a function of time of year, an average of 45% is representative of the Atlantic region.

Synthesis of Case Study Results

The results of the case studies were synthesized to identify common trends. The specific questions asked in the synthesis were:

- What are the break-even prices of energy biomass produced in the various systems?
- How much are break-even prices affected by a potential requirement to replace exported nutrients?
- What kinds of harvesting systems are most likely to produce energy biomass at low prices?
- What are the likely silvicultural impacts of energy biomass production in conventional operations?
- How are changes in merchantability standards likely to affect biomass yields and production costs?

Nomenclature

Some key terms used in this report are defined in the Glossary to help readers with common North American technical terms. In addition, tree species scientific names are provided in the List of Tree Species found at the end of the report (p. 30).

Case Studies

Three case studies were prepared—one for each of the main biomass-producing provinces in the Atlantic Region (New Brunswick, Newfoundland, and Nova Scotia). In each study, a general description of the context for the study is provided. This is followed by specific assumptions used in the particular case and by the results of the various analyses. A synthesis of the case studies is then presented in the following section (p. 17).

New Brunswick – Tolerant Hardwood Partial Cutting

General Context

The Edmundston and Plaster Rock Crown licence and freehold limits of the Fraser Paper Inc. company contains a large area of hardwood forests in northwestern New Brunswick. These can be divided into three categories on the basis of covertype.

The first category, which comprises 10% of the hardwood forest area, is composed of residual trees left after clearcut harvesting. These areas are made up of low-quality intolerant hardwood stands that will be planted with softwood species when stands are not sufficiently restocked with natural regeneration. One to three years later, both planted and unplanted areas are treated with herbicides to control competing vegetation. Naturally regenerated stands are often precommercially thinned 10 to 15 years after harvest and treated with herbicides to control competing vegetation. Felling is done with feller-bunchers, and grapple skidders then move full trees to roadside, where those with commercial value are mechanically delimbed. All other trees and the unmerchantable portion of delimbed trees, are chipped into hogged fuel.

The second category, composed of hardwood and hardwood-dominated stands comprising 30% of the hardwood forest area, has generally experienced repeated hygrading (removal of high-quality and high-value trees) throughout its history. Hygrading results in stands made up of low-quality trees and low-value species. The silvicultural objective in these stands is to convert them to a high-value, high-quality condition with an uneven-aged structure. Stands are therefore clearcut in strips with feller-bunchers and grapple skidders when the ground is not frozen to promote soil exposure. Large quantities of natural regeneration are expected to develop from stump and root suckers as well as from accumulated seed and surrounding seed trees. These stands are then precommercially thinned at age 20 to remove low-quality trees and to release potential crop trees.

The third category, which comprises 60% of the hardwood forest area, is composed of hardwood stands or mixedwood stands with a preponderance of tolerant hardwoods that do not have a history of hygrading. They typically contain a mix of good and poor-quality material with a diverse age class distribution. These high-quality, even-aged hardwood and mixedwood sites are the focus of the New Brunswick case study for four reasons: 1) they represent most of the hardwood forested area; 2) to grow and capture the high-value, high-quality wood producing potential of these stands requires management of abundant low-value material within the stands that is well suited to the production of biomass; 3) Fraser Inc. brought its own 45-megawatt wood-fired electrical generation plant on-line in Edmundston in 1997 and these stands will supply the bulk of Fraser Inc.'s biomass fuel; and 4) they represent a particular challenge to foresters since they will be managed on an uneven-aged basis.

Intervention Strategies

The stands on Fraser Inc. land are to be treated with a partial cutting system on a 15-18 year cycle (Ouellet 1996). At each intervention, the basal area will be reduced by approximately one-third of the original amount by harvesting trees with undesirable characteristics such as excessive size ("wolf trees" greater than 45 cm in diameter), poor form, animal damage, and decay, in the following order of priority:

1. Beech (*Fagus grandifolia* Ehrh.)
2. Wolf trees (dbh>45cm) of all species
3. White birch (*Betula papyrifera* Marsh.)
4. Trembling aspen (*Populus tremuloides* Michx.)
5. Red maple (*Acer rubrum* L.)
6. Balsam fir (*Abies balsamea* [L.] Mill.)
7. Black spruce (*Picea mariana* [Mill.] BSP)
8. White spruce (*Picea glauca* [Moench.] Voss.)
9. Yellow birch (*Betula alleghaniensis* Britt.)
10. Sugar maple (*Acer saccharum* Marsh.)

This type of intervention will help promote growth in the high-quality residual trees (yellow birch and sugar maple) for future harvest of high-value conventional products (i.e. veneer, clearwood, sawlogs, etc.). The removal of wolf trees will allow for more rapid growth of co-dominant trees and for the establishment of natural regeneration in the gaps created. They are targeted for removal because they also typically have little potential for value growth and occupy a large stand area. Crop and other residual trees help establish regeneration while providing sufficient shade to avoid excessive competition from undesirable species of trees and ground vegetation. Sugar maple is favoured as a "leave" tree because of its high value and its ability to respond to thinning. Beech is priorized for removal because much of it is decadent because of disease.

Most of the harvesting is done as a full-tree harvest with feller-bunchers and grapple skidders. However, wolf trees are harvested by woodsworkers with power saws. These trees are taken out as tree-lengths to avoid damage to residual trees from abrasion with the large crowns of wolf trees during skidding. Trees with commercial value are mechanically delimbed at roadside. All other trees, and unmerchantable portions of delimbed trees, will be chipped into hogged fuel by means of a Morbark 23 chipper and shipped to the 45-megawatt electrical generating station in Edmundston.

Table 1 summarizes the preharvest and postharvest conditions of this stand type on the basis of information obtained from Fraser Inc. (Ouellet 1996).

System Evaluation

Biomass Yield Prediction

The average yields of the tolerant hardwood stand type were calculated from diameter at breast height (dbh), height and stem count data supplied by Fraser Paper Inc. The data is based on ground surveys throughout this 19 000-ha forest type. The amount of energy biomass recovered for use was estimated by subtracting the merchantable stem mass from the gross mass component. The total above-ground mass (ovendried tonnes or odt) of the entire tree and the mass of the merchantable stem of each harvested tree were estimated on the basis of equations from Ouellet (1983) and the inventory data. The mass of unmerchantable tree components was then multiplied by a biomass recovery rate used to account for

Table 1. Volume and Basal Area before and after Partial Cutting in Tolerant Hardwood Stands in Northwestern New Brunswick Where Approximately One-third of the Total Basal Area (m^2) Was Harvested in a Partial Cutting Based on a Species and Quality Priority System.

	Pre-harvest Conditions		Post-harvest Conditions	
Species	**Volume per Hectare (m^3 ha)**	**Basal Area (m^2/ha)**	**Volume per Hectare (m^3 /ha)**	**Basal Area (m^2/ha)**
Beech	58.60	7.44	0.00	0.00
White birch	6.53	1.24	6.53	1.24
Trembling aspen	1.59	0.24	1.59	0.24
Red maple	13.29	2.22	13.29	2.22
Balsam fir	21.15	2.62	21.15	2.62
Black spruce	0.30	0.07	0.30	0.07
White spruce	8.93	1.19	8.93	1.19
Sugar maple	213.71	25.80	139.17	18.90
Yellow birch	46.15	7.37	34.33	6.16
Total/ha	**370.25**	**48.19**	**225.29**	**32.64**

N.B. The data presented are aggregate average/ha values for the 19 000 ha of this stand type rather than results of an inventory estimate for a single stand.

Table 2. Biomass and Merchantable Volume Yield Estimates by Component from Partial Cutting Based on Tolerant Hardwood Stands in Northwestern New Brunswick.

Species	Gross Mass (odt/ha)	Merchantable Mass and Volume Harvested		Unmerchantable Mass (odt/ha)	Net Biomass (odt/ha)
		(odt/ha)	(m^3/ha)		
Beech	48.96	36.33[1]	58.60	12.63	48.33
Sugar maple	279.18	46.96	74.53	22.54	0.00[2]
Yellow birch	36.62	7.56	11.82	1.80	0.00[2]
Total/ha	**364.76**	**90.85**	**144.95**	**36.97**	**48.33**

1 This material is composed of beech stems that fall within merchantable dimension restrictions but due to their diseased state and poor quality are actually converted to energy biomass.

2 All maple and yellow birch volumes were large wolf trees and were therefore extracted as tree lengths. As a result they did not produce any energy biomass at roadside.

branch and top loss during skidding to determine the net biomass obtained from harvested species. Biomass recovery rates were estimated at 70% for softwood (Routhier 1982) and 95% for hardwoods. While no literature was found to support the hardwood recovery rate, it is based on the observation that the branching angles of tolerant hardwoods in conjunction with a higher resiliency indicate a much higher recovery rate than for softwoods, but not fully 100%. The effect of this assumption on overall yield was tested (see Environmental Impacts, p. 7).

The merchantable volume for each stem was determined by dividing the merchantable mass by the specific gravity of each species (Panshin and DeZeeuw 1980). Biomass yield estimates are found in Table 2.

Intervention Costs

Full-tree Harvesting

Trees with a dbh of less than 45 cm are harvested by a feller-buncher. Productivity is a function of average tree size and volume per hectare (Zundel 1992b). The following production function summarizes this relationship for a northern Maine softwood harvesting operation with stem volumes between 0.15 m^3 and 0.40 m^3 (Zundel 1992b) and is assumed to be applicable for these similarly sized hardwood trees. To find the unit cost of harvesting, a rental rate of $113.62[1] per productive machine hour (pmh) is divided by the estimated production from Equation 1.

Equation 1: $m^3/pmh = 13.33 \ln(vha) + vstem - 50.03$

where

vha = merchantable volume (m^3) per hectare harvested, and

vstem = average merchantable volume (m^3) per stem harvested.

Trees felled by the feller-buncher are skidded to roadside by a Clark C7D grapple skidder. The average skidding distance is 200 m (Ouellett 1996) and on average a load size of 3.0 m^3 was assumed (Zundel 1992b). The average productivity of a grapple skidder is 28 m^3/pmh (Gingras *et al.* 1991). The hourly rental rate for a grapple skidder is assumed to be $71.71/pmh, the same as a TJ-550 cable skidder (which has roughly the same horsepower). The cost of the grapple skidding is $2.56/$m^3$ (Equation 2).

Equation 2: $\$2.56/m^3 = \$71.71/pmh \div 28\ m^3/pmh$

Tree-length Harvesting

Trees larger than 45 cm dbh are cut and skidded as tree lengths to roadside by a two-man cut-and-skid crew. Woodsworkers use a combination of power saws for felling and a TJ-550 cable skidder for extraction of the large hardwood tree lengths. The TJ-550 is well suited for the large stem sizes. The average skidding distance remains 200 metres. The average load size of 2.7 m^3 is assumed due to the scattered distribution of the wolf trees. The average productivity of a cable skidder is 15.1 m^3/pmh on the basis of a production function from Zundel (1992b). The hourly rental rate for the TJ-550 cable skidder is $88.38/pmh, including operator and woodsworker. The unit cost of the cable skidding is $5.85/$m^3$ (Equation 3).

