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USING LIFE CYCLE ASSESSMENT (LCA) AS A TOOL TO ENHANCE ENVIRONMENTAL IMPACT ASSESSMENT (EIA) WITH A CASE STUDY APPLICATION IN THE PULP AND PAPER INDUSTRY

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USING LIFE CYCLE ASSESSMENT (LCA) AS A TOOL TO ENHANCE ENVIRONMENTAL IMPACT ASSESSMENT (EIA) WITH A CASE STUDY APPLICATION IN THE PULP AND PAPER INDUSTRY

présenté par: CORNEJO ROJAS Fernando Alonso
en vue de l'obtention du diplôme de: Maîtrise ès sciences appliquées
a été dûment accepté par le jury d'examen constitué de:

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M. STUART Paul, Ph.D., membre et directeur de recherche
M. SAMSON Réjean, Ph.D., membre et codirecteur de recherche
M. MINNS David, Ph.D., membre

To my father, for being my model and source of
inspiration,
To my mother, for being my strength and intimate friend
To my brother and sister, an infinite source of joy and pride
To Erica, for being an amazing woman and a great friend

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RÉSUMÉ

Au sens de la loi, une Évaluation des Impacts sur l'Environnement (ÉIE) est requise pour de nouveaux projets industriels. La portée et les frontières de l'ÉIE sont limitées à l'évaluation des impacts locaux sur le milieu récepteur. Une autre limitation de l'ÉIE est d'effectuer l'évaluation sur l'option la plus rentable seulement plutôt que de permettre l'analyse de solutions un peu moins économiquement attrayantes, mais ayant un impact environnemental moindre. Ceci suggère que l'ÉIE nécessite l'intégration d'une série plus complète d'indicateurs afin d'analyser non seulement les impacts locaux de projets industriels, mais aussi afin de pouvoir améliorer la performance environnementale de ces derniers tout au long de la chaîne de produit.

L'analyse du cycle de vie (ACV) couvre une large variété d'impacts locaux, régionaux et globaux associés à un produit par l'utilisation de approche « du berceau au tombeau », c'est-à-dire de l'extraction des matières premières à la disposition finale de produit. Il existe de nombreuses applications de l'ACV dont l'utilisation comme un outil de comparaison de différents scénarios afin d'en retenir le meilleur du point de vue environnemental.

L'objectif de ce projet et de proposer un outil améliorant l'ÉIE classique de nouvelles alternatives de procédés en y intégrant certains éléments de l'ACV afin d'élargir la portée de l'analyse environnementale. Les critères environnementaux spécifiques à

l'usine (spécifiques au site) sont traités par l'ÉIE classique tandis que les critères reliés au produit (génériques au site) sont traités par l'ACV. Cette méthodologie inclut aussi une analyse technico-économique afin d'identifier les alternatives ayant l'impact environnemental minimal tout en étant rentable.

Afin d'illustrer l'approche proposée, 18 alternatives de procédé visant l'implantation de la cogénération et l'augmentation de la capacité de pâte désencrée à une usine ont été développées. Une analyse technico-économique a été effectuée afin de confirmer la faisabilité technique et économique des alternatives. De cette analyse, seulement 4 alternatives se sont révélées économiquement faisables lorsque soumises aux conditions actuelles du marché. Les alternatives retenues ont été analysées à l'aide de l'outil proposé.

L'importance relative de divers résultats environnementaux calculés à l'aide de l'outil proposé a été évaluée par un panel d'experts en utilisant un d'analyse multicritère de décision afin d'évaluer et de pondérer les différents critères d'ÉIE et d'ACV. Cet outil aide les experts à évaluer et pondérer les différents critères. Une plus grande importance était accordée aux critères ACV (génériques au site) qu'aux critères d'ÉIE. La principale cause de ce résultat est que les alternatives rencontraient toutes les normes et règlements (mesurés par les critères ÉIE) rendant ces derniers moins importants lors de la prise de décision.

Un indice environnemental a été calculé en utilisant les facteurs de pondération et les résultats environnementaux afin d'obtenir un indice unique représentant la performance environnementale globale des alternatives. Cet indice a été représenté graphiquement en même temps que la performance économique afin de déterminer l'alternative présentant le meilleur compromis entre la performance économique et la performance environnementale.

Finalement, en utilisant une méthodologie basée sur l'ACV, la réduction en émissions de $CO_{2\ eq.}$ due aux activités d'avant-plan (usine) et d'arrière-plan (production des utilités et des combustibles) a été quantifiée pour les alternatives faisables. Les implications monétaires de la monétisation de cette réduction dans un futur programme d'échange de droits d'émission ont été analysées en utilisant un intervalle de valeurs de crédit (entre 10 et 50 \$/t $CO_{2\ eq.}$).

Les résultats de cette étude démontrent que l'ÉIE peut être améliorée par l'intégration d'éléments d'ACV lors de l'évaluation d'alternatives. Les résultats suggèrent que les alternatives peut avoir un effet (ou impact) marginal sur l'environnement récepteur (relié à l'ÉIE) tout en présentant d'importants bénéfices environnementaux au niveau de la chaîne de produit (relié à l'ACV) tels que la réduction des niveaux courant d'impact global, régional et local.

Aussi, l'outil proposé permet d'identifier la meilleure alternative du point de vue environnemental et économique. Les résultats ont montré que, en considérant les conditions actuelles du marché, l'installation d'équipements de cogénération de 40 MW et l'augmentation du ratio de pâte désencrée à 100% est l'alternative préférable pour l'environnement tout en étant la plus compétitive économiquement (VAN : 39 MM$CAN).

Les économies de carbones peuvent affecter la performance économique d'un projet dans le cas où le prix considéré serait élevé (50 SCAN/t $CO_{2\ eq.}$ épargnée). Afin d'observer un effet important sur la performance économique du projet, il est aussi nécessaire de considérer les réductions d'avant-plan et d'arrière-plan.

ABSTRACT

As part of the current regulatory framework, an Environmental Impact Assessment (EIA) is required for new industrial projects. The scope and boundaries of this environmental assessment are restricted to assess the local environmental impacts in the receiving environment only (i.e., site-specific impacts). Another limitation of EIA is that it starts its environmental evaluation based on the most economically feasible option. It does not analyze other design alternatives that might not be as economically attractive but have a lower environmental impact. This suggests that EIA needs to include a wider set of indicators to analyze not only local impacts of new industrial projects in order to achieve improved environmental performance across the product chain.

Life Cycle Assessment (LCA) covers a wider set of indicators at the local, regional and global levels compared to EIA. LCA analyzes environmental impacts (i.e., site-generic impacts) associated with a product or a process by using a "cradle-to-grave" approach, meaning from the extraction of the raw materials to the final disposal of the manufactured product. LCA is commonly used to compare different design alternatives from an environmental standpoint.

This project is intended to propose a tool to enhance Environmental Impact Assessments (EIA) of new process design alternatives by integrating Life Cycle

Assessment (LCA) considerations into EIA in order to be able to execute a broader environmental analysis. Site-specific (or facility level) environmental criteria are addressed by the classical EIA methodology, whereas site-generic (or product-chain level) environmental criteria are assessed by the LCA methodology. Also, as part of this methodology a techno-economic analysis is included considering technically feasible alternatives, in order to identify the designs that have the lowest environmental impact while being economically feasible.

In order to illustrate this proposed approach, 18 design alternatives were developed for the implementation of co-generation and increased de-inked pulp (DIP) production at an integrated newsprint mill. A techno-economic analysis was carried out, finding that only 4 out of the 18 initial alternatives were economically feasible under current market conditions. The economically feasible design alternatives were then analyzed with the proposed tool.

The relative importance of the results for the different calculated environmental criteria was evaluated by a panel of experts using a Multi-Criteria Decision Making (MCDM) tool. This tool helps the experts to evaluate and weight the different EIA and LCA criteria based on a panel method. Greater weights were assigned to LCA (site-generic) criteria than to EIA (site-specific). The main reason why the experts assigned a higher weight to the LCA criteria was that the EIA criteria already met the regulatory limits, whereas LCA criteria is not considered in the regulatory framework.

An Environmental Index (EI) was calculated using the results from the expert panel and environmental results in order to calculate a single indicator which represents the overall environmental performance of each design alternative. These overall environmental performances were plotted against the projects' economic performances in order to choose the most preferable alternative, from both an environmental and economic perspective.

Additionally, the results from using the proposed tool; foreground (facility level) and background (utility and fuels production) carbon savings were quantified for the feasible design alternatives. The economic implications of monetizing these carbon savings in a future Carbon Trading System were analyzed, considering a range of carbon credit values (between 10 and 50 \$/t $CO_{2\ eq.}$).

Results from this study demonstrate that Environmental Impact Assessment (EIA) can be enhanced by including Life Cycle Assessment (LCA) elements in the overall evaluation of the proposed design alternatives by showing different trends for LCA and EIA results. Results suggested that current design alternatives could have a marginal effect (or impact) in the receiving environment (related to EIA). However, at the product-chain level (related to LCA), there are important environmental benefits such as the reduction of current global, regional and local impact levels.

Also, the proposed tool allows to identifying the best design alternative from an environmental and economic stand point. Results showed that under current market conditions, the implementation of a 40 MW co-generation facility and the increase of 100% DIP pulp production is the most environmentally preferable alternative and at the same time, the most competitive from an economical point of view (NPV of CDN 39 MM).

Carbon savings can affect the economic performance of new projects if a higher figure is considered ($50 CDN/ ton of carbon credit). At the same time, results highlighted the need to consider both foreground and background carbon credits together in order to account for important effects on the economic performance of projects.

CONDENSÉ EN FRANÇAIS

INTRODUCTION

« Il y a un intérêt grandissant des communautés, des institutions politiques et de l'industrie pour une variété de problématiques environnementales. Les préoccupations peuvent être reliées aux ressources naturelles, à la santé humaines ou à l'environnement en tant que tel. Quelque en soient les raisons, ces inquiétudes résultent en actions telles que de nouveaux règlements et, en conséquence, les industrie doivent s'adapter » *(Baumann et Tillman 2004, p.20)*

De nouveaux engagements internationaux tells que le protocole de Kyoto combinés avec ces nouveaux règlements incitent les industries à optimiser leurs procédés et ainsi réduire leurs émissions et leurs déchets via des projets de modernisation. Des projets tels que la cogénération utilisant la biomasse et le remplacement de la pâte thermomécanique (PTM) par de la pâte désencrée (DIP) sont d'excellentes façons de réduire la consommation d'énergie. En effet, une usine de pâte désencrée aura typiquement une consommation énergétique correspondant à 25-27% de la consommation d'une usine de PTM *(Dessureault 1999)* et la cogénération représente un moyen important pour l'industrie papetière afin de réduire l'utilisation de combustibles fossiles puisque la biomasse est une forme acceptée d'énergie propre.

De plus, puisque l'implantation des susmentionnés projets industriels peut potentiellement représenter une réduction des émissions de $CO_{2\ eq.}$, il devient nécessaire de développer des outils afin de quantifier les bénéfices économiques et environnementaux de ces réductions à un stade précoce du processus de conception (si un programme d'échange de droits d'émission était implanté au Canada).

Au sens de la loi, une Évaluation des Impacts sur l'Environnement (ÉIE) est requise pour de nouveaux projets industriels. L'ÉIE met l'accent sur l'identification des effets environnementaux potentiels, sur la proposition de mesures de contrôle et d'atténuation des effets identifiés ainsi que sur la prédiction de l'importance des effets sur le milieu récepteur après l'application des mesures d'atténuation. Cependant, l'ÉIE ne considère pas d'indicateurs ayant une portée plus vaste afin d'évaluer les impacts de la chaîne de produit parce qu'elle est limitée à l'analyse des impacts sur l'environnement récepteur.

À l'opposé, l'analyse du cycle de vie (ACV) couvrent une grande variété d'impacts locaux, régionaux et globaux associés à un produit ou à un procédé par l'utilisation de approche « du berceau au tombeau », c'est-à-dire de l'extraction des matières premières à la disposition finale de produit. Cependant, dû à sa vaste portée, l'ACV utilise des modèles ne considérant pas les caractéristiques du site pour la description des impacts environnementaux. Il existe de nombreuses applications de l'ACV dont l'utilisation comme un outil de comparaison de différents scénarios afin d'en retenir le meilleur du point de vue environnemental.

L'hypothèse de recherche proposée est la suivante :

L'Évaluation des Impacts sur l'Environnement (ÉIE) classique de différentes configurations de procédé peut être améliorée par l'intégration de l'Analyse du Cycle de Vie (ACV) pour analyser et présélectionner une série d'alternative et ce, afin d'obtenir un ensemble d'alternatives techniquement et économiquement faisables ainsi qu'attractives pour l'environnement.

Les sous hypothèses suivantes sont aussi reliées à ce projet de recherche:

- Une méthode de prise de décision multicritère utilisant le procédé analytique hiérarchique peut être un outil efficace afin d'évaluer globalement les impacts spécifiques au site de l'ÉIE et les impacts génériques au site de l'ACV.
- La nouvelle méthodologie propose peut être utilisée pour démontrer que, pour une usine intégrée de papier journal hypothétique, l'implantation de la cogénération et l'augmentation de la production de pâte désencrée peuvent être rentable et bénéfique pour l'environnement de façon simultanée sous certaines conditions. Au même moment, différents coûts énergétiques et différents mélanges d'énergie peuvent affecter de façon significative le retour sur l'investissement (ROI) et la réduction de l'émission de gaz à effet de serre de ces projets.

- Les économies de carbone à l'avant-plan et à l'arrière-plan obtenus par l'implantation de la cogénération et l'augmentation de la production de pâte désencrée pourraient avoir un effet positif sur le ROI de ces projets dans le cas où un système d'échange de crédits de $CO_{2\,eq.}$ serait implanté.

Les objectifs de ce projets sont de :

- Proposer une nouvelle méthodologie pour évaluer une plus vaste famille d'impacts environnementaux de projets majeurs de modernisation d'usines de pâtes et papier en estimant des indicateurs d'ACV (chaîne de produit) en addition aux indicateurs classiques d'ÉIE (usine) pour différentes alternatives de configurations de procédé,
- Combiner les indicateurs de performance environnementale provenant de l'ÉIE et de l'ACV en utilisant une méthodologie systématique de prise de décision multicritère afin de calculer un indicateur environnemental unique qui exprime la performance environnementale globale des projets tant au niveau de l'usine qu'au niveau de la chaîne de produit,
- Démontrer la nouvelle méthodologie pour le cas de l'implantation de la cogénération et de l'augmentation de la production de pâte désencrée à une usine intégrée de papier journal existante,
- Démontrer que le coût de l'électricité provenant du réseau d'alimentation ainsi que le type de combustibles utilisés pour générer cette électricité peuvent affecter la performance économique et environnementale de projets d'implantation de cogénération et d'augmentation de la production de pâte désencrée,

- Analyser et monétiser différents scénarios futurs tels que les économies de carbone reliées aux différentes alternatives afin d'en observer l'impact sur la performance économique des projets.

MÉTHODOLOGIE

Ce projet présente une méthodologie intégrée combinant plusieurs outils tels que (1) l'analyse technico-économique, (2) l'ÉIE, (3) l'ACV et (4) l'analyse multicritère de décision.

Lors de l'analyse technico-économique, un ensemble d'options sont proposées afin d'augmenter la capacité de production de pâte désencrée et d'implanter la cogénération. Ces alternatives ont été validées par des experts de procédé.

À la suite de l'identification de technologies rencontrant les objectifs de conception, les bilans de masse et d'énergie sont calculés afin d'estimer les nouvelles consommations de matières premières, de combustibles, de produits chimiques d'électricité et autres pour chacune des alternatives. Une analyse technico-économique des alternatives est effectuée. La valeur actualisée nette (VAN) et le taux de rentabilité interne (TRI) sont utilisés à titre d'indicateurs majeurs financiers afin d'exprimer la faisabilité économique des alternatives proposées.

Des critères environnementaux dérivés de l'ACV et de l'ÉIE sont proposés afin d'évaluer la performance environnementale des alternatives tant à l'échelle de l'usine qu'à l'échelle du produit. Les critères d'ÉIE comprennent plusieurs émissions atmosphériques et aqueuses ainsi que la génération de déchets solides. Les critères d'ACV considèrent des catégories d'impact globales, régionales et locales. Les critères utilisés sont présentés au tableau suivant.

Table 0.1 Critères environnementaux considérés

Catégorie d'impact		**Échelle**	**Indicateur de catégorie**
ÉIE	Émissions atmosphériques	Usine	
	Particules suspendues totales (PST)		µg/m3
	Oxydes d'azote (NOx)		µg/m3
	Dioxyde de soufre (SO_2)		µg/m3
	Émissions aqueuses		
	Demande biologique en oxygène (DBO)		kg/j
	Génération de déchets solides		
	Génération de cendres		t/an
ACV	Changements climatiques	Globale	g CO_{2eq}
	Destruction de la couche d'ozone		g $CFC11_{eq}$
	Acidification	Régionale	mol $H+_{eq}$
	Eutrophisation		g N_{eq}
	Formation de smog photochimique		g NO_{xeq}/m
	Écotoxicité	Locale	g $2,4D_{eq}$
	Santé humaine – cancer		g C_6H_{6eq}
	Santé humaine – non cancer		g C_7H_{7eq}
	Santé humaine – particules		DALY

Une méthodologie d'analyse de décision basée sur un panel d'experts est intégrée dans cette approche afin de combiner tous les critères environnementaux en un indice environnemental unique. L'indice environnemental représentant la performance global des alternatives est représenté graphiquement en même tant que la performance économique (exprimée par la VAN) afin de déterminer la solution présentant le meilleur compromis.

Les différences entre l'approche classique et l'approche proposée sont présentées à la figure suivante :