Equation 3: $\$5.85/m^3 = \$88.38/pmh \div 15.1\ m^3/pmh$

Chipping and Hauling of Biomass

A Morbark 23 Chipharvester is used to complete the chipping of biomass. The cost of chipping at Fraser Inc. is a flat fee per unit mass (Ouellet 1996). The current rate for hardwood tops, low quality hardwoods and up to 15% softwood tops is $7.70 per metric green tonne (Gt) or $14.00/odt at 45% moisture content (Ouellet 1996). This kind of chipper cannot process softwood tops and branches unless they are mixed with hardwood tops and full trees. The infeed rollers are designed to be used with full trees only. The decision to concentrate on hardwood stands as a source of biomass for the Fraser Paper Inc. powerplant is driven largely by the availability of the Morbark chipper in the region. As a basis for comparison, Appendix 2 (p. 32) presents the analysis of the chipping costs associated with a Bruks Ct 1002 residue chipper, which can process the softwood residues. The cost of hauling the biomass from roadside to the end-use site is also a flat fee per unit mass ($/odt/km). Assuming a 45% moisture content (wet basis), the hauling cost is $0.19/odt/km (Ouellet 1996).

The costs associated with conventional products and energy biomass have been summarized in Tables 3 and 4. In the second cutting intervention (in 15-18 years), a large volume of full trees will be harvested, composed mainly of intolerant hardwoods and softwood species. This will reduce the cost of biomass harvesting and bring its price down to a level slightly above that for the Nova Scotia and Newfoundland case studies. In addition, the reduction in the number of wolf trees harvested will simplify the operations and raise biomass yields by reducing the proportion of the stand harvested by the tree-length system.

[1] All dollar amounts in this study are in Canadian dollars.

Table 3. Unit and per Hectare Costs of Harvesting Biomass and Conventional Products.

Activity	Full-tree Harvesting ($/m³)[1]	($/odt)[2]	Tree-length Harvesting Wolf Trees[3] ($/m³)[1]	($/odt)[2]
Felling	5.69	6.90	5.85	9.58
Skidding	2.56	3.10		
Delimbing[4]	0.00	0.00		
Total Unit Cost	8.25	10.00	5.85	9.58
Activity	**Cost per Hectare ($/ha)**		**Cost per Hectare ($/ha)**	
Felling	333.43		505.15	
Skidding	150.16			
Delimbing[4]	0.00			
Total Cost Per Hectare	483.59		505.15	
Total Cost, Integrated Harvest			**988.74**	

[1] Calculated with merchantable stem volume (m³).
[2] Calculated with merchantable oven-dried tonnes (odt) of energy biomass.
[3] Wolf trees have a dbh of 45 cm or more.
[4] As beech is the only tree species harvested by means of the full-tree system and will all be chipped, no delimbing cost is incurred.

Table 4. Biomass Chipping and Hauling Unit and per Hectare Costs.

Activity	Dollars per Oven-dried Tonne and Green Tonne ($/odt)[1]	($/Gt)	Dollars per Hectare ($/ha)
Harvesting	10.00	6.50	483.59
Chipping	14.00	7.70	676.62
Hauling [2]	9.49	5.22	458.65
Ash Application[3]	2.09	3.21	101.00
Total Biomass Recovery Cost	**35.58**	**22.63**	**1719.86**

[1] Calculated with net biomass (Table 2) at 45 % moisture content.
[2] At a hauling distance of 50 km.
[3] Based on figures from Strauch (1992).

Silvicultural Implications

The stand type being considered in this case will change in quality and composition over the first few cutting cycles. Sugar maple and yellow birch will be favoured as leave trees which will result in increased stand value. The composition of the stand should stabilize once the majority of leave trees are maple and yellow birch. Residual crop trees should respond with accelerated diameter and value growth rates. This will be particularly evident for trees just below the minimum dimension requirements for sawlogs or veneer.

Environmental Impacts

Nutrient Depletion Estimation

Approximately 40% of the total harvest in the first cutting intervention is carried out using a full-tree system. A major concern with the full-tree system is that nutrients that are present in the foliage, limbs and small branches are extracted with the bole of the tree and could lead to a depletion in the soil nutrient levels and a reduction in site quality. The amount of nutrient (phosphorus [P], potassium [K], nitrogen [N], calcium [Ca] and magnesium [Mg]) removed was estimated on the basis of concentrations from Maliondo *et al.* (1990) and the amount of net biomass removed (see Table 5).

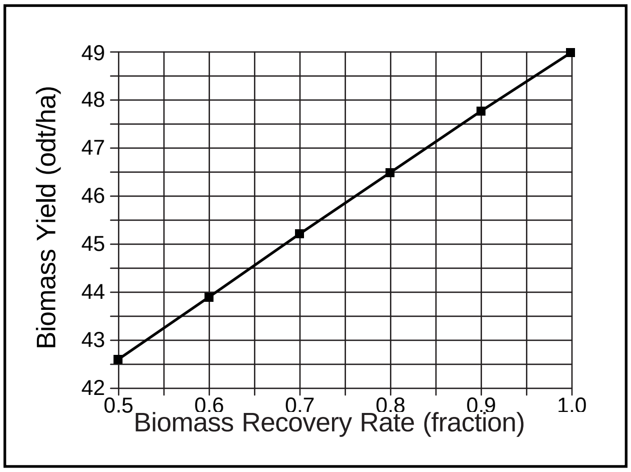
The effect these removals have on nutrient supply can be reduced by applying ash that is a byproduct of biomass burning at the electrical generating plant. Four of the five nutrients can be replaced with an ash application to the harvested site. Nitrogen is unavailable because it is completely volatilized when biomass is burned. The macronutrient requiring the highest tonnage to compensate for removals was determined to be potassium (0.1348 tonnes/ha) and the amount of ash required to replace it was estimated on the basis of figures from Unger and Fernandez (1990).

Table 5. Nutrient and Ash Analysis for the New Brunswick Case Study.

Macro-nutrient	Macro-nutrient Removed (tonnes/ha)	Macronutrient in Ash (percent of ash by mass)	Amount of Ash Required for Redistribution of Macronutrients (odt)	Cost of Ash Application (@ $21.00/odt)
Nitrogen (N)	0.1628	0	na[1]	0.00
Phosphorus (P)	0.0219	0.9	2.43	0.00
Potassium (K)	0.1348	2.8	4.81	101.00
Calcium (Ca)	0.1901	13.0	1.46	0.00
Magnesium (Mg)	0.0176	1.4	1.25	0.00

[1] Nitrogen is volatilized on combustion and not available in wood ash.

Figure 1. Influence of Biomass Recovery Rate on Biomass Yield per Hectare.



The costs associated with ash application are summarized in Tables 4 and 5. If the ash-producing firm were to dispose of the ash in a landfill site, a tipping fee of $30-60/odt of ash would apply. If the ash were to be trucked within a 50 km radius of the production site, the hauling cost (based on a rate of $0.15/odt/km) would be $7.50/odt of ash. Shipping the ash for application in the forest is, therefore, much less expensive than disposing of it in a landfill site. It is therefore assumed that the ash will be delivered to the forest roadside by the power plant owner at no cost to the company that will apply the ash. The cost of applying one oven-dried tonne (odt) per hectare is $21.00 (Unger and Fernandez 1990; Ericsson 1991; Parker 1992). Given that the ash is provided at no cost, the total cost of ash application is $21/odt/ha.

Biomass Recovery Rate

One of the major assumptions used in this study is that 95% of hardwood branch and top biomass is recovered. Unlike the assumptions made for softwoods, there is no published information on the recovery rate for hardwoods. The effect of this assumption on yield estimates has therefore been tested and results for recovery fractions of between 0.5 and 1.0 are presented in Figure 1. In the first intervention in the tolerant hardwood stand, only 0.25 of the energy biomass is derived from branches and tops. This reduces the sensitivity of yield to recovery rate. As the proportion of energy biomass derived from branches and tops increases, the effect of recovery rate on yield will also increase.

Newfoundland – Clearcut Harvesting in Black Spruce and Balsam Fir

General Context

The Newfoundland case study is based in the Corner Brook area of western Newfoundland on the operations of the Corner Brook Pulp and Paper Ltd. company. The pulp mill in Corner Brook is fed largely from a Crown timber licence typified by softwood-dominated sites of medium to good fertility. The stand type chosen for this study is dominated by balsam fir with small components of black spruce, white spruce, and white birch. Stands in this type are typically in the 90-year age group and have good pre-established spruce and fir regeneration due to incomplete crown closure (approximately 51-75%). The poor windfirmness of balsam fir and spruce grown in stands that have never been thinned requires the use of clearcut harvesting.

Intervention Strategies

Corner Brook Pulp and Paper Inc. aims to maintain the softwood composition of the stands it harvests and to achieve high yields of pulpwood in future rotations. The company tries to use natural regeneration rather than planting to reduce reforestation costs. As a result, its reforestation strategy tends to focus on protection of advanced regeneration. One of the key elements in the protection of small seedlings is the shade afforded by slash distributed on the site after harvest and, in areas where seedlings are prone to burning off (e.g., where thin soils cover bedrock), the use of full-tree harvesting is considered to be undesirable. The consequences of windrowing harvesting residues in shortwood harvesting is not yet fully understood. These issues are discussed under the heading of Silvicultural Implications below (p. 11).

Table 6. Biomass and Merchantable Volume Yield Estimates in Clearcutting Balsam Fir Stands for the Newfoundland Case Study.

Species	Gross Mass (odt/ha)	Merchantable Mass (odt/ha)	Volume[2] (m^3/ha)	Unmerchantable Mass (odt/ha)	Recoverable [3] Energy Biomass (odt/ha)
Balsam fir	89.1	59.9	176.3	29.2	20.4
Black spruce	6.0	3.9	10.2	2.1	1.5
White spruce	6.6	4.3	11.6	2.3	1.6
White birch	21.1	0	0	21.1	20.0
Total	**111.8**	**68.1**	**198.1**	**54.7**	**43.5**

[1] Biomass predictions based on Lavigne (1982).
[2] Based on average specific gravity per species (Panshin and de Zeeuw 1980).
[3] Assumes a 70% recovery rate for softwoods (Routhier 1982) and 95% for hardwoods.