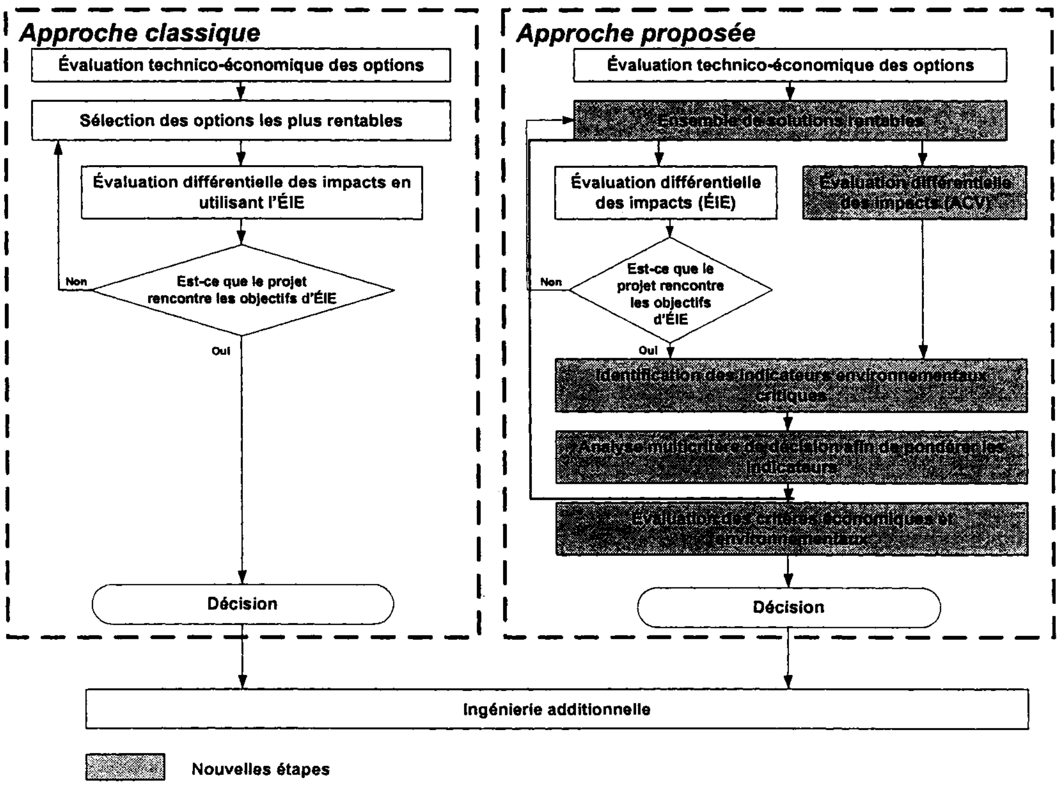


Figure 0.1 Méthodologie proposée afin d'inclure l'ACV dans l'ÉIE classique

De plus, une analyse de réduction des gaz à effets de serre est effectuée en utilisant les résultats de potentiel de réchauffement global obtenus à l'aide de l'ACV. Ceci a pour but d'identifier la réduction de $CO_{2\ eq.}$ due à la modification des activités d'avant-plan (usine) et d'arrière-plan (production d'électricité et de combustibles) engendrée par l'implantation de la cogénération et l'augmentation de la capacité de production de pâte désencrée.

Les crédits de $CO_{2\ eq.}$ sont monétisés en utilisant un intervalle de prix proposé et ce nouvel élément économique est ajouté à l'analyse économique afin d'en évaluer l'impact sur la faisabilité des alternatives.

RÉSULTATS

Les options considérées dans cette étude sont les suivants:

Table 0.2 Sommaire des options considères

Option	Description
DIP 1	Augmentation à 550 ADMT/j par l'implantation de nouvelles installations, 1 boucle.
DIP 2	Augmentation à 550 ADMT/j par l'implantation de nouvelles installations, 2 boucles.
DIP 3	Augmentation à 1100 ADMT/j par l'implantation de nouvelles installations, 1 boucle.
DIP 4	Augmentation à 1100 ADMT/j par l'implantation de nouvelles installations, 2 boucles.
DIP 5	boucle.
DIP 6	boucles.
Cogen 1	Une des chaudières à gaz naturel est convertie afin de pouvoir brûler des déchets de bois et les turbogénératrices sont maintenues en service.
Cogen 2	Une nouvelle chaudière à déchets de bois (Très Haute Pression) est installée. La moitié des chaudières existantes sont converties pour des opérations à THP. De nouvelles turbogénératrices sont ajoutées.
Cogen 3	Un nouveau condenseur à air et une nouvelle turbogénératrice sont ajoutés.

L'analyse technico-économique a permit d'identifier 4 options rentables (18 avaient été originalement proposées) qui ont été évaluées à l'aide de l'outil proposé. Les options rentables sont :

Table 0.3 Sommaire des options rentables

Option	VAN MM$ CDN	TRI %
DIP 3 – Cogen 1	39.0	3.34
DIP 5 – Cogen 1	22.6	2.78
DIP 1 – Cogen 1	14.2	1.56
DIP 3 – Cogen 2	4.3	0.29

L'ÉIE a permis de démontrer que les 4 options faisables rencontraient toutes les normes environnementales considérées dans cette étude. Cependant, toutes les options ont montré une augmentation marginale du taux d'émission à l'environnement récepteur. Les alternatives reliées à la pâte désencrée ont eu un impact positif sur l'émission de contaminants à l'effluent (DBO) parce que la production de pâte désencrée produit moins de DBO que le procédé de PTM et celle-ci est plus biodégradable. La DBO était la principale émission de l'usine de référence. L'augmentation de la combustion de biomasse dans la chaudière a résulté en une augmentation maximale de 37% des cendres générées.

Les résultats d'ACV suggèrent que les alternatives visant à remplacer totalement la PTM par de la pâte désencrée en combinaison avec l'implantation de la cogénération génèrent le plus de bénéfices environnementaux d'une perspective produit et ce, pour la majorité des catégories d'impacts quelles soient globales, régionales ou locales. L'acidification, la formation de smog photochimique et la catégorie « santé humaine – particules » font exception. Fondamentalement, ce bénéfice est attribuable à la réduction de la consommation d'électricité par rapport au cas de référence et à la quantité d'électricité cogénérée. Le scénario *DIP 3 – Cogen 1* réduit le potentiel de réchauffement planétaire de 63%, le potentiel d'acidification de 36%, le potentiel d'eutrophisation de 24% et toutes les catégories reliées à la santé humaine en générale. Ce même scénario cause, par contre, une augmentation de 35% du potentiel de destruction de la couche d'ozone car la production de pâte désencrée requière l'utilisation de plus de produits chimiques que la production de PTM. Aussi, cette alternative résulte l'augmentation de 3% du potentiel de formation de smog photochimique car les installations de cogénération consomment plus de biomasse et produisent plus de NO_x, CO et émissions autres que le méthane dû en une baisse de l'efficacité de la combustion et un plus grand entreposage de déchets de bois et de boues.

En résumé, les alternatives proposées devraient augmenter de façon marginale les émissions atmosphérique dans l'environnement récepteur, mais résulter en des avantages environnementaux significatifs lors qu'évaluées en optant pour une approche « produit ». De plus, le remplacement de la PTM par de la pâte désencrée réduira de façon significative la consommation énergétique de l'usine car la raffineurs de PTM sont responsables d'environ 70% de la consommation actuelle de l'usine.

Les experts du panel ont attribué une importance supérieure aux critères génériques au site (ACV). Une discussion avec ceux-ci a permis d'expliquer ce résultat par la conformité des alternatives aux normes relatives aux critères d'émissions spécifiques diminuant ainsi l'importance de ceux-ci pour la prise de décision.

La performance environnementale globale a été calculée en utilisant l'indice environnemental unique pour chacune des alternatives. Cet indice a montré des résultats très semblables pour toutes les alternatives. Le scénarios *DIP 3-Cogen 1* a montré la meilleure performance, suivi de près par les scénarios *DIP 3 – Cogen 2* et *DIP 5- Cogen 1.* Le scénarios *DIP 3 – Cogen 1* a toutefois surclassé significativement les autres alternatives du point de vue économique, suggérant ainsi que cette option (100% pâte désencrée, 40 MW d'électricité cogénérée) doivent être retenue pour une étude d'ingénierie détaillée.

Le scénario *DIP 3 – Cogen 1* permet une des plus importante réduction de $CO_{2\ eq.}$ (63% ou 272 000 tonnes $CO_{2\ eq.}$/année) lors que comparé au cas de référence. En attribuant une valeur monétaire de 50$/tonne aux crédits de $CO_{2\ eq.}$ (émissions d'avant-plan et d'arrière-plan), la VAN du projet est améliorées de 13M$. Cependant, en considérant seulement les émissions d'avant-plan, on obtiendrait peu de bénéfices (moins de 3M$). Ceci illustre l'importance de la façon dont les réductions de $CO_{2\ eq.}$ seront considérées dans un futur programme d'échange de crédits de $CO_{2\ eq.}$.

CONCLUSIONS

La méthodologie courante pour l'Evaluation des Impacts Environnementaux (ÉIE) de nouveaux projets possède certaines limitations. Elle met généralement l'accent sur l'identification des impacts environnementaux sur le milieu récepteur au niveau du site uniquement sans considérer la chaîne de produit. Dans ce projet de recherche, une méthodologie a été propose afin d'améliorée l'ÉIE de projets de modernisation majeurs par l'intégration de l'Analyse du Cycle de Vie (ACV). Les conclusions suivantes peuvent être tirées de l'application de chacune des étapes de cette méthodologie

- La méthodologie propose permet d'élargir la portée de l'analyse de projets industriels. Les résultats obtenus de l'application de l'outil propose montrent que la performance environnemental à l'échelle de l'usine est différente de celle à l'échelle de la chaîne de produit. De plus, d'importants bénéfices sont perçus tout au long de la chaîne de produit lors de l'implantation d'un ensemble d'alternatives rentables et techniquement faisables reliées à la cogénération et à l'augmentation de la production de pâte désencrée.
- Les critères environnementaux peuvent être efficacement combinés en un indice environnemental unique par l'application d'une méthodologie de prise de décision multicritère (procédé analytique hiérarchique). Cet indice peut être utilisé pour évaluer la performance environnementale de différentes alternatives lors du procédé de conception.
- En considérant le remplacement total de la PTM par de la pâte désencrée en combinaison avec l'installation d'équipements de cogénération, tant la

performance économique que la performance environnementale globale peuvent être améliorées.