Consequently, the harvesting interventions used in this stand type are typically a tree-length or shortwood clearcut harvesting, followed by precommercial thinning once softwood regeneration is free to grow. The stand is then left to grow until the next clearcut harvest at 40-60 years. If natural regeneration stocking is insufficient, sites are planted with white or black spruce. The harvesting system selected depends on terrain conditions. Stands in steep terrain (approximately 20-25% of the total area in this stand type) are felled and delimbed by woodsworkers with power saws and cable skidded as tree-lengths to roadside. On flatter ground, mechanical shortwood harvesters and forwarders harvest half the total area, while motor-manual shortwood operations harvest the remaining quarter of the area. In this study we assume that sufficient regeneration is available to successfully restock the forest after a full-tree harvest with feller-bunchers.

System Evaluation

Biomass Yield Prediction

Average yields of typical stands within the western Newfoundland study area were calculated from height, diameter and stem counts supplied by the Newfoundland Forest Service (NFS). Yield equations from Lavigne (1982) and merchantability fractions from Honer (1971) were used in the biomass calculations based on their relevance to sample data collected in the study area. Biomass was broken down into stem wood, stem bark, branch and twig-foliage components to facilitate merchantability analysis and nutrient depletion analysis. Overall residual biomass recovery rates were estimated at 70% for softwood (Routhier 1982) and 95% for hardwoods. Yields of energy biomass and conventional products are summarized in Table 6.

The conventional product yield (softwood pulpwood) is 198 m^3/ha. Associated with this total are 43.5 odt/ha of energy biomass, derived from both hardwood full trees and the branches and tops of softwood trees.

The yields of biomass and conventional products are affected by definitions of merchantability that are expressed by minimum butt and top diameters and species considered commercially usable. A sensitivity analysis was conducted to examine changes in these merchantability standards. When the minimum top diameter was reduced to 5.1 cm to test the sensitivity of the yield and cost, this 2.54 cm reduction in minimum top diameter resulted in an increase of 2.6% in merchantable material and a reduction of 2.8% in residual biomass. The reduced merchantable diameter also causes a reduction of the overall cost of conventional harvesting (through savings in skidding cost) of \$0.18/m^3. Further decreases in the minimum top diameter beyond 5.1 cm result in a cost reduction of less than 1.8% per 2.54 cm.

Yield sensitivity was also tested as a function of possible future changes to the merchantability of the hardwood stems. Hardwood stem recovery as merchantable material results in an increase of 32% in merchantable material and a 33% reduction in residual biomass. The sensitivity analysis results are summarized in Table 7.

Intervention Costs

Conventional tree-length harvesting in the Newfoundland study area was used as a benchmark against which incremental energy biomass costs were assessed. The Newfoundland case study compares the costs of conventional tree-length harvesting to a full-tree harvesting system.

The incremental cost of full-tree harvesting compared to conventional tree-length harvesting was calculated using methods developed by Zundel (1992a). The conventional tree-length harvesting system recovers stem wood and stem bark up to a minimum merchantable top-end diameter standard leaving unmerchantable stem, branch, twig and foliage residual biomass at the stump. The full-tree harvesting system recovers a portion of the residual biomass at roadside for use in the production of energy.

Table 7. Sensitivity of Energy Biomass Cost to Merchantability Standards for the Newfoundland Case Study.

Merchantable Diameter and Hardwood Merchantability	Total Residual Biomass kg/ha	Cost per Over-dried Tonne $/odt	Percent Change in Cost Relative to Base Case
7.6 cm minimum top diameter for softwood, hardwood not merchantable	43.5	38.79	Base
5.1 cm minimum top diameter for softwood, hardwood not merchantable	42.4	38.07	-1.8
7.6 cm minimum top diameter for softwood and hardwood, hardwood is merchantable	29.3	30.43	-22.0

Table 8. Unit Costs and per Hectare Costs of Harvesting Conventional Products for the Newfoundland Case Study.

Activity	Tree-length Harvesting			Full-tree Harvesting		
	($/m³)[1]	($/odt)	($/ha)	($/m³)[1]	($/odt)	($/ha)
Felling	10.25	29.81	2030.52	6.00	17.45	1188.60
Delimbing				3.00	8.73	594.30
Skidding	10.5	30.54	2080.05	7.31	21.26	1448.11
Total	**20.75**	**60.35**	**4110.57**	**16.31**	**47.74**	**3231.01**

[1] Calculated by using merchantable stem volume.

Conventional tree-length and full-tree harvesting costs for the study area were provided by Corner Brook Pulp and Paper Company (Brown 1996) for felling, delimbing, and skidding. Harvesting costs for bucking and hauling of shortwood to the mill are the same for both the conventional tree-length and the full-tree systems and do not affect incremental costs. These costs are therefore not considered in this analysis. Conventional tree-length harvesting costs for cutting and delimbing are based on a three-person operation (two loggers and one skidder operator) for cutting and delimbing at the stump. No separate delimbing cost is incurred, as trees are felled and delimbed by the same woodsworker in a single operation. Corner Brook Pulp & Paper, Inc. pays its contractors and workers on a piecework pay rate for skidding and felling-delimbing separately. For full-tree harvesting with no delimbing at the stump, cutting costs are based on the use of a tracked feller-buncher where delimbing is completed mechanically at roadside based on mechanical stroke delimber costs from Zundel (1992b).

Skidding

Skidding costs for full-tree harvesting are calculated based on the assumption that softwood residual biomass (tops and branches) and all hardwood biomass (assuming that all hardwoods are converted to energy biomass) incur an additional skidding cost for recovery of merchantable material. This proposition is based on the fact that the weight of this material displaces conventional products in each skidder load. The additional skidding cost is based on the ratio of total dry mass moved under full-tree harvesting relative to the dry mass of stems moved under the tree-length harvesting (see Appendix 1 for a sample calculation). Total costs per hectare under both systems are calculated based on the merchantable softwood dry tonnage.

Table 8 summarizes the cost calculations for harvesting and processing energy biomass. The shift from tree-length harvesting to full-tree harvesting will save approximately $4.44/m^3 even without capturing biomass for energy. As a result, the biomass is delivered to roadside at a zero cost.

The savings in harvesting could theoretically be applied to the cost of processing biomass which would result in much lower biomass costs.

Chipping and Hauling of Biomass

A Bruks CT1002 residue chipper was used for this case study since it is specifically designed to treat roadside and stump area logging residues. Based on a rental rate of $85/hour (Robichaud 1996) and a production of 14Gt/hour, the unit cost of chipping is $6.11/Gt. Robichaud (1996) cited a production in the range of 9Gt/hour (picking hardwood tops out of mixed species roadside piles) to 24 Gt/hour (birch full trees at roadside). A conservative compromise for chipping roadside debris and birch full trees is 14Gt/hour. The same hauling costs as used in the New Brunswick case study were applied for the Newfoundland case study. Delivered energy biomass costs are summarized in Table 9.

Ash Application

The costs of ash application to replace incremental nutrient depletion attributable to energy biomass removal are discussed in the next section.

Biomass Costs

In the absence of energy biomass production, an economically rational firm would use only the full-tree system to harvest if the cost of roadside residue removal were less than $4.44/m^3. The costs of roadside slash treatment for the New Brunswick case study and slash disposal costs were less than $1.00/m^3. As a result, the cost of biomass is more likely to be equivalent to the sum of its chipping and hauling costs as well as ash application if compensatory fertilization is carried out. Table 9 summarizes the costs of energy biomass for the Newfoundland case.

Silvicultural Implications

One of the other important dimensions in evaluating energy biomass production approaches in Newfoundland is the effect on reforestation. The overall attractiveness of recovering biomass in the Newfoundland case study area is affected by harvesting/reforestation trade-offs and issues that centre on the organization of harvesting operations at the forest level. The key components of these two issues are discussed below.

The tree-length harvest tends to produce an even distribution of residues over the cut area. Shortwood systems (both manual and mechanized) concentrate debris in windrows over which forwarders drive to reduce soil disturbance. Full-tree harvesting removes a higher proportion of biomass from the site than do any of the other methods. Corner Brook Pulp and Paper personnel are concerned with the effects of residue removal with full-tree harvest from these sites but are also concerned with the residue distribution from mechanical shortwood harvests. The latter have the effect of burying regeneration that is under the residue piles and exposing the regeneration to excessive drying in the areas where residues have been removed, resulting in a situation similar to that in areas harvested by the full-tree system. The effects of shortwood harvesting on regeneration survival and growth are not yet documented in Newfoundland.

Gingras *et al.* (1991), while not studying the effect of full-tree harvesting, did study the effect of three skidding methods on advance regeneration (of fir and black spruce) in a feller-buncher operation. What this study showed was that “most areas maintained a stocking level of at least 60% after the harvest” (down from 85-98% pre-harvest stocking levels). The lowest post-harvest stocking was found to be 37% (down from 85%). These results were concluded to be a combination of skidder selection and prevailing site conditions (low bearing capacity, long skidding distances, and high piling density). Gingras *et al.* (1991) state: “[skidders are] the main reason for advance regeneration destruction. They result in an absence of regeneration over 20% to 40% of the cutover area. Lateral sweep resulting from moving trees out to the skid trails caused negligible destruction of regeneration, except with the cable skidder.”

Another study done in western Newfoundland compared full-tree and tree-length harvesting systems (Cormier 1993) This study was undertaken with the intent of serving as a case study to assess the possible negative environmental effects of a return to full-tree harvesting systems in western Newfoundland. The author writes: “In general, the results of this study show no evidence that full-tree logging will effect the regeneration stocking more than tree-length. The stocking after harvest was more abundant for the full-tree system in the only block where both

Table 9. Cost of Biomass for Energy Production at an End-use Site for the Newfoundland Case Study.

Activity	Per Unit Cost $/odt	Per Unit Cost $/Gt	Per Hectare Cost $/ha
Chipping	11.11	6.11	484.26
Hauling	9.49	5.22	413.72
Ash application	1.56	0.86	67.88
Total Biomass Recovery Cost	**22.16**	**12.19**	**965.86**

Table 10. Nutrient and Ash Analysis for the Newfoundland Case Study.

Macro-nutrient	Macro-nutrient Removed (tonnes/ha)[1,2]	Marco-nutrient in Ash[3] (% of Ash by Mass)	Amount of Ash Required to Replace Macro-nutrients Removed (odt/ha)
Nitrogen (N)	0.23	0.0	na[4]
Phosphorus (P)	0.03	0.9	3.2
Calcium (Ca)	0.17	13.0	1.3
Magnesium (Mg)	0.02	1.4	1.6

[1] Nutrient concentrations based on Freedman *et al.* (1982).
[2] Based on net energy biomass delivered to roadside (i.e. 95% recovery for hardwoods; 70% recovery for softwoods).
[3] Ash content from Unger and Fernandez (1990).
[4] Nitrogen is volatilized upon combustion and not available in wood ash.

systems were assessed side-by-side. However, the tree-length system with manual felling may offer more potential for protecting advance growth when careful logging techniques are adopted."