- La performance économique et le potentiel de réduction de l'émission de gaz à effet de serre liés à l'augmentation de la production de pâte désencrée et à l'implantation de la cogénération sont dépendants du mélange d'énergie du réseau d'alimentation ainsi que du prix de l'électricité.
- Les économies de carbone peuvent affecter fortement la performance économique d'un projet. Les réduction à l'avant-plan et à l'arrière-plan doivent être considérées afin d'observer un impact positif important sur le retour sur l'investissement d'un projet.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABREVIATIONS

ADMT	Air Dried Metric Ton
AHP	Analytic Hierarchy Process
BOD	Biochemical Oxygen Demand
BDMT	Bone Dry Metric Ton
CI	Consistency Index
COD	Chemical Oxygen Demand
CR	Consistency Ratio
CWS	Canadian Wide Standards
DALY	Disability Adjust Lifetime Years
DIP	De-Inking Process
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EPDS	Environmental Profile Data Sheet
ETP	Effluent Treatment Plant
FMT	Finished Metric Ton
IRR	Internal Rate of Return
ISO	International Organization for Standardization
KWh	Kilo-Watt hour
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MCDA	Multi-Criteria Decision Analysis
MCDM	Multi-Criteria Decision Making
MMBTU	Million British Thermal Units
MWh	Mega-Watts hour
NOx	Nitrogen Oxides

NPV	Net Present Value
NRCAN	Natural Resources Canada
ONP	Old Newspaper
OME	Ontario Ministry of Environment
OMG	Old Magazines
PM	Paper Making
PM_{10}	Particulate Matter < 10 microns
$PM_{2.5}$	Particulate Matter < 2.5 microns
RI	Random Index
POI	Point Of Impingement
PPER	Pulp and Paper Effluent Regulations
ROI	Return On Investment
SETAC	Society of Environmental Toxicology and Chemistry
SG&A	Sales, General & Administration
SIC	Pulp and Paper sector experts
SO_2	Sulphur Oxide
TMP	Thermo-Mechanical Pulping
TRACI	Tool for the Reduction and Assessment of Chemical and other environmental Impacts
TSP	Total Suspended Particles
TSS	Total Suspended Solids
UNEP	United Nations Environmental Program
USEPA	US Environmental Protection Agency
VOC	Volatile Organic Compound

CHAPTER 1: PROBLEM INTRODUCTION

The Canadian pulp and paper industry is Canada's largest industrial employer. "In 1999 the industry generated over 1 million direct and indirect jobs across the country" *(FPAC 2005).* This suggests that while the industry has been in decline for the last several decades, it remains an important source of both trade and employment.

"Total capital spending by Canadian pulp and paper producers is approaching $3 billion annually, another economic boost, particularly for Canada's pulp and paper communities" *(FPAC 2005).* Several smaller pulp and paper mills have closed in the recent years due to the capital intensity of the pulp and paper sector (*Nilsson et al. 1996*). In Canada, a number of projects have been carried out to reduce energy and virgin fibre consumption in several newsprint mills in order to increase the competitiveness of those mills.

With the ratification of the Kyoto Protocol, Canada is obliged to reduce its $CO_{2\ eq.}$ emissions considerably; this will probably lead to new economic incentives for industry to reduce its $CO_{2\ eq.}$ emissions. In the Kyoto protocol context, Canadian Pulp and Paper sector has already reduced its $CO_{2\ eq.}$ emissions by 28% in comparison with 1990 levels *(Lynch 2005).* This suggests that the pulp and paper sector has been implementing a fairly high number of projects oriented to reduce energy consumption over the last 15 years.

"Energy consumption and energy reduction are widely discussed in the literature for mechanical pulp mills and de-inked pulp mills. One reason is that recycled pulp mills typically have only 25-27% of the gross energy consumption of thermo-mechanical pulp (TMP) mills" *(Dessareault 1999, p.147)*. Consequently, by increasing de-inked pulp production and implementing co-generation, several benefits can be achieved; the consumption of much less electricity per Finished Metric Ton (FMT) of newsprint, when it is based on recycled fibre rather than on virgin fibre as well as reduced amount of purchased electricity which can help mills become more cost-effective.

Market conditions play an important role in determining whether a project is economically viable or not. Current electricity prices are forecasted to rise in future years as a consequence of the increased cost of fossil fuels. At the same time, the decrease in recycled fibre quality is an important element to consider, as expensive technologies may be required to treat the recycled fibre, and this will have a significant impact on the economic competitiveness of those projects.

As part of the current regulatory framework, an Environmental Impact Assessment (EIA) is required for new industrial projects *(Environment Canada 2004)*. EIA focuses on the identification of possible environmental effects, proposing control and mitigation measures for those identified effects and to predict whether or not those effects will have a significant impact in the receiving environment even after the mitigation control has been implemented *(Canter 1998)*. Due to the site-specific nature of EIA, the scope and boundaries of this environmental assessment are restricted to assess the environmental impacts in the local receiving environment only. Another limitation of EIA is that it starts its environmental evaluation based on the most economically feasible option. It does not analyze other design alternatives that might not be as economically attractive but have a lower environmental impact.

Life Cycle Assessment (LCA) is a tool to assess the potential environmental impacts associated with a product or process during its complete lifecycle. Its potential applications include the identification of improvement opportunities, as well as a decision-making tool in strategic planning and product or process design *(ISO 1997, Miettinen et Hamalainen 1997, Bauman et Tillman 2004, Burgess et Brennan 2000).* LCA uses a "cradle to grave" approach meaning that all the environmental impacts are quantified from the extraction of the raw materials to the final disposal of the manufactured product. Sugiyama (2004) pointed out that environmentally benign processes with reduced end-of-pipe technologies can be realized by incorporating LCA as a function in the evaluation of a defined project.

In order to meet Canada's Kyoto commitment, it is likely that new policies and regulations will come into place and new tools are needed in order to assess Kyoto implications (i.e., $CO_{2\ eq.}$ emissions) of new industrial projects. These new tools require a broader set of environmental impact categories in order to quantify future valuable elements such as carbon savings. This specific analysis should be executed during the early stages of a process design in order to be able to incorporate monetized carbon savings in the overall economic evaluation of industrial projects.

CHAPTER 2: LITERATURE REVIEW

This chapter discusses several elements in the literature such as co-generation and De-Inking Process (DIP), Environmental Impact Assessment (EIA), Life Cycle Assessment (LCA), Multi-Criteria Decision Making (MCDM), carbon savings and environmental regulation for pulp and paper mills.

2.1. De-Inking Process (DIP)

The principal raw material consumed by the DIP process is wastepaper, which can be obtained from several sources such as Old Newspapers (ONP), Old Magazines (OMG), recycled cardboard, etc. Municipal recollection systems collect and select wastepaper based on its characteristics to finally be sold to costumers. Smook (1992) defines DIP as a cleaning process where the ink is removed from the pulp fibers obtained from wastepaper.

DIP process consumes different percentages of Old Newspaper (ONP) and Old Magazines (OMG) depending on its wastepaper furnish and quality. Conventionally, those percentages are 70% ONP and 30% OMG. Nowadays, one of the biggest challenges faced by the industry using recycled fiber is related to the decline in the quality of the wastepaper stream *(Cody 2003).* Figure 2.1 shows a marked decrease in recycled fiber quality during the last 10 years, as measured by percentage of real newsprint that comprises old newspaper (ONP) *(Cody 2003).* In addition, the level of non fibrous contaminants and the amount of unbleached fiber and office waste fiber present in ONP secondary fiber has increased significantly in the past five years *(Cody 2003).*

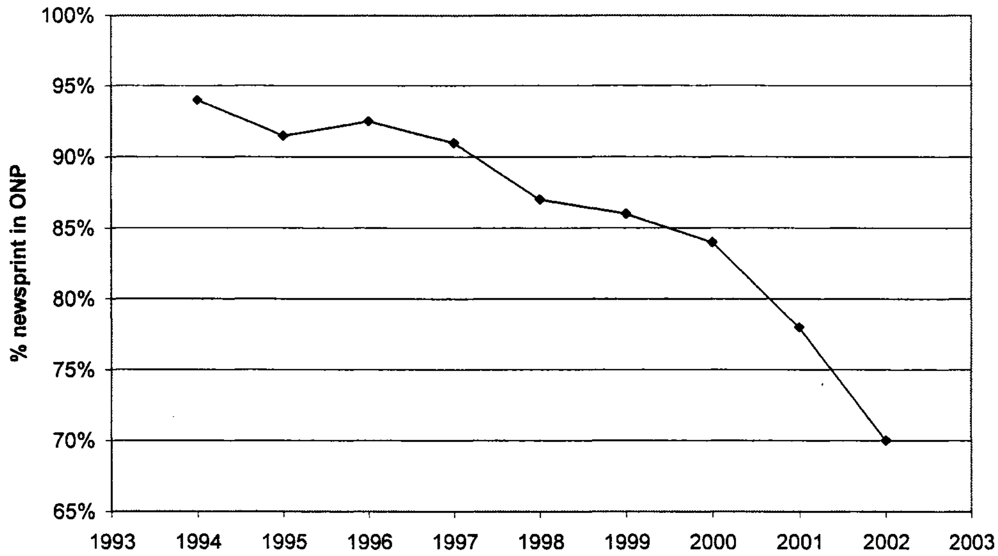


Figure 2.1 Decline in ONP quality due to other papers and contaminants

Wastepaper is widely used in industry having several applications in different sectors such as pulp and paper, construction, etc. The global consumption of wastepaper increased approximately 6% annually between 1980 and 1996 *(Gottsching et Pakarinen 2000)*. In 1997, the world paper production based on wastepaper was of 42% *(Gottsching et Pakarinen 2000)*. This suggests that recycled fibers are playing an important role in the pulp and paper industry because they represent a substitute for virgin fibers. Figure 2.2 shows global usage values in 1997 *(Gottsching et Pakarinen 2000):*

World – Paper production 300 MT

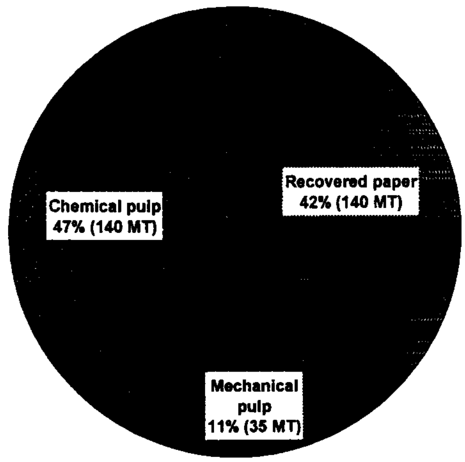


Figure 2.2 Fiber material consumption for paper and board production in the world for 1997 (MT, Million tons) (Gottsching and Pakarinen, 2000)

In North America, newsprint producers are the most important consumers of Old Newspaper (ONP), raking first with 33.8% of the total ONP consumption in 2003 *(American Forest & Paper Association 2003)*. At the same time, statistics show that Canada has spent \$1.7 billion to increase the production of recycled content products from different types of recovered paper *(Dessureault 1999)*. This suggests that recycled fibers are having an increased demand in the Canadian and in general, the North American market.