Cormier (1993) indicates that one of the potentially misleading results of post-harvest studies of regeneration stocking levels is that the stocking assessments are done immediately after harvest. Under normal conditions, regeneration studies are conducted at a minimum of five years after harvest. On the basis of results from a 13-year-old full-tree and tree-length cut in which initial post harvest stocking was lower for the full-tree area, the author concludes that the "evolutionary pattern" of natural regeneration seems to be the same, "even if the type of sites and the systems were not exactly the same."

An additional concern about the full-tree system is that it requires a larger number of machines to produce the shortwood required at the mill. In a typical operation, the machines would include feller-bunchers, grapple or cable skidders, stroke delimbers and slashers. Two of these machines are usually tracked (feller-buncher and stroke delimber) and as a result are expensive to move because of their slow travel speed. Although both feller bunchers and delimbers can be mounted on wheeled carriers, this configuration is quite rare, particularly in steep terrain such as that found in parts of the Corner Brook area. Mechanized shortwood harvesting equipment, on the other hand, is wheeled and relatively mobile. It includes only two types of machines: shortwood forwarders and single-grip harvesters (either dedicated shortwood processors or excavators with processing heads). Although the manual shortwood harvesting system requires more people, it requires only one machine type — the shortwood forwarder. As a result, shortwood harvesting systems have lower costs associated with setting up and moving to new blocks than do full-tree harvesting systems. The full-tree harvesting system has lower unit costs of production than the shortwood systems because of the very high productivity of its single-function machines. This advantage can, however, be lost when frequent moves to small-cut blocks increase the cost of moving and reduces the machine utilization rate. These considerations, combined with the public perception of negative environmental impacts of full-tree harvesting, have provided the impetus to shift to shortwood systems in Newfoundland (Brown 1996). If biomass energy were to be recovered from conventional operations it would have to take into account these operational issues.

Environmental Impacts

Nutrient Depletion Estimation

Nutrient removals were calculated based on concentrations given by Freedman *et al*. (1982) for Nova Scotia. The Nova Scotia data represent the most relevant estimates available for Newfoundland soil conditions and forest composition. Incremental nutrient removals attributable to the removal of nonmerchantable material by full-tree harvesting was itemized for individual tree components to reflect the distribution of nutrients in the living tree. No reliable estimates of the dead and living branch proportions are available for the study area, so nutrient removal is based on an assumption of 100% live branches.

Amounts of ash required to replace incremental removal of phosphorous, potassium, calcium and magnesium due to full-tree harvesting are estimated from nutrient concentrations of wood ash given by Unger and Fernandez (1990). Ash amounts are estimated as the ash required to replace or exceed all nutrient exports except nitrogen which is volatilized in wood combustion and unavailable in wood ash.

Silvicultural and Environmental Issues

On the basis of assumptions identical to those in the Environmental Impacts (New Brunswick) section (p.7), ash application and nutrient analysis results are summarized in Table 10. Phosphorus is the nutrient that defines the compensatory fertilization level for this site (3.2 tonnes/ha). The costs of ash application are summarized in Table 9 above. These costs represent a very small fraction (7%) of total biomass costs.

Wildlife Habitat
Biomass recovery from conventional operations removes material which may have a number of repercussions for certain types of wildlife. The importance of coarse woody debris (CWD) and snags as components of wildlife habitat has been discussed by several authors (Amaranthus *et al.* 1994; McCarthy and Bailey 1994; Carey and Johnson 1995; Coulombe and Lemay 1983; Hunter 1990).
The importance and use of snags by multiple forest animalspecies (e.g., pine marten in Newfoundland) is well documented. Hunter (1990) recommends systematic distribution of residual living and dead standing trees to facilitate this important habitat element. He recommends a systematic management policy of leaving 5 to 10 large living and dead trees per hectare. Several authors have confirmed a half-life of downed woody material of 7 to 10 years for hardwood debris resulting in the loss of 99% of residual CWD in 20 to 25 years. The slower decay rate of softwood species can achieve significant retention of forest floor debris structure until the forest regenerates significantly at 40-60 years. A practice of leaving several live stems of significant dimension at harvest to ultimately contribute to the residual debris distribution in the regenerated forest adds additional longevity and continuity to the dead structure.

Important questions remain to be answered on the importance of landscape debris distribution to achieve habitat connectivity for small animal species. The additional importance of CWD as a substrate for the production of hypogeous fungi as a significant food source for small mammals has been established (Maser *et al.* 1984; Amaranthus *et al.* 1994; Amaranthus and Perry 1994; Berg *et al.* 1994) but recommendations for specific dimensions, amounts and distribution patterns of residual CWD are not well documented. In light of the many unanswered questions, Coulombe and Lemay (1983) recommended intensive study of areas where CWD is removed to determine ongoing effects of this removal on wildlife habitat. Although the importance of debris has been well established, specific recommendations for management objectives remain elusive.

Nova Scotia – Shelterwood Harvesting in Red Spruce

General Context
The Nova Scotia case study is based on red spruce (*Picea rubens* Sarg.) stands found in the Mooseland area of Nova Scotia (Halifax County). These stands are highly fertile and by age 80-90 years can contain 350-500 m^3 of wood per hectare. These stands should, according to silviculturists in Nova Scotia, be harvested at 80-90 years either by clearcutting or through partial harvesting, to leave a large number of stems per hectare to provide shelter for establishing regeneration. Ten to fifteen years after harvest, the stands may contain up to 30 000 stems per hectare of red spruce regeneration. Once seedlings attain a height of 30 cm and are no longer in danger of burning off through exposure to full sunlight, the remaining trees will be removed, preferably in winter when the seedlings are protected by the cover of snow. The protection afforded by the snow is necessary as the residual trees being removed can have crown diameters of 5-7 m which pose a significant threat to seedlings from the sweeping action of skidding operations (Prest 1996). Harvesting methods tend to be either manual or mechanized shortwood, although there is a significant productivity capacity available in cable skidders used in full-tree or tree-length harvest systems.

Intervention Strategies
This case study examines the biomass production potential of shelterwood harvesting in Nova Scotia. The fundamental strategy on these highly productive sites is to develop a high stocking of red spruce based on natural regeneration. Red spruce grows best initially under partial shade. For this reason, and to protect the spruce trees from excessive competition, this stand type will be managed under a two-stage shelterwood cutting system.

The initial intervention will be full-tree harvesting using manual felling and cable skidders. This harvesting system replaces the tree-length or shortwood systems that would normally be used in this stand type. In this first entry, harvesting will occur without snow cover to provide good germination sites for regenerating red spruce. Forty percent of the basal area is the targeted removal goal: 10% from the trees in the largest diameter at breast height (dbh) classes, with the remaining 30% from the lower dbh classes. After harvesting, it has been assumed that all of the remaining trees grow at approximately 0.2 cm per year, a rate that allows them to move into the next diameter class during the 10 years before the next intervention.
In addition, intolerant hardwoods such as white birch are harvested to capture potential mortality losses in these short-lived, shade intolerant species. Trees will be delimbed at roadside with a stroke delimber, and the merchantable stems cut into log lengths and pulpwood with a roadside slasher. Residual biomass will be chipped at roadside with a Bruks 1001CT residue chipper and shipped 50 km to its end-use facility.

Ten years after the initial harvest, a second removal cut will be performed, with manual full-tree harvesting using cable skidders. This operation will be done under snow cover to minimize damage to seedlings and regeneration. Fifty percent of the basal area of the remaining trees of the original stand will be targeted for removal, applied evenly across all of the diameter classes. Roadside processing will be as described for the initial harvest.

Table 11. Biomass and Merchantable Volume Yield Estimates from Harvests at Years 0 and 10 for the Nova Scotia Case Study.[1]

Species	Gross Mass (odt/ha)	Merchantable Mass (odt/ha)	Volume[2] (m^3/ha)	Unmerchantable Mass (odt/ha)	Recoverable Energy Biomass[3] (odt/ha)
Year 0					
Softwood	70	52	162	18	13
Hardwood	11	8	18	3	2.8
Total	**81**	**60**	**180**	**21**	**15.8**
Year 10					
Softwood	86	71	224	15	10
Hardwood	0	0	0	0	0
Total	**86**	**71**	**224**	**15**	**10**

1 Biomass predictions based on Freedman *et al.* (1982).
2 Based on average specific gravity per species (Panshin and de Zeeuw 1980).
3 Assumes a 70% recovery rate for softwoods (Routhier 1982) and 95% for hardwoods.

Table 12. Biomass Chipping and Hauling Costs per Unit and per Hectare Based on the Amount of Biomass Recovered in Tree-length and Full-tree Harvesting for the Nova Scotia Case Study.

Activity	Per Unit Cost		Per Hectare Cost
	$/odt	$/Gt	$/ha
Year 0			
Harvesting	0.45	0.25	7.18
Chipping11.1	6.11	244.2	
Hauling 9.5	5.22	209	
Ash application	2.58	1.42	56.76
Year 10			
Harvesting	0.9	0.5	8.96
Chipping11.1	6.11	166.5	
Hauling 9.5	5.22	142.5	
Ash application	3.91	2.15	58.65
Total Biomass Recovery Cost	25.41	13.98	376.61

Fifteen years after the initial entry, a final removal of the original stand will be scheduled. In this instance a mechanized shortwood harvest will be used to a) protect stocking of the natural regeneration and b) maintain as much nutrient potential on the site for the established regeneration. At this stage, regeneration will be in a rapid growth phase with large nutrient demands.

A further treatment of the regenerating stand will consist of a precommercial thinning as it is likely that regeneration densities can reach 30 000 stems/ha. Thinning will improve the quality of the final stand and hasten the onset of merchantable volume production. This thinning is best performed when the trees reach a height of 2-3 m.

System Evaluation

Biomass Yield Prediction

The summary of the harvesting results showing merchantable stem (conventional) yield and energy biomass yield is presented in Table 11. Biomass calculations are not given for the final (shortwood) harvest as this method does not lend itself to energy biomass removal and, as stated above, it is felt that the nutrient rich foliage is better left on site at this stage.

Intervention Costs

Felling, Skidding, and Forwarding

While the study is based on the use of full-tree harvesting methods as outlined above, costs for conventional tree-length harvesting have been included as a basis for

Table 13(a). Unit Costs and per Hectare Costs of Harvesting Biomass for Energy Use for the Nova Scotia Case Study.

Activity	Full-tree Harvesting ($/m^3)[1]	Tree-length Harvesting ($/m^3)
Felling	9.91	11.94
Skidding		
Delimbing	2.07	
Slashing (roadside)	2.93	2.93
Total	**14.91**	**14.87**

[1] Calculated by using merchantable stem volume.

Table 13(b). Net Costs Incurred for Harvesting Energy Biomass for the Nova Scotia Case Study.

	Energy Biomass Harvested and Net Cost on a per Unit Basis		
	Energy Biomass (odt/ha)	Net Cost of Biomass ($/ha)	Net Cost of Biomass ($/odt)
Year 0	16	7.13	0.45
Year 10	10	8.96	0.9

comparison. Skidder costs are based on three-man crews for tree-length operations and two-man crews for full-tree. Tree-length felling, delimbing and skidding costs are $11.94/m^3 (Prest 1996). Full-tree felling and skidding costs are $9.91/m^3. Costs for these various activities are combined since they are carried out by the same crew at the same time. The final harvest costs (i.e., for the final residual tree removal at age 15) are calculated using the costs for a Valmet 901 shortwood harvester ($12.34/m^3) and a forwarding cost of $5.70/m^3 (Zundel and LeBel 1992; Zundel 1992c; Kuitto *et al.* 1994; Gingras 1996).

Delimbing, Slashing, Chipping, and Hauling Costs

In the full-tree system, delimbing is completed mechanically at roadside with stroke delimbers. Delimbing costs from Zundel (1992b), at a rate of $2.07/m^3 are used. See the New Brunswick section on Intervention costs for the details of delimbing costs. Chipping costs were determined to be $6.11 per green tonne and chip hauling costs were calculated at $5.22 per green tonne based on the same assumptions as in the Newfoundland case (see Table 12 for a cost summary). Roadside slashing costs were estimated at $2.93/m^3 (Prest 1996). Table 13(a) summarizes the intervention costs.

The total cost of production for the harvests at years 0 and 10 are presented in Table 12. Costs are given in dollar values per green and oven dried tonne as well as on a dollars per hectare basis.

The marginal costs associated with biomass harvesting are presented in Table 13(a). The marginal cost is calculated from the difference between tree-length harvest in which energy biomass is not recovered and full-tree harvest from which energy biomass can be recovered. Table 13(b) uses the costs obtained in Table 13(a) combined with the production quantities from Table 11.

Silvicultural Implications

This section deals with a number of elements in the Nova Scotia case study that have implications for implementing the silvicultural system described. In general, these elements deal in some detail with the assumptions that were made when the case study was put together; some are based on the dynamics of the developing stand while others deal with the systems proposed for the energy biomass harvesting.

The case study presents a red spruce stand on a high yield site that is taken through a fifteen year cycle of interventions. In such a productive stand as described here, a high density of red spruce seedlings (20 000 to 30 000 stems/ha) can be expected (Prest 1996). The growth of regeneration poses a problem for ash application. This is a particular problem at year 10 when the regeneration may well reach over 2 m in height, as the type of spreader used is most effective in wide-open situations. Since the ash is essentially spread by broadcasting, dense and tall regeneration interferes with both the movement of machinery and the ability of the ash to be dispersed. It may thus be necessary to delay the second ash treatment until the first subsequent commercial thinning or to blow the ash in dry form under appropriate wind conditions. If the application of ash at the time of the first cut does not unduly encourage the growth of competing vegetation, it may be possible to make a double application at that time and forego the year 10 application. There are significant economies of scale inherent in applying ash once rather than twice. It is assumed that the biomass burning plant would be able to supply sufficient ash for a double

Table 14. Nutrient and Ash Analysis for the Nova Scotia Case Study.

Macro-nutrient	Macro-nutrient Removed (tonnes/ha)[1,2]		Macro-nutrient in Ash[3] (% of ash by mass)	Amount of Ash Required to Replace Macro-nutrients Removed (odt/ha)	
	Year 0	Year 10		Year 0	Year 10
Nitrogen (N)	0.2	0.15	0	na[4]	na[4]
Phosphorus (P)	0.02	0.02	0.9	2.7	2.3
Potassim (K)	0.08	0.07	2.8	2.7	2.5
Calcium (Ca)	0.15	0.13	13	1.1	1
Magnesium (Mg)	0.02	0.02	1.4	1.4	1.2

1 Nutrient concentrations based on Freedman *et al.* (1982).
2 Based on net energy biomass delivered to roadside (i.e. 95% recovery for hardwoods; 70% recovery for softwoods. See section on New Brunswick biomass yield prediction for cost details).
3 Ash content from Unger and Fernandez (1990).
4 Nitrogen is volatilized on combustion and not available in wood ash.

application. In cases where the plant burned a range of fuel types (e.g, logging and sawmill residues) or where residues come from a range of interventions within the same forest area, this should pose no problem.

The high density of regeneration will also require some additional tending to maximize value growth and timber yield. While the harvesting at year 10 will undoubtedly cause some reduction in density and stocking, it will probably still be necessary to thin and space the stand at the time of the shortwood harvest. If spacing is not done at the time of the final shortwood harvest of residual trees, a pre-commercial thinning would be expected to be done no later than twenty years after the initial entry into the stand.

The case study assumes that the first entry will consist of a removal of 40% of the total basal area of the stand — 10% from the largest diameter classes and 30% from the smallest ones. As well, for simplicity sake, all hardwoods were removed at the time of the first cut, which effectively changed the stand into a single species (red spruce) stand. A complex cutting operation like this will require either experienced cutters or marking of trees to ensure that the appropriate stems are harvested.

For the purpose of the study it has been assumed that all trees will grow at the same rate — 0.2 cm per year for the next 10 years — which allows all trees to move fully into the next dbh class at the time of the second harvest (10 years). The same growth rate is expected to continue until year 15, which has been modeled by moving half of the trees of each diameter class up into the next larger class. While this seems reasonable, it is also safe and suggests that the biomass estimates for years 10 and 15 may well be somewhat on the conservative side.

This study also makes the assumption that all of the ingrowth will be red spruce—either that which exists as regeneration present or as result of prolific seeding in after the harvest at year 0. It is expected that the stand will not be in danger of windthrow due to the fact that only 40% of the basal area is removed at year 0 and by year 15 the regeneration will be firmly enough established. This is reasonable given that most of the trees removed (30% of the basal area) are suppressed and that residual trees are likely to be from larger size classes that are windfirm.

Environmental Impacts

In this case study it was found that for both of the first two entries, ash applications at approximately 2.7 oven-dried tonnes (odt)/ha will be required to replace the exported potassium (K) (Table 14). At this application rate, all of the other nutrients are satisfactorily replaced.

As indicated earlier, there may be some operational challenges in applying ash in a shelterwood system at a time that is conducive to nutrient retention in the stand and that does not encourage the growth of competing vegetation. This may require that ash be applied in a single dose rather than two.

Synthesis of Case Studies

This section brings together the results of the three case studies with respect to the primary parameters used to evaluate them, i.e. biomass yield, biomass cost, and silvicultural and environmental consequences. Forest level consequences of energy biomass harvesting are described and the applicability of the silviculture systems proposed is briefly discussed.

Biomass Yields

The per hectare yields for the three case studies had a wide range. The shelterwood harvests in Nova Scotia yielded from 10-16 odt/ha while the Newfoundland clearcuts yielded 43.6 odt/ha. The New Brunswick partial cuts yielded 48.3 odt/ha. The high values for Newfoundland and New Brunswick yields are due to the fact that they were recovering biomass from the stems of unmerchantable tree species (white birch in Newfoundland, beech in New Brunswick). The Nova Scotia energy biomass was produced only from the tops and branches of merchantable trees. In the New Brunswick case, the yield was brought down somewhat by the need to harvest wolf trees with a tree-length system. If the cutting cycle is such that most trees are below this 45 cm diameter threshold in future interventions, the energy biomass yield may increase, although this depends on which species are harvested.

Merchantability standards play a key role in determining biomass yield. This is particularly true for the cases where non-merchantable species are converted to energy biomass. In the Newfoundland study the impact of changing white birch from unmerchantable to merchantable would be a 22% reduction in energy biomass yield. In New Brunswick, the impact would have been a 75% reduction in the yield in the first intervention. Since the pressure on the hardwood resource is increasing in the Atlantic region as pulp mills are modified to accept a proportion of their furnish in the form of hardwood chips, there is a significant potential for currently unmerchantable species to become merchantable.

The effect of changing the minimum top diameter on biomass yield is much less pronounced. Yields were affected by a only few percentage points by lowering the minimum top diameter from 7.6 to 5.1 cm in the Newfoundland case. The pressure to lower top diameters is likely to be much less pronounced in the Atlantic region than the pressure to accept hardwoods, given the much smaller contribution it could make to wood supply and the fact that top diameters are already quite small. In addition, the tops of trees are largely composed of juvenile wood which has lower quality for pulping than mature wood. In addition, debarking very small diameter stem sections is difficult and expensive.

Biomass Cost

The three cases studies indicate that energy biomass could be produced for between \$20.39/odt and \$35.58/odt at 50 km distance from an end-use facility. The cost was highest in New Brunswick because the full-tree harvest of beech recovered no merchantable volume that could bear some of the harvesting cost. The narrowness of the range between Nova Scotia and Newfoundland is a function primarily of the fact that, in both cases, energy biomass is produced in a full-tree harvesting system. The cost of full-tree harvesting (\$/m^3 of conventional products) was lower than or only slightly above the cost of the cheapest alternative (usually tree-length harvesting). As a result, there was very little incremental biomass harvesting cost and the cost of the biomass is essentially equivalent to the cost of chipping, hauling and compensatory fertilization.

The reasons for the low absolute cost of biomass processing is that the unmerchantable material from which energy biomass is made is concentrated at roadside by the full-tree harvesting system, raising the productivity of the Bruks 1001CT chipper to, in our assumptions, 14 Gt/hour (9.1 odt/hour). The Bruks chipper cost (used in NewBrunswick and Newfoundland) was \$9.34/odt. The Morbark chipper used in the New Brunswick case study cost \$14/odt. After harvesting, it has been assumed that all of the remaining trees grow at approximately 0.2 cm per year allowing them to move into the next diameter class during the ten years before the next intervention. If the chipper were to treat stump-area debris following shortwood harvesting, the chipping cost would rise (assuming a \$85/hour machine rental rate) to between \$17-28/odt since production would drop to between 3-5 odt/hour (Mitchell *et al.* 1988).

There are no fixed costs (e.g., associated with moving equipment from block to block) considered in this analysis, as these tend to be quite site-specific. It should be noted, however, that the fixed costs will be higher per unit of production in the Nova Scotia case because it is set in private woodlots where blocks are typically smaller. Both the New Brunswick and Newfoundland cases are set on large tracts of land where blocks tend to be bigger. As a result, the cost of biomass production is likely to be slightly underestimated in Nova Scotia. Recent studies of the effect of block size and dispersement (Duizer 1995) show that block size and distance between blocks only becomes an important factor for harvesting costs when sizes get very small (<5ha) and distances large (>20km). If the cost of moving from one block to another was \$500 for trucks to haul the chipper to another block and the area of the block were 5 ha, in the Nova Scotia case, this would raise the biomass cost by \$6.25-10/odt (\$100/ha divided by

10-16 odt/ha). The sensitivity to fixed costs is also greatest in Nova Scotia because energy biomass yields per hectare are approximately one-third of those in the other two case studies. Since the fixed costs are divided by yields to calculate unit costs, the latter will fall as yields rise.