DIP process can be configured as either a 1-loop or a 2-loop system. The yield of a 1-loop system is in the range of 87 –92%, whereas the 2-loop system operates with a yield of 80 – 85%, depending on the characteristics of the recycled paper *(Cody 2003, Emery 2002, and Gottsching et Pakarinen 2000)*. Furthermore, the 2-loop system produces a higher quality product, and/or has the additional benefit of being able to process a wastepaper stream of lower quality. Depending on the availability and quality of raw materials and/or the customer specifications (e.g., quality, printing characteristics), either of these systems may be selected. Conventionally, the 1-loop system is prevalent in North America due to its lower capital expenditure, and the 2-loop system is more common in Europe and the Orient. However, the decline in wastepaper quality could suggest a possible future consideration of different technologies to treat the recycled fiber, such as the two-loop flotation system, which is more expensive than the technologies prevalent in North America.

The economic implications related to implementation of a DIP process are linked to the availability of wastepaper and the cost of transportation. At the same time, implementation of a DIP process in an integrated newsprint mill can have technical issues as well. An example is the possible increase of stickies in the treated pulp that is fed to the paper machines, this in turn can causes an elevated number of breaks affecting the runnability and thereby causing a negative economic impact.

2.2. Co-generation systems

In the pulp and paper industry, co-generation technologies are based on steam systems. Boilers produce steam by burning several types of fuels such as fossil or woodwaste. Then, the generated steam is sent into a steam turbine in order to generate electricity, the steam loses pressure and temperature when it goes through the turbine and the released energy is converted into the mechanical rotation energy of the turbine. The shaft of the turbine is connected to a generator where the mechanical rotation is finally converted into electricity. Steam is taken for heating purposes from the extraction turbine or turbine exhaust to various consumer points in the process *(Prasad 1994).* In integrated newsprint mills, the back pressure or the multi-extraction condensing turbine are commonly used *(Gullichsen et Fogelholm 1999)*

The Pulp and Paper industry commonly uses hog fuel for steam production, which is a biomass by-product of sawmill operations *(Gullichsen et Fogelholm 1999).* In addition, there is a potential to use sludge produced in the process as a fuel. Some of the most important benefits of sludge combustion include recovery of energy from the waste material to produce steam for mills and the reduction in landfill requirements and related costs *(Scott et Smith 1995).* In Canada, more than 55% of the industry's energy requirements are derived from biomass-based fuels, and the energy intensity is declining as a result of efficiency improvements *(Canadian's National Climate Change Process 2002).*

At the same time, sector experts have identified that increased co-generated electricity production is a means of achieving a national reduction of energy used for electricity production *(NRCAN 1999).* Also, replacing fossil fuels by biomass-based fuels (biofuels), which are an accepted form of renewable energy, will help reduce global

Currently, there is a debate related to the use of biomass and its importance in the energy market due to its neutral effects on global warming. However, economic implications of co-generation systems using biomass are related to its availability, the cost of its transportation and prices per MWh supplied by the grid. Electricity prices are expected to rise due to several factors such as the global fuel market situation, available energy reserves, etc (*Triki et al. 2005).* This expected raise of electricity prices could improve the economic performance of projects related to co-generation using biomass making them more competitive even if the source of biomass is far from the facility. For integrated newsprint mills, steam turbines and combustion turbines are commonly used to co-generate electricity.

2.3. The design process and the techno-economic analysis methodology

The development of process design involves many different steps. Peters and Timmerhaus (1980) mentioned the following classifications, depending on the accuracy and detail required:

Preliminary designs: This is a basic design analysis where all the calculations are kept at minimum and the time spend on details is marginal. This analysis shows whether further work should be done on the proposed project. It is based on approximations and rough cost estimates.

Detailed-estimated designs: This design contains detailed calculations and analyses in order to analyze the profit potential of the design. However, exact specifications are not given for the equipment, and the drafting-room work is minimized.

Firm process designs or detail designs: During this final step, complete specifications are presented for the designed plant; accurate costs are quoted and obtained with high preciseness.

There can be numerous estimates that may vary in their level of accuracy based on the stage of development of the project. Peters and Timmerhaus (1980) propose five categories related to the accuracy range and designation normally used for design purposes, after completing the first two design steps, the accuracy is estimated to be ± 10%. The total investment for any process consists of fixed capital investments and working capital.

Fixed capital investment

Fixed capital investment in manufacturing facilities is the capital needed to install process equipments with auxiliaries (i.e., piping, instruments, etc) in order to complete the process. The non-manufacturing fixed capital investment is the capital required for construction overhead (i.e., home office expenses, engineering expenses, etc) and for all plant components (i.e., land, buildings, warehouse, etc) that are not directly related to the designed process operation. *(Peters et Timerhaus 1980).*

Working capital

"Working capital is the amount of money used in (1) raw materials and supplies carried in stock, usually 1-month supply of raw materials, (2) finished products in stock and semi finished products in the process of being manufactured, (3) accounts receivable, (4) salaries, wages and raw material purchases, (5) accounts payable, and (6) taxes payable" *(Peters et Timerhaus 1980, p.155).*

Investment performance indicators for new projects

Conventionally, financial indicators are used to measure the economic feasibility of a new industrial project. The most commonly used is Net Present Value (NPV) (see formula 1) and Internal Rate of Return (IRR). The NPV can be expressed as:

$$NPV = -I_0 + \sum_{n=1}^{L} CF_n \left(\frac{1}{1+i} \right)^n \qquad (1)$$

Where: I_0 = initial investment;

CFn = cash flow in year n;

i = interest rate;

L = plant life.

One of the main disadvantages of using NPV in project's economic analysis is that it does not account for flexibility and/or uncertainty of project's economic performance in the future *(Value Based Management 2005).* The IRR often used as complement to the NPV, because it allows finding the real rate of return of the project. The IRR consists of determining the rate of return of the net cash flows that gives a net present value of zero. In other words, it is the rate where the present value of the net cash flows is equal to the present value of the investment *(Value Based Management 2005).*

2.4. Environmental Impact Assessment (EIA)

An EIA is an environmental methodology required by the federal government to ensure that the adverse environmental effects of proposed industrial projects or activities are identified and mitigated where possible. Ideally, the assessment of environmental effects and provision for mitigation measures is an integral part of the project planning process. *(Environment Canada 2004).* Figure 2.3 shows the methodology used in Environmental Impact Assessments (EIAs).

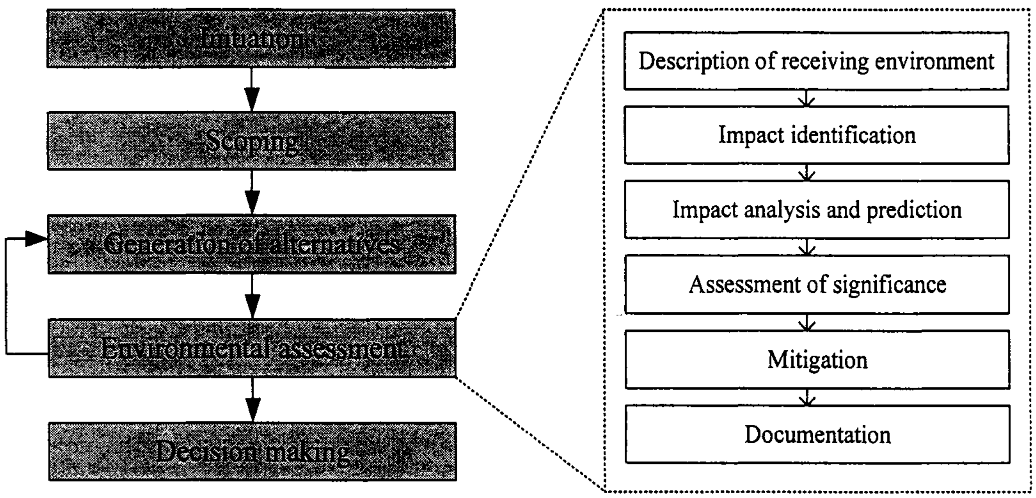


Figure 2.3 EIA methodology (Canter 1998)

During the Initiation phase, the level of EIA is defined along with the EIA team and their responsibilities. Scoping is defined as an iterative process between an interested public, government agencies and project proponents to determine the important issues and alternatives that should be examined during the EIA *(Andre et al 1999)*. During the Scoping, the following elements have to be addressed: (1) Description of the purpose and need for the proposed activity, (2) Description of the proposed activity,

(3) Identification of the potentially affected geographic area, (4) Description of the important characteristics of the area, (5) Review of the initial alternatives and (6) Discussion of known project related issues *(Canter 1998, USEPA 1993).*

The description of alternatives in an EIA process facilitates side-by-side comparisons in terms of environmental and economic risk and benefits (*USEPA 1993)*. Once project alternatives have been selected, the EIA process starts by defining the characteristics of the receiving environment or the area where the project will be erected and installed.

During the Impact Identification phase, many choices must be made, including the choice of impacts that should be assessed and the level of analysis that is required. The nature of the impacts, in addition to the magnitude, likelihood, temporal and spatial distribution of potential impacts from the proposed activity, must be determined and must be provided to the EIA team by the proponent or the owner of the project *(Andre et al 1999)*. All this information is identified using several well-established techniques in parallel with benchmarking data and professional experience. To analyse and predict environmental impacts, there are several methods that range from relatively simple matrices to sophisticated computer models involving dispersion models *(Canter 1998)*. Once the environmental impact assessment and prediction is finished, mitigation measures are proposed to achieve better environmental performances by the proposed project.