Environmental Impacts

The environmental impacts of biomass energy recovery are more difficult to generalize. One of them is the potential reduction in long-term yield of conventional products due to nutrient removal during harvesting. This problem can be partially addressed by spreading wood ash in sufficient quantities in areas harvested. This activity has a relatively low cost ($0.50-3.91/odt) since the ash applied is assumed to be essentially free. It does not, however, compensate for the removal of nitrogen. Should this need to be replaced as well (e.g., where nitrogen is the limiting nutrient), it would cost in the range of $457/tonne applied (at 45% nitrogen content). This could add another $6-20/odt of biomass based on the yields and nutrient removals presented above. It should be noted, however, that the case study sites have inherently high fertility and may well not need compensatory fertilization.

Another environmental issue related to energy biomass harvesting is the role that coarse woody debris (CWD) plays as wildlife habitat. Specific recommendations have been developed to maintain CWD in managed forests to provide wildlife habitat. In the Newfoundland example, a systematic practice of leaving 5 stems per ha of average dbh 30 cm would lead to a reduction of 1.0 odt (-1.5%) of merchantable material per hectare and 0.4 odt (-1.0%) of energy biomass. This implies that this kind of wildlife management prescription would have a small effect on biomass yield.

Another dimension to the wildlife habitat issue is the role of smaller biomass in providing a substrate for fungus growth and thereby food for species that consume it. It should be noted that the full-tree systems described in the three case studies do not recover all the harvesting residues. The recovery rates used here vary between 70 and 95%, implying that between 5 and 30% of the harvesting residues remain on the site after full-tree harvest. These materials would remain available as wildlife habitat.

Little attention has been given to the spatial distribution of logging debris following harvesting. It is clear that biomass distribution varies as a function of the harvesting systems used. The lack of attention to this phenomenon is curious given the importance of debris in regeneration survival in some situations (McInnis and Roberts 1994) and the importance of debris in providing habitat for a variety of wildlife.

Silvicultural Impacts

Another potential impact is the effect of biomass removal on the germination, survival, and growth of regeneration. This is unlikely to be a major factor in either the New Brunswick or Nova Scotia cases, where the post-harvest environment is likely to favour regeneration by desired species. In Newfoundland, there is widespread concern over the use of full-tree harvesting on exposed, nutrient poor and short growing season sites. Existing literature indicates that over the long term, full-tree harvesting does not result in significantly different stocking of regeneration from tree-length or shortwood systems in Newfoundland. The range of sites dealt with by the studies cited is limited and it would be prudent to evaluate the impacts on the poorer sites. If full-tree harvesting resulted in insufficient regeneration stocking, while both shortwood and tree-length harvesting did not (as is currently the popular view), the cost of artificial regeneration would have to be added to the biomass price. If we assume replanting costs to be $550/ha, the cost of biomass could be increased by as much as $13/odt in the Newfoundland case (based on current biomass yields). It should be noted, however, that plantations of desirable species have better long-term yields and potentially lower costs of protection and tending (e.g., pre-commercial thinning) than do partially stocked stands of natural regeneration with highly variable density. This factor can have significant effects on sustainable harvests that could, to some extent, compensate higher planting costs.

Forest-level Implications

Studies of silvicultural practices are an important component in helping to increase biomass production. They deal with stand-level issues related to harvesting and reforestation costs and revenues. For most Canadian forestry situations, however, the stand-level issues are integrated into management planning at the forest level. The silvicultural practices carried out in any given stand type on large Crown land licences or industrial freehold from coast to coast are decided as a result of forest level concerns. The need for forest-wide sustainability of timber supply, environmental quality and social values is what drives the choices of where to apply the various silviculture systems available to foresters. If we treat the impacts only at the stand level, we may reach conclusions that are inappropriate when we evaluate their broader implications at the forest level. The same may be true of energy biomass production.

Some of the forest-level effects of energy biomass harvesting may be felt through the “allowable cut effect” phenomenon. An allowable cut effect occurs when, in forests constrained to produce even flows of timber, forest managers are allowed to liquidate old growth stands more rapidly in the short term by putting in place young stands that grow more quickly than the old stands they replace. They may also occur when the productive landbase is expanded. Energy biomass harvesting can create allowable cut effects through at least three mechanisms: by increasing yield in harvested stands by forcing the use of planting over natural regeneration; by reducing site productivity through nutrient removal; and by increasing the productive land base area. Since nearly all Crown land in Canada (90% of productive forest land) is under non-declining timber flow constraints, there is a need to analyze biomass production at the forest level.

Consider the example of a full-tree harvesting system used to recover energy biomass that resulted in unacceptably low natural regeneration survival, which would increase stand-level costs by requiring subsequent planting. The use of a tree-length system might not require planting because it achieved a marginally satisfactorily restocked status. At a stand level, the full-tree system might be assumed to have a negative impact because of higher reforestation costs. At the forest level, however, a fully stocked planted stand will produce more yield over the long term than a marginally stocked stand based on natural regeneration. Under certain forest conditions, this may mean a greater immediate harvest due to the "allowable cut effect" which more than offsets planting costs. On the other hand, reduced growth due to nutrient removal will have little effect on stand level revenues since the losses would occur in the distant future. They would, however, cause a negative "allowable cut effect" and reduce current harvests at the forest level. Biomass harvests may also convert stands that are currently economically inoperable due to low quality of products to ones that can be harvested and returned to high value stand types. This could again have important effects at the forest level.

Potential Applicability of the Silvicultural Systems Described

While the silvicultural systems described and their respective stand types are province-specific, they were selected because they represent situations that exist broadly throughout the Atlantic Canada. For example, not only does the tolerant hardwood stand type described in the New Brunswick case study occupy 19 000 ha, but similar stand types occupy 54 000 ha on Fraser Paper Inc. lands alone. Approximately 60% of their hardwood forest will be managed in the manner described. Most of the northern New Brunswick crown land and industrial freeholds contain some of the stand type described. Tolerant hardwood stands are found in all the Maritime Provinces (New Brunswick, Nova Scotia and Prince Edward Island). The increased demand for hardwood may well make the silviculture system described an increasingly common practice in the Maritimes.

Windthrow-prone, even-aged softwood stands of the kind described in the Newfoundland full-tree clearcut harvesting case dominate Newfoundland's forest. Even-aged balsam fir stands in New Brunswick could be managed in the same way. The coastal areas of Nova Scotia would also be eligible for this kind of treatment. The risk of negative silvicultural impacts from nutrient depletion and seedling burn-off would seem to indicate that the nutrient poor or extremely dry sites should not be treated in the way described. The fixed costs associated with full-tree harvesting (due to the need to move four machine types rather than two from block to block) may also preclude its use in areas where blocks are very small and widely dispersed.

The shelterwood system described in the Nova Scotia case study will also find applicability in New Brunswick and Prince Edward Island, where forest stands that are windfirm and composed of species that will regenerate well in partial shade are found. Stands of red and black spruce hybrids, growing alone or in admixture with balsam fir would be logical candidates for the shelterwood system.

The potential applicability of the silviculture systems described is also affected by the availability of the harvesting technology used to implement them. Full-tree harvesting is used in all three of the proposed harvesting systems. By delaying delimbing until trees reach roadside, it raises chipper productivity and reduces the need for handling. It also capitalizes on technology (e.g., cable skidders) which is readily available in all provinces in the Atlantic region.

While full-tree harvesting technology is widely available in Atlantic Canada at the time of writing, there is an emerging trend toward mechanized shortwood harvesting. At first glance, this might seem to indicate that the productive capacity in skidders and other full-tree harvesting equipment might decrease over the next 5 to 10 years. In determining whether this trend toward shortwood harvesting might reduce the potential of energy biomass harvesting, it is important to consider the grounds for the trend. The interest in shortwood harvesting systems was rekindled in the early nineties by three main factors (in order of importance):

- increasing government restrictions on piling or burning roadside slash left by full-tree harvesting operations;
- easier harvesting with shortwood systems in the growing number of partial cutting situations in second-growth stands; and
- the perception that nutrient and organic matter removal could adversely affect future stand growth.

Roadside slash disposal is only a problem in places where energy biomass is not harvested. As a result, the shortwood system would lose one of its main advantages in the context where a market for energy biomass could be developed. Full-tree harvesting systems can also be successfully used in partial cutting systems as has been demonstrated at Fraser Paper Inc. and elsewhere. The nutrient removal problem can be dealt with effectively through compensatory fertilization and by appropriate site selection. As result, it is likely that, if markets for biomass energy develop, the trend toward shortwood harvesting will be slowed for many silviculture systems, with a reversion to full-tree technology.

In general, all of the systems presented in the case studies use conventional silvicultural practices. What distinguishes them is that they use full-tree rather than tree-length or shortwood harvesting. In other words, where a shelterwood harvest is being carried out with a shortwood harvesting system, the full-tree equivalent could be used and biomass recovered at roadside. As a result, the general guideline for applicability would be that the proposed silviculture systems could be used wherever their conventional analogues are used so long as there is a market for the biomass produced. A further *caveat* is that they should not be used where harvesting residues and unmerchantable species must be used for purposes other than energy production (e.g., as a nutrient source, wildlife habitat or to help ensure survival of seedlings). It should, therefore, be clear that the systems proposed could find widespread applicability.

Policy Changes and Incentives to Make Energy Biomass Production More Attractive

Biomass energy production is currently constrained by two main forces: the lack of markets and the perceived balance between its advantages and disadvantages. The following sections discuss these two forces and propose action that might be taken to make energy biomass production from conventional operations more attractive.

Markets for Energy Biomass

Where a market exists for energy biomass, the private sector finds effective and efficient methods of resolving silvicultural and operational problems that would otherwise limit exploitation of that market. Technical issues involved in biomass production do not seem to be limiting. Instead, the existence of a market seems to be one of the main impediments restricting growth in biomass use. Some of the factors affecting market development include fear of competition, fear of independent electrical production, and clean air legislation.

Fear of Competition

The forest industry has long resisted independent development of biomass energy facilities for fear of competition for forest fibre. Competition could increase prices, reduce fibre supply or both. This situation may simply be perception. Where biomass energy has been successfully developed (for example at Fraser Paper Inc. and Miramichi Pulp and Paper Inc. in New Brunswick), the forest industry was ofen involved. Forest industry participation in developing facilities is important because the forest land managers' fear of wood supply losses can be mitigated and because forest industry facilities are both suppliers and potentially large users of the low-pressure steam and heat that is a byproduct of wood fired electrical plants.

Fear of Independent Electrical Production

Many public electrical utilities have maintained energy pricing structures that inhibit development of independent production facilities. Since the utility companies have a monopoly on the transmission and distribution infrastructure, they have effectively inhibited private power generation by paying rates equivalent to only avoided fuel costs rather than paying for the full cost of displaced production capacity. For example, an electrical utility might pay an independent electrical producer a rate equivalent to the cost of the coal that it does not need to use in its own facilities rather than a rate that includes the cost of the coal and the cost of building and operating the facility. Where utility pricing policies allow for payment of the full cost of energy produced, biomass projects have a better chance of being developed successfully. In New Brunswick, such a policy led to the development of the Fraser Paper Inc. co-generation plant (Ouellet C. 1996).

Clean Air Legislation

One of the advantages of biomass as a fuel is that it contains very little sulphur. As a result, it can be burned without the use of sulphur dioxide scrubbers. This is an advantage over most fossil fuels, which contain greater amounts of sulphur. The lack of clean air legislation that clearly provides incentives to reduce air pollution in power generation facilities in many jurisdiction makes fossil-fueled production comparatively attractive by reducing the air pollution advantage of biomass energy plants.

Advantages and Disadvantages of Biomass Energy

Production of energy from forest biomass is not an end in itself; rather, it has been proposed as an alternative or complement to conventional sources of energy such as fossil fuels and nuclear power. In a society increasingly concerned with sustainable development, proponents of biomass energy address their arguments to the main components of sustainable development, namely environmental, economic and social (World Commission on Environment and Development 1987). Opponents of biomass harvesting routinely cite environmental issues focusing on the spectre of over-harvesting and denuding of the landscape and the attendant rise in air pollution from the combustion of wood products. The current perception held by industry and government is that while there is merit to both sides of the argument, the advantages and disadvantages cancel each other out and, as a result of this, there is no incentive to pursue commercial production of biomass energy. If policy changes and incentives aimed at encouraging energy production from forest biomass are to be effective they need to concentrate on strengthening its advantages and weakening its disadvantages. Table 15 presents the main advantages and disadvantages cited for biomass energy.

It becomes clear from Table 15 that the disadvantages centre around the perception that biomass energy is economically and environmentally unattractive. This kind of perception is rooted in the following main factors:

- fears of soil nutrient depletion come from the agricultural experience based on annual crops rather than crops harvested on a 50-100 year cycle where nitrogen fixation, mineral weathering and atmospheric nutrient inputs can replenish periodic harvest losses;
- opponents of biomass energy production normally compare it to conventional forestry rather than to

Table 15. Advantages and Disadvantages of Biomass Energy Production.

Dimension		Proponents – Advantages	Opponents – Disadvantages
Environmental	Forest site productivity	i)"Unproductive" land can now be utilized and put under more productive cover ii) Enhances "plantability" of harvested sites iii) Productivity on sites of adequate fertility is not affected	i) Nutrient exports negatively affect long-term site productivity ii) Removal of coarse and woody debris has adverse affects on some wildlife species iii) Removal of debris increases soil and plant desiccation, increasing reforestation costs
	Air pollutants	If properly combusted, can meet stringent standards more cheaply than fossil fuels	Generates air pollution in the form of particulates
	Energy production wastes	Ash is a benign byproduct that can be used on agricultural or forest land as a lime replacement	Ash from generating plant poses a disposal problem
	Atmospheric carbon	Zero net addition if harvest of forests is not greater than growth	Generates carbon dioxide from combustion
Economic	Costs of energy biomass production	Cheaper than fossil fuels when produced in conjunction with conventional products and at reasonable distances	Uneconomical because of high harvesting and transportation costs and because fossil fuels are currently much cheaper than they were in the seventies and eighties
	Revenues from forest land	New products added without competing for fibre with traditional products	Produces very little value-added for the economy when compared to conventional forest product manufacturing
	Markets	Creates a market for non-merchantable trees	
Social	Employment creation	Creates jobs and distributes them regionally	
	Public sector debt	Public-sector debt load can be avoided and energy capacity can be added incrementally and regionally due to smaller size of biomass plants	
	Energy type	Renewable	

- alternative energy production (e.g., from fossil fuel), which overemphasizes its drawbacks and ignores those of conventional energy production; and
- analysis of biomass energy is often carried out at the stand level from a private-firm perspective: but this ignores forest-level issues and societal benefits arising from employment and increased utilization of land.

Fears of nutrient depletion can be calmed by a combination of information about the likely impacts, judicious use of existing ecological site classification information to limit biomass harvesting to sites with low susceptibility to productivity losses, and use of compensatory fertilization where appropriate. Concerns about negative silvicultural impacts and financial unattractiveness have little basis as general rules and can only be addressed by local analyses, some of which will need a forest-level perspective.

Biomass energy has significant advantages in the area of socioeconomic impacts. However, these are only revealed if analyses are carried out at the socioeconomic level rather than the single-firm financial level. Socioeconomic analysis considers issues such as net national value-added, employment, public sector debt, shifting use of forest resources, wildlife and other environmental effects. Comparative analysis of biomass energy production from conventional forestry operations with alternative energy sources is needed to provide a more comprehensive evaluation and is likely to identify more opportunities for biomass production than now exist.

Suggested Policy Changes and Incentives

The recommendations for policy changes and incentives are divided into two parts: those that can be implemented by the International Energy Agency (IEA) and those that must be implemented by governments and utility corporations.

IEA

- Continue research and publication about the effects of biomass energy production on environmental, social and economic factors.
- Develop and document availability of effective and efficient technology for compensatory forest fertilization.
- Demonstrate how to analyze energy biomass production and use at the forest and societal level in ways that include the full range of economic, social, and environmental issues.

Public Sector and Utility Corporations

- Encourage the development of markets by putting in place electrical pricing policies that pay for the full avoided cost of power.
- Put in place clean air legislation that provides incentives for reducing air pollution and emission of greenhouse gases.

Conclusions

Cost and Yield of Specific Systems

- The cost of biomass delivered to a plant varied between $20.39/odt and $35.88/odt assuming a hauling distance of 50km and that compensatory fertilization will be carried out.
- Biomass net yields will be in the range of 10-48 odt/ha for the stand types tested or 0.05-0.56odt/m^3 harvested for conventional products.

Applicability of Energy Biomass Harvesting in Conventional Operations

- The silvicultural systems described have wide applicability. Wherever their shortwood or tree-length analogues are used and residues are not needed for other purposes, the full-tree systems proposed are likely to provide good results.
- A large proportion of the land base can be managed by one of the three systems described, although the specifics of the prescription might change (e.g., basal area removed, harvest priority, shape of clearcut).
- Harvesting systems that leave the biomass attached to the stem until it reaches roadside are likely to have the lowest costsof energy biomass harvesting and chipping.

Merchantability Standards

- As hardwood utilization increases, biomass yields will decrease significantly.
- Changes in minimum top diameters are unlikely to reduce biomass yields significantly.

Environmental Consequences

- Compensatory fertilization with wood ash would cost little relative to the cost of harvesting and chipping and could replace all nutrients except nitrogen.
- Compensatory fertilization with nitrogen would cost approximately $300/ha unless a cheaper source of nitrogen could be found (e.g., municipal sewage residues or agricultural wastes).
- Prescriptions currently in use to provide coarse woody debris and snag trees for wildlife can be accomodated without significant biomass yield reduction.
- Although the exact amount of medium and fine woody debris important to wildlife that should be left on harvesting areas is unknown, 5-30% of the non-merchantable biomass will be left on site by the full-tree harvesting systems described in this study.

Point of View and Scale of Analysis

- There are a number of implications of energy biomass harvesting that will be felt mainly at the forest level rather than at the stand level, including: allowable cut effects in forests constrained to produce non-declining yields, expansion or shrinkage of the operable land base and net value-added from energy biomass production.
- Distance, through its effect on hauling cost, will be a major factor affecting the proportion of the land base from which energy biomass production will be financially feasible.

Policy Changes and Incentives to Encourage Energy Biomass Production

- Electrical utility pricing policies that pay for full avoided cost of power are needed to create markets for energy from biomass.
- Clear air legislation that provides incentives for reducing air pollutants and net greenouse gas emissions would help give biomass energy a competitive advantage over fossil fuels.
- Biomass energy projects need to be evaluated at a socioeconomic level from environmental, social and economic perspectives to show the full range of their positive impacts.
- A simple protocol for analyzing biomass energy projects at the socioeconomic level (including forest level impacts analysis) needs to be developed and documented.
- Effective and efficient techonological approaches to compensatory fertilization need to be documented and developed to calm the main fears about biomass energy.

Recommendations

1) A socioeconomic study of biomass energy production should be carried out in some location in Canada as a model for this kind of analysis. It should deal with social, environmental and economic impacts of biomass harvesting and utilization for a specific project. The forestry component of this analysis should contain a forest-level, long term biomass supply analysis that specifically considers the implications of potential yield reductions and of changes in the cost or effectiveness of reforestation interventions.
2) Literature on the long-term growth effects of biomass harvesting with and without compensatory fertilization should be analyzed and summarized in an IEA report. Biomass energy harvesting should also be compared to natural disturbances in this report.
3) A study of the state of the art in compensatory forest fertilization with wood ash and other fertilizers should be carried out. It should deal with technologies available to work in stands at a range of different development stages including: recent cutover; high-density regenerating; immature; and early-mature.

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Glossary

Advanced Regeneration
Trees that have become established naturally under a mature forest canopy and are capable of becoming the next crop after the mature crop is removed.

Biomass
For this study, biomass is defined as the mass of above ground components of a tree such as the stem, top, branches, and foliage.

Cable Skidder
An articulated, four-wheel-drive tractor that uses winches and a steel cable to gather tree stems and drag them to roadside.

Chip Harvester
A motorized logging machine that reduces full trees (stem and branches) and logging residue into pulp or energy chips, usually at roadside or at a landing.

Clearcut
The harvesting of all merchantable trees from an area of forest land.

Coarse Woody Debris (CWD)
Tree stems and sections that form part of the habitat of wildlife species adapted to mature and overmature forests.

Conventional Pulp Chip Van
A trailer or semi-trailer designed to haul chips.

Cubic Metre (m^3)
A measure of solid wood volume under bark: 1 m^3 is equivalent to 35.31 ft^3.

Diameter at Breast Height (dbh)
The stem diameter of a tree measured at breast height (1.3 m above ground level).

Energy Biomass
The mass of tree components that are destined to be converted into fuel. Usually this consists of unmerchantable trees as well as the top, stem branches, and unmerchantable sections of merchantable trees.

Feller-buncher
A wheeled or tracked machine used in felling and grouping stems together.

Full-tree Harvesting
The harvesting of the entire felled tree, including the stem and branches for processing at roadside or at the mill.

Grapple Skidder
An articulated, four-wheel-drive tractor that drags the trees to roadside. It uses a grapple mounted at the rear to take hold of trees that have been bunched.

Green Tonne
A metric measure of the mass (1000 kg) of wood that includes the moisture in the wood.

Hectare (ha)
A measure of area: 1 ha is equivalent to 10 000 m^2 or 2.47 acres.

Hygrading
A partial harvest removing only the most valuable species or trees of desirable size and quality from the stand, often resulting in a poor-quality residual stand.