After all these different stages, an Environmental Impact Statement (EIS) is written and presented as the final document of this evaluation, including conclusions and recommendations *(US Environmental Protection Agency 2005)*. The final stage of this complex process is the decision making, which is based on the results of the EIS and several other elements such as social concerns, etc.

Benefits and Limits of EIA

Environmental Impact Assessment (EIA) is the main methodology that can identify possible environmental effects in the receiving environment caused by new industrial projects and to propose mitigation measures for the identified effects. Its focus is to minimize or avoid these effects to ensure environmental compliance and good local (site-specific) environmental performances *(Environment Canada 2004)*.

The Rio Declaration (United Nations 1992) calls for Environmental Impact Assessment (EIA) to be carried out for activities or projects that are likely to have a significant negative impact on the environment. However, an activity can represent adverse impacts at both receiving environment and product-chain level. The scope and boundaries of EIA are focused on the receiving environment by assessing direct impacts due to pollutant discharges and other emissions released by projects. EIA does not consider the impacts of projects at the product-chain level and their global environmental implications.

Several authors have pointed out limitations of EIA. Tukker (1998) highlighted the necessity to include broader tools such as Life Cycle Assessment (LCA) into Environmental Impact Assessment (EIA) in order to address several elements such as goal and policies, process alternatives, abatement alternatives used in new industrial projects and location alternatives. However, no methodology was proposed. At the same time, one of the main remarks from a case study of 55 Environmental Impact Statements (EIS's) in Sweden was that the EIA process presented a few signs of functioning as a tool to promote sustainable development. *(Bruhn-Tysk et Eklund 2002).* Steinneman (2001) highlighted that global effects and the management of natural resources, which may affect future generations, are not considered either. Additionally, the costs related to carry out an EIA are usually very high because several different fields of expertise are needed. At the same time, the collection of data, the impact modeling and the final analysis of results for the study are time demanding.

2.5. Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) is a broad tool used to analyze and assess the environmental impacts of a product, process or activity using a cradle-to-grave approach, which accounts for different global, regional and local environmental impacts from the extraction and processing of raw materials, manufacturing, transportation, distribution, use and final disposal *(Seppala et Hammalainen 2001,* *Baumann et Tillman 2004, Hertwich et Hammitt, 2001, Burgess et Brennan 2001, Norris 2001, Salazar 2004, Tukker 1998, Udo de Haes et al 2002).*

General Methodology

Based on ISO guidelines *(ISO 1997*), the LCA methodology has 4 main steps; (1) Goal and scope definition, (2) Inventory analysis (LCI), (3) Impact assessment (LCIA) and (4) Interpretation. Figure 2.4 shows the general LCA phases *(ISO 1997).*

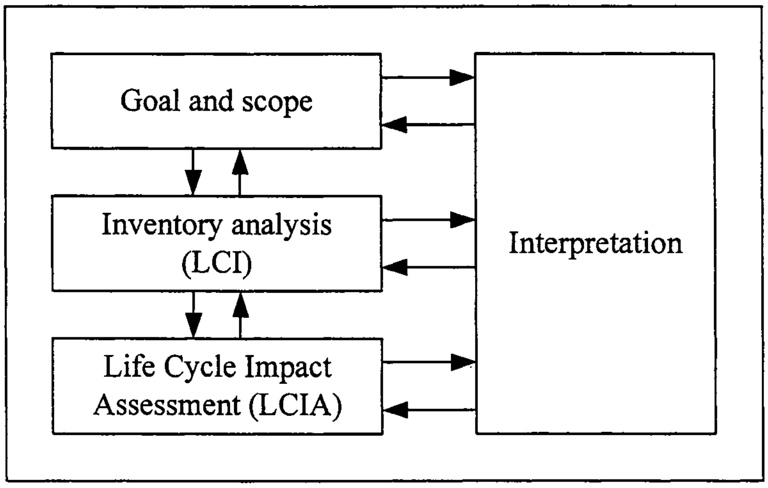


Figure 2.4 Phases of LCA according to ISO 14040

<u>Goal and Scope Definition</u>

In this first step, the scope of the study and the functional unit are defined. At the same time, the intended application is established, as well as the procedures for data collection and data quality.

The functional unit is a measure of the system function, and its primary purpose is to establish a reference to relate input and output data. In comparative process analysis, the same functional unit should be considered to be consistent in the final comparison.

ISO recommends including all life cycle stages of a product and the processes included from the resource extraction (cradle) to the product disposal (grave). During the goal and scope definition, the processes to be modeled and their level of detail are defined. ISO also recommends excluding those processes or data that will not significantly change the general conclusions of the study *(Baumann et Tillman 2004, ISO 1999).*

Miettinen (1998) pointed out that goal and scoping is a subjective step that should be guided by the preferences of the real decision makers and the information requirements related to the application.

Life Cycle Inventory Analysis (LCI)

The LCI is focused on gathering information according to the requirements of the goal and scope definition. The collected data covers all the activities considered in the system boundaries. Data collection in the product system is related to the inputs and outputs considered in the model, which includes raw materials, products, air emissions, water emissions and solid wastes. Finally, the calculation is related to the functional unit.

Data considered in LCA has a primary and secondary nature. Primary data is obtained and recollected from primary data sources from the process (i.e. PI systems, reports, etc). Secondary data is related to data obtained from indirect sources such as commercial databases.

Allocation is used when processes produce more than one product. ISO recommends avoidance of allocation, when possible, in order to maintain the inventory straightforward and much simpler *(ISO 1999)*. This work does not cover allocation rules since this project did not deal with this specific problem.

Life Cycle Impact Assessment (LCIA)

"LCIA aims to describe, or at least to indicate, the impacts of the environmental loads quantified in the inventory analysis. The purpose of the LCIA is thus to turn the inventory results into more environmentally relevant information, i.e., information on impacts on the environment rather than just information on emissions and resource use" *(Baumann et Tillman 2004, p.29)*. According to ISO, LCIA consists of mandatory and optional elements as described in Figure 2.5 *(ISO 2001a)*.

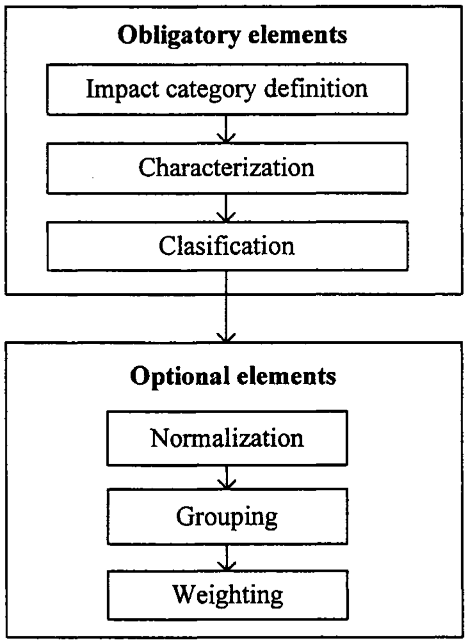


Figure 2.5 Elements of LCIA phase according to ISO 14042(Baumann, 2004)

A LCA related model has been created by the US Environmental Protection Agency called: Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI) *(Bare et al. 2003, Norris 2003)*. This is a stand–alone computer program that can assess environmental impacts related to global warming, ozone depletion, acidification, eutrophication, photo-oxidant formation, human health particles, human health cancer, human health non cancer and eco-toxicity. This model was developed for the United States of America *(Bare et al. 2003).*

The characterization models used for the global impacts are the ones proposed by the International Panel on Climate Change (IPCC) for calculating Global Warming and the World Meteorological Organization for calculation Ozone Depletion *(Bare et al.*

2003). TRACI estimates Acidification (i.e., increasing acidity) for both water and soils by measuring hydrogen Ion Concentration (H^+). For Eutrophication, TRACI uses a category indicator based on nutrient factor, including different nutrients (i.e., nitrogen and phosphorus) and others such as Biological Oxygen Demand (BOD), etc. TRACI estimates photo-oxidant formation by using oxide nitrogen equivalent *(Bare et al. 2003, Norris 2003).* Udo de Haes (1999) called "problem approach" impacts to these mid-point impact categories. Table 2.1 shows impact category indicators and their characterization factors:

Table 2.1 Life Cycle impact categories considered for the analysis

Impact Categories	**Scale**	**Category Indicators**	**Characterization Models**
Global Warming	Global	g CO_{2eq}	IPCC
Ozone depletion		g $CFC11_{eq}$	WMO
Acidification	Regional	mol $H+_{eq}$	TRACI – Location
Eutrophication		g N_{eq}	TRACI – Location
Photo-oxidant formation		g NO_{xeq}/m	TRACI – Location
Eco-toxicity	Local	g $2,4D_{eq}$	TRACI – USA
Human health-cancer		g C_6H_{6eq}	TRACI – USA
Human health-non cancer		g C_7H_{7eq}	TRACI – USA
Human health criteria pollutants		DALY	TRACI – Location

The most important advantage that TRACI presents is the fact that geographical location can be chose for regional impacts (i.e., US east or wet of the Mississippi, etc).

This is also the case for Human Health particles (or Human Health Criteria Pollutants) *(Norris 2003).*

Interpretation

Interpretation is the final stage of an LCA study. It is the process of assessing results in order to draw conclusions and recommendations. Limitations of the study should be included in this final step.

Benefits and Limits of LCA Methodology

LCA is a tool that covers broad environmental impacts at the global, regional and local level. Finnveden (2000) highlighted the fact that LCA is the only tool that can be used for comparisons of products and processes using a cradle-to-grave approach, due to its large scope and its use of broad indicators. This suggests that LCA could represent a valuable tool in combination with other environmental tools with a more limited scope.

LCA uses site-generic environmental models, which means that in order to model the potential environmental impacts, generic meteorological and geographical conditions are considered. In a single a study this site-generic characteristic could represent a limitation since the results will not be absolute for a single alternative. However for a comparative study the site-generic characteristic represents a benefit since it allows to model cradle-to-grave systems with a fairly easy and non-time demanding methodology. This will enable choosing the more environmentally preferred process alternative. Also, spatial and temporal limitations of LCA can be linked to its site-generic characteristic *(Owens 1999)*. The tool that can be used to analyze single design alternatives, is EIA. However, its scope only considers the facility and receiving environment and not the entire life cycle of the product.

LCA has limitations related to the availability of data to model cradle-to-grave systems. Since commercial databases do not include all the chemicals, fuels or materials consumed across the product chain of a product, sensitivity analysis should be performed in order to set conclusions on whether or not, these substances would have an effect on the results. Another limitation is related to data quality and the procedures used to assess the quality (i.e., quality indicators, etc).

LCA in the Pulp and Paper industry

Life Cycle Assessment has been applied in the pulp and paper industry and for integrated newsprint mills; specific LCA applications have been published. Salazar (2004) highlighted that LCA can identify improvement opportunities in order to achieve better environmental performances at the facility and product-chain level. Also, a better environmental communication with the stakeholders can be accomplished.

Pineda-Henson (2001) refers to LCA as a tool that offers a comprehensive and systematic framework within which different stages of the pulp and paper manufacturing process can be examined by analyzing their global, regional and local environmental performance. Analytical Hierarchy Process (AHP) and LCA are used in this methodology, which has been proven useful for decision analysis on the environmental performance of pulp and paper manufacturing; this may likewise be applied to other manufacturing sectors. At the same time, Gauldreault (2005) presented a survey related to the application of LCA in the pulp and paper sector suggesting that applications oriented to process analysis and comparisons have increased in the past years, which suggest that the pulp and paper sector is increasingly motivated to implement "Life Cycle Thinking" into their environmental policies and planning.

2.6. Greenhouse Gas Mitigation (GHGM) in the pulp and paper industry

In this section, a generic approach related to the role of the pulp and paper industry in the CO_2 balance is discussed. Also discussed are the implications of the Kyoto Protocol in the Canadian pulp and paper industry.

Paper recycling and CO_2 balance

Gottsching and Pakarinen (2000) highlighted that the pulp and paper sector plays an important role in the strategy to reduce global warming since products from the pulp and paper sector consist primarily of wood, which is a renewable resource.

One of the current initiatives in the pulp and paper industry is to reduce carbon consumption (i.e., wood chips) by increased use of recycled fibre in order to produce a higher quantity of recycled products such as newsprint based on recycled fiber. By increased recycling of wastepaper, landfilling can be partially avoided and as a consequence, the reduction of greenhouse gas emissions such as methane (CH_4) coming from these type of installations can be achieved.

Implications of the Kyoto Protocol

Nelson and Vertinsky (2003) stated that the Kyoto Protocol will mainly affect the Canadian pulp and paper sector in two ways. First, the forest resources on which it relies play an important role in the global carbon cycle, and secondly, the production of forest products is an energy-intensive activity. The forest product sector can make a contribution to the Climate change mitigation objectives, which are related to reduce Greenhouse Gas (GHG) emissions and increasing carbon sequestration *(Nelson et Vertinsky 2003, Canada Climate Change 2005, Browne 2003).*

"Canada's efforts to meet its climate change commitments in 2008-2012 and beyond will require changes in how energy is used and how forest carbon is managed. While the Kyoto Protocol establishes a policy framework and mechanisms by which countries can seek to mitigate GHG, the Protocol leaves some key issues to be addressed" *(Nelson et Vertinsky 2003, p.4).*

There is uncertainty about the potential impact the Kyoto Protocol may have on the Canadian pulp and paper sector, uncertainties that are related to a future carbon trading system *(Nelson et Vertinsky 2003).* In Europe, a carbon trading system has already been implemented and it has more than 10,000 installations involved and it is estimated conservatively that, by 2010, the EU scheme will trade as much as $1 billion in allowances each year *(Johnson et Heinen 2005).*

With the Kyoto Protocol, the Canadian pulp and paper sector is currently promoting energy efficiency and increased used of biomass based energy sources in order to respond to the future challenges related to this international agreement. Since the pulp and paper industry is energy-intensive and energy costs typically comprise an important percentage of the total production costs, energy projects such as fuel savings or fuel switching technologies, that is, switching from more GHG-intensive fuels to less GHG-intensive and even CO_2 neutral fuels (biomass based) could represent a measure to achieve cost reduction *(Nelson et Vertinsky 2003)*. However, the ability to switch fuels is dependent, among other things, on the availability of alternative fuel supplies.

According to the Kyoto Protocol, Canada has to reduce its $CO_{2\ eq.}$ emissions to 6% below the 1990 levels *(Canada Climate Change, 2005, Lynch 2005, Grant 1999).* At this moment, the Canadian Pulp and Paper sector has already reduced its $CO_{2\ eq.}$ emissions by 28% in comparison with 1990 levels which suggests that the pulp and paper sector has been implementing in a fairly high number projects oriented to reduce energy consumption by improving energy efficiency in their mills over the last 15 years. *(Lynch 2005)*

In the pulp and paper industry, increasing use of biomass to produce energy and implementing de-inking processes represent an excellent opportunity to reduce electricity and fossil fuels consumption at integrated newsprint mills. Theses reductions can be estimated as carbon savings, which can be monetized in a future trading market.

2.7. Multi-criteria Decision Analysis (MCDA)

MCDA approaches have as principal aim to help decision makers organize and synthesize information in a way that leads them to feel comfortable and confident about making a decision *(Belton et Steward 2002, Seppala 2003, Seppala et al. 2002)*

Belton and Steward (2002) group these into three key phases: problem identification and structuring, model building and the development of action plans. Figure 2.6 shows the process of MCDM:

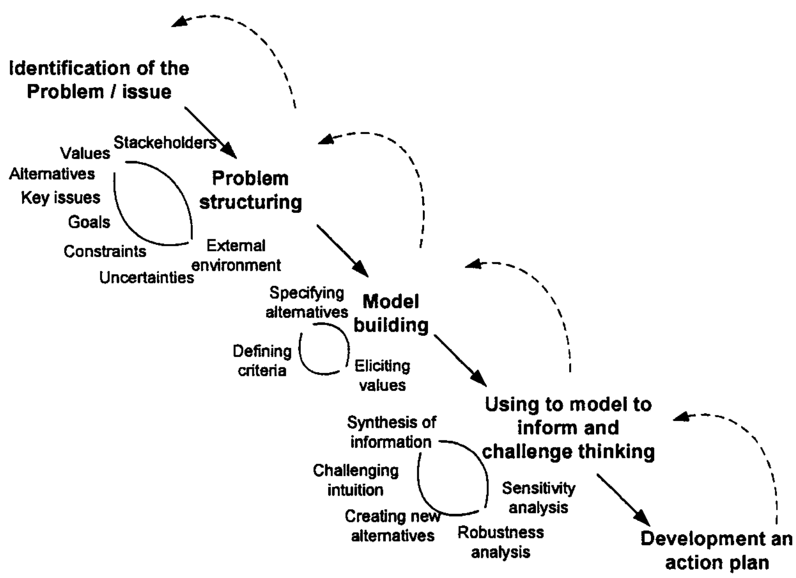


Figure 2.6 The process of MCDM (Belton et Steward 2002)

In EIA, Canter (1998) highlighted that there is no universal decision-focused methodology for meeting the EIA needs for all project types in all environmental settings. Weighting–scaling (ranking) checklists can be used in comparisons and evaluations *(Canter 1998)*. Scaling refers to the assignment of algebraic scales or letter scales to the impact of each alternative being evaluated on each identified environmental factor *(Canter 1998)*. Also, ranking checklists are used to rank alternatives from best to worst in terms of their potential impacts on identified environmental factors *(Canter 1998)*. These types of checklists are useful for comparative evaluations of alternatives since they provide a basis for selection of the preferred alternative (*USEPA 1993, Canter 1998)*).

In LCA, numerous decision analysis methodologies are used (*Finnveden 2000)*. Seppala (2003) stated that there is a need for decision making tools to evaluate different environmental configurations of products and services. In LCA, Multi-Criteria Decision Making Methods are divided in Multi-Attribute Decision Analysis (MADA) methods and Multiple Objective Optimization (MOO) methods (*Seppala 2003*). "Multi Attribute Decision Analysis (MADA) methods have been developed for the sorting or ranking of a finite set of alternatives in decision making situations with multiple objectives, whereas Multiple Objective Optimization (MOO) assists in the synthesis of a preferred solution when the potential solution set is described by continuous variables (or a mix of discrete and continuous variables)" (*Seppala 2003, p.9*). Multi-Attribute Utility Theory (MAUT), the Analytical Hierarchy Process (AHP), and outranking methods are the most popular polular MADA methods *(Seppala 2003).*

Analytical hierarchy process (AHP)

The AHP model is based on the theory of Saaty (1980). AHP is one of the simplest MCDM models in decision making because of its simple mathematics and the ease of which the results can be understood. Also, AHP contains a consistency index, which measures consistency on the pairwise comparisons used to weight criteria *(Saaty 1980).* Based on pairwise comparisons, this method is used in decision making related to environmental problems with successful applications in real case studies (*Ong at al. 2001, Huang et al. 2004, Pineda-Hensson et al. 2002, Wen et Shonnard. 2003*). AHP has become one of the most widely used valuation techniques for prioritizing factors, attributes, or alternatives, as evidenced by the significant number of applications published in books and journals (*Ong at al. 2001, Pineda-Hensson et al. 2002; Wen et al. 2003, Saaty, 1980, Eagan, 1999*). AHP can use different numerical scales to compare the criteria to be weighted (see Table 2.2)

Table 2.2 Analytic Hierarchy Process (AHP) valuation Scale (Saaty 1980)

Numerical Rating	**Definition**
1	Equally important or preferred
3	Moderately more important or preferred
5	Strongly more important or preferred
7	Very strongly more important or preferred
9	Extremely more important or preferred

A panel of experts or decision makers may be utilized in the application of AHP. Saaty (1980) recommends that the ratings from the experts may be accepted if the consistency ratio of the pairwise comparison matrix is less than or equal to 0.10 (i.e., 90% consistent or 10% inconsistent). Otherwise, it is recommended that the pairwise comparisons be revised to improve the consistency of these comparisons.