Hogged Fuel
Particles of various shapes and sizes obtained by the chipping or shredding of slash and logging residue, to be used specifically for energy conversion.

Manual Felling
Felling of trees with the use of a power saw by a woodsworker.

Leave Trees
Trees left unharvested after a partial cut (e.g., the trees left for seed production in a seed-tree cut or those in a residual stand in a single-tree selection system).

Oven-dried Tonne (odt)
A tonne of wood (1000 kg) which has lost all of its free moisture after drying in an oven at 100°C until mass stabilizes.

Partial Harvest
Any cutting in which only part of the trees in a stand are harvested.

Precommercial Thinning
A thinning that does not yield trees of commercial value, usually designed to improve crop spacing.

Productive Machine Hours (PMH)
The number of hours in which a machine is performing the functions for which it was designed (includes no delay time).

Pulpwood
Trees that will yield logs of a standard size suitable for the production of pulp.

Regeneration
Renewal of a forest crop by natural or artificial means. Also the new crop so obtained. The new crop is generally less than 1.3 m high.

Residuals
Trees left in a cut-over after a partial harvest.

Roadside Slasher
A machine that cuts the stems into log lengths at roadside.

Sawlogs
Trees that will yield logs suitable in size and quality for the production of lumber.

Shelterwood Cutting
Any regeneration cutting in a more or less regular and mature crop, designed to establish a new crop under the protection (overhead or side) of the old, as typically in shelterwood systems, or where the resultant crop will be more or less regular.

Shortwood
Delimbed trees that have been cut into various standard lengths. The length varies with demand.

Shortwood Forwarder
A four wheel drive tractor which contsists of a bunk and a loader. The shortwood (typically 1.2 m or 2.4 m) is loaded onto the bunk and then carried to roadside for shipping.

Single-grip Harvester
A a tree-harvesting machine that uses a single felling-delimbing slashing head mounted on a boom, which is attached to a carrier chassis. It grabs the tree and processes it, never releasing the tree until the bucked shortwood falls to the ground.

Slash
The residue left on the ground after felling, including unused logs, uprooted stumps, broken tops, etc.

Snag
A standing dead tree from which the leaves and most of the branches have fallen.

Stroke Delimber
A machine that delimbs and tops whole trees at the landing or in the woods. It processes a tree by holding it in stationary arms while pushing a knife-edged skidding grapple along the stem.

Tree-length Harvesting
Harvesting trees in such a way that they arrive at roadside in delimbed and topped form.

Windrows
Slash, brushwood, etc. concentrated along a line so as to clear the intervening ground between two of them.

List of Tree Species

1. Balsam fir (*Abies balsamea* [L.] Mill.)
2. Beech (*Fagus grandifolia* Ehrh.)
3. Black spruce (*Picea mariana* [Mill.] BSP)
4. Red maple (*Acer rubrum* L.)
5. Red spruce (*Picea rubens* Sarg.)
6. Sugar maple (*Acer saccharum* Marsh.)
7. Trembling aspen (*Populus tremuloides* Michx.)
8. White ash (*Fraxinus americana* L.)
9. White birch (*Betula papyrifera* Marsh.)
10. White spruce (*Picea glauca* [Moench.] Voss.)
11. Yellow birch (*Betula alleghaniensis* Britt.)

Appendix 1
Incremental Skidding Cost Calculation: Full-tree versus Tree-length Harvesting

The calculation of incremental skidding/forwarding costs of full-tree versus tree-length harvesting is based on a concept of incremental costs accrued for hauling additional energy biomass per unit of merchantable material. Typical costs for tree-length skidding/forwarding in the Newfoundland case study are \$10.50 /m^3. In the base case of a 7.6 cm minimum top diameter, 68.1 tonnes/ha (198.1 m^3/ha) of merchantable softwood material is retrieved. Under full-tree harvesting, the same amount of merchantable material is retrieved with an additional load of 43.6 tonne/ha of residual biomass. The effective skidding/forwarding costs of the merchantable material is inflated by the ratio of total biomass moved relative to the merchantable mass moved.

$$\mathbf{Cost_{FT} = Cost_{TL} * (Mass_{Bio} + Mass_{merch.}) / Mass_{merch.}}$$

If a hypothetical base case involves a tree-length skidding/forwarding cost of \$10.50/m^3, 111.7 tonne/ha total biomass and 68.1 tonne/ha merchantable material.

$$\mathbf{Cost_{FT} = \$10.50 * (43.6+68.1) / 68.1 = \$17.22}$$

The effective full-tree skidding/forwarding cost is \$17.22 /m^3.

It should be noted that this cost is presented only to describe the prodcedure that would be used to estimate full-tree skidding costs if these were not available from other sources. This calculation assumes that skidder load size is limited by weight.

Appendix 2
Softwood Residue Recovery and Slash Disposal Cost at Fraser Paper Inc.

Roadside logging residues in hardwood operations at Fraser Paper Inc. will be chipped with a Morbark 23 Chipharvester. This is not possible in softwood harvesting operations because the infeed rollers on the Morbark chipper are not suited to handling tops and branches. As a result, roadside residues of softwood chipping operations must be disposed of and roadside areas planted with drought-resistant species to compensate for the removal of organic matter during slash disposal operations. This operation incurs a cost. Residues of softwood harvesting operations, which form the majority of Fraser Paper Inc.'s timber base, are therefore not available for the wood-burning power plant. This analysis explores the cost of recuperating energy biomass from roadside slash piles in softwood cut overs. The main elements of uncertainty in this analysis are related to the hourly production cost and output for chippers that are suited to processing softwood residues. In this case we base our analysis on the Bruks CT1002 chipper. We estimate the cost of chipping roadside slash piles and the avoided costs of roadside rehabilitation.

Slash Disposal Cost Where No Energy Biomass Recovery Occurs

The cost of piling roadside slash piles in softwood harvesting operations is $425/km of at Fraser Paper Inc. (Ouellet 1996). This does not include the cost of planting or of seedlings, since these costs will be incurred regardless of whether residues are piled or chipped for energy.

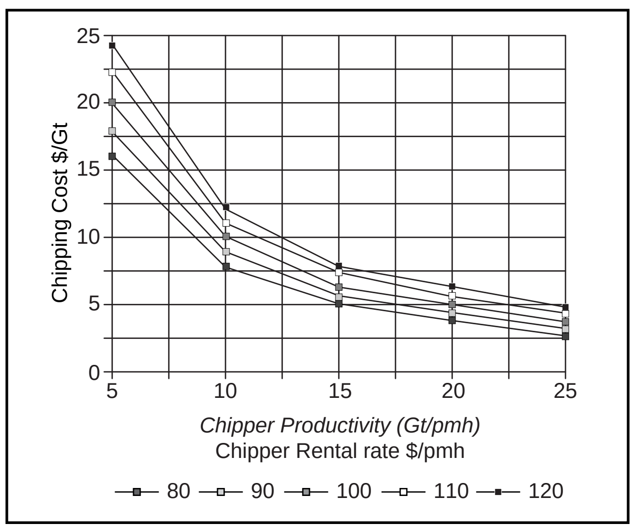
Since the maximum skidding distance is 390 m (1300 feet), the average is 195 m (390 m/2). Each kilometre of road serves a strip of forest approximately 780 m in width (390 m x 2) or approximately 78 hectares. To estimate the cost ($/m^3 of merchantable wood) of treating roadside slash piles, divide the cost per km ($425) by the number of cubic metres served by the road in a particular cut (78 ha x m^3/ha harvested in a particular cut). If we assume that softwood stands contain approximately 150 m^3/ha and that they are harvested by clearcutting, each kilometre of road would produce 11 700 m^3. This implies that the cost of treating roadside slash piles (in the absence of branch and top biomass recovery) is $425/km, divided by the volume served per kilometre (11 700 m^3). This cost works out to approximately $0.036/m^3. If the energy biomass were to be harvested, it would thus save approximately $0.036/m^3 of conventional forest products.

This savings would be a credit to the biomass harvesting operations in softwood stands. Assuming that softwood forests have a net yield of approximately 0.15 odt of biomass per cubic metre of merchantable wood (Routhier 1991; Zundel 1990), the cost savings translate into $0.24/odt of biomass recovered.

Chipping Costs

The Bruks CT1002 residue chipper is commonly used in residue harvesting in Scandinavia, the United Kingdom and in Canada (Mitchell *et al.* 1988). The chipper is carried on a shortwood forwarder chassis and blows chips into a self-unloading bin. It can, therefore, be used in stump-area chipping. The production varies greatly between applications. In the stump-area mode, its productivity is relatively low (5-8 Gt/hour). This is due to the dispersed nature of the branches and tops that it chips, which increases travelling time and reduces chipping time. When it is used in a roadside chipping mode, its productivity increases dramatically. Chipping white birch full trees, it attained 24 Gt/hour (Robichaud 1996). While picking out hardwood tops from roadside delimbing piles containing both hardwood and softwood, this same chipper's productivity was slightly more than 9 Gt/hour. Other studies indicated that in roadside chipping applications, productivity could be in the range of 14 Gt/hour (Mitchell *et al.* 1988).

Figure 2. Chipping Cost as a Function of Chipper Productivity and Hourly Rental Rate.



The hourly rental rate for a Bruks chipper ranged between $110 and $155 (adjusted to 1996 costs by compensating for inflation; Mitchell *et al.* 1988). These amounts are probably an overestimate since forest industry producer costs have not risen at the rate of inflation indicated by the Consumer Price Index. Robichaud estimated hourly rental rates for a used chipper and forwarder chassis at $85/hour. Given the range of values for both rental rate and productivity, a sensitivity analysis was performed on the unit cost of chipping. Its results are presented in Figure 2. Chipping costs are quite sensitive to productivity and can be seen to drop off dramatically as productivity exceeds 5 Gt/pmh. Hourly rental rate has a smaller effect over the range tested. A reasonable estimate of productivity working in roadside slash is 10-15 Gt/productive machine hour (pmh). As can be seen in Figure 2, this combination of rental rates (i.e., $85/hour) and productivity would imply a chipping cost range of $5-8/Gt. Even at $120/hour rental rate, the cost range would be $8-12/Gt. Fraser Paper Inc. currently pays $7.70/Gt for it chipping with a Morbark chipper in hardwood stands. Taking a horizontal line from $7.70/Gt on the vertical axis of Figure 2 will identify the critical levels of both hourly rental rate and productivity below which the Bruks chipper matches the Morbark chipper in cost. The savings in roadside slash removal costs ($0.24/odt or $0.16/Gt) must also be figured in the biomass production cost estimates in softwood stands. In this case, the $7.87/Gt line ($7.70/Gt + $0.16/Gt) would be used as the break-even point.

Given the large volume of softwood harvested on Fraser freehold and Crown licence land, a more complete investigation of softwood residue chipping seems warranted.