Weighting methods

There are several weighting methods to qualify environmental criteria; probably the most important methods to perform weighting are distance-to-target methods and panel methods *(Finnveden 2000, Udo de Haes et al. 2002).* Panel approaches are used to assign relative importance of damages, impact categories, or interventions (weighting factors) by using expert feedback and the panel can be derived from an individual or a group of people by elicitation. Elicitation is the process of gathering judgments concerning the problem through specially designed methods based on verbal and or written communication (*Udo de Haes et al. 2002, Bengtsson et Steen 2001, Ayyub 2001)*. Panel methods differ according the following aspects:

- Size of the panel and type of panelists: environmental experts, experts from other sciences, stakeholders, representative mix.
- Elicitation situation: questionnaires, interviews, interactive groups, and Delphi.
- Question format and the presentation of background information
- Answer modes: ranks, ratings, pairwise comparisons, ranges, etc.
- Type of aggregation : a consensus, use of mathematical methods

Several weighting methods relate the weighting factors to some sort of target *(Udo de Haes et al. 2002)*. These methods are called distance-to-target methods. Targets are commonly established by economic, politic, environmental and other series of interested parties giving to their definition a subjective base. Due to subjective nature of targets, distance-to-target methods have been criticized by LCA community because subjective targets would provide subjective weights.

2.8. Environmental regulations for the pulp and paper sector in Canada

On the federal level, pulp and paper mills are subject to the general pollution control provisions and the effluent regulations of the Fisheries Act. In addition, each of the provinces has its own environmental legislation. For air pollution control, the provinces have almost exclusive responsibility and authority. Since the mill in question is situated in Ontario, the air and water regulation for Ontario will be discussed.

Water regulations

The Pulp and Paper Effluent Regulations (PPER) under the Fisheries Act set discharge limits for TSS and BOD and prohibit the discharge of effluent that is acutely lethal to rainbow trout. PPER includes as well a requirement for an Environmental Effects Monitoring (EEM) program in order to demonstrate whether or not the major improvements in wastewater treatment processes can be associated with similar improvements in the receiving environment. *(Environment Canada 2003).*

Air regulations

Two main requirements for the province of Ontario can be distinguished (1) Ambient Air Quality (AAQ) and (2) Point Of Impingement (POI)

Current guidelines in Ontario for air emissions are given by the POI which is defined as "any point on the ground or on a receptor, such as nearby buildings or a local area outside the company's property at which the highest concentration of a contaminant caused by the aggregate emission of that contaminant from a facility is expected to occur" *(Ontario Ministry of Environment OME).* Table 2.3 gives POI criteria for several air contaminants established by the Ontario government.

Table 2.3 POI criteria (Ontario Ministry of the Environment, OME)

Contaminant	**POI Ontario (μg/m^3)**
H_2S	30
TSP	100
NO_x	500
SO_2	830
CO	6000

The following Table 2.4 gives an overview of all air quality standards for the Province of Ontario:

Table 2.4 Air quality criteria

Contaminant	**Air quality Ontario ($\mu g/m^3$)**
H_2S	
1 hour	6
SO_2	
1 hour	690
24 hour	275
Annually	55
NO_x	
1 hour	400
24 hour	200
Annually	100
CO	
1 Hour	36200
8 Hour	15700
TSP	
24 Hour	120
Annually	60

Also, Canada-wide Standards (CWS) for Particulate Matter (PM) and Ground-level Ozone have been defined by the Canadian Government. These standards set limits for PM less than 2.5 microns ($PM_{2.5}$) and ozone to be obtained by the year 2010. These standards are as follows (Table 2.5).

Table 2.5 Canadian-Wide Standards (CWS)

Contaminant	**Averaging time**	**Limit**
Ozone (Achievement to be based on the 4th highest measurement annually, averaged over 3 consecutive years)	8 hours	65 ppb
$PM_{2.5}$ (Achievement to be based on the 98th percentile ambient measurement annually, averaged over 3 consecutive years)	24 hours	30 μg/m^3

2.9. Synthesis of literature review

The pulp and paper sector, being one of the most capital intensive of the manufacturing industry, is important in the Canadian context since it represents an important source of employment and trade. The capital intensity can be attributed to various capital investment projects to upgrade current facilities (Brownfield projects) and at the same time, invested capital to build Greenfield projects. There are many motivations for continuously improving the sector's environmental performance such as more stringent regulations and the Kyoto Protocol.

The environmental regulatory framework obliges mills and/or companies to perform an Environmental Impact Assessment (EIA) to assess future environmental performance and impacts of new industrial projects at the site-specific level (*Environment Canada 2004)*. However, several authors have pointed out some limitations of the EIA, limitations due to its site-specific nature, EIA does not assess broader environmental impacts and global effects caused by new projects.

Life Cycle Assessment (LCA) is a tool to assess broader environmental impacts associated with a product or process using a cradle-to-grave approach. Four main stages are presented in LCA studies: goal and scope definition, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA) and finally, an interpretation of the results.

Several differences between LCA and EIA have been found. However, the most important ones are the following:

- LCA is not required by law, whereas EIA is mandatory by the Country Environmental Assessment Act and regulatory framework, depending on the technological characteristics of the project.
- LCA uses site-generic models, which means that the models consider a generic receiving environment to translate the system data inventory into final impact categories. Whereas, EIA uses site-specific models to predict future environmental impacts, taking into account specific characteristics of the receiving environment such as geography and meteorological conditions.
- LCA takes into account a broader scope and system boundary than EIA, including external unit processes such as electricity production, chemical production, etc.

Multi-Criteria Decision Making (MCDM) methods are currently used in combination with Life Cycle Assessment (LCA) and Environmental Impact Assessment (EIA). From all the MCDM tools, Analytic Hierarchy Process (AHP) has been widely used in decision making problems related to environmental issues, with successful applications in real case studies *(Ong at al. 2001, Pineda-Hensson et al. 2002; Wen et al. 2003, Saaty, 1980, Eagan, 1999*). Specific applications on the Pulp and Paper industry have been reported by Pineda-Hensson (2002) where AHP was used as a decision making tool to for new industrial project modifications.

The Kyoto Protocol will potentially have an effect on the pulp and paper sector since it most likely will lead to future economic incentives for mills and corporations to implement new projects related to energy efficiency. These incentives are related to elements such as carbon credits. There is still uncertainty related to the implementation of a future carbon trading system in Canada. However, Europe has already implemented such a system, which could serve as a base to help in planning for the future Canadian trading system.

Several elements related to technical, environmental and economic considerations of increasing de-inked pulp (DIP) production and the implementation co-generation have been discussed. At the same time, methodological elements related to Life Cycle Assessment (LCA), Environmental Impact Assessment (EIA), and Multi-Criteria Decision Making (MCDM) were presented.

In section 2.1 and 2.2, general aspects about de-inked pulp production (DIP) and implementation of co-generation were described, as well as current market conditions and factors affecting prices of electricity and recycled fibre quality. Technical issues were addressed for different DIP configurations (1-loop and 2-loop systems). Also, co-generation and the use of biomass as a fuel in pulp and paper mills were discussed.

In section 2.3, current engineering design process was presented highlighting economic considerations and the accuracy of these analyses depending on the design step. As well, an introduction to the financial indicators used to analyze the feasibility of industrial projects was also provided.

In section 2.4, Environmental Impact Assessment (EIA) was discussed in terms of its methodology, its current advantages and disadvantages. It was highlighted that EIA needs to be complemented by including broader indicators in order to assess wider environmental impacts at the global level.

In section 2.5, Life Cycle Assessment (LCA) was discussed by explaining the main steps, such as the goal and scope definition, inventory, impact assessment, and interpretation.

Also, some of its advantages and disadvantages were discussed, highlighting that LCA is a site-generic tool and its application has evolved from product comparisons to process analysis as well as technical options comparisons based on a recent survey of the pulp and paper industry.

In section 2.6, carbon credits and Greenhouse Gases (GHGs) mitigation implications in the pulp and paper industry were discussed by highlighting the uncertainty regarding future implementation of a carbon trading system in Canada.

Section 2.7 focused on describing the decision making process and the different applications of decision making tools in Life Cycle Assessment and Environmental Impact Assessment studies. Analytic Hierarchy Process (AHP) was discussed showing its main advantages.

Section 2.8 discussed current regulatory framework for the Province of Ontario related to air and water emissions. Federal and Provincial regulatory landscape for air emissions such as Point-Of-Impingement (POI) and Air Quality Standards were presented. At the same time, the Pulp and Paper Effluent Regulations (PPER) were discussed.

Specifically, the following issues have been identified as being important for the application of an integrated LCA-EIA approach in the pulp and paper industry, but not well addressed in the literature:

- The need for an integrated methodology to analyze the environmental performance of new projects with respect to the receiving environment and product-chain level by determining potential benefits and impacts and thereby define best performing technological alternatives from an environmental point of view.
- The potential benefit of a systematic procedure for weighting environmental criteria by integrating a Multi-Criteria Decision Making (MCDM) tool in the overall integrated environmental evaluation.
- The proposal of technological alternatives for increasing DIP pulp production and the implementation of co-generation at an integrated newsprint mill by analyzing their economic and environmental performance in order to answer broad questions surrounding current strategies in the pulp and paper industry, and in particular for integrated newsprint mills (e.g. the conditions under which economic and environmental benefits related to the implementation of DIP and co-generation are clear). Definition of techno-economic feasible and environmentally good designs is a complex and non-obvious process.
- To analyze Greenhouse Gas Mitigation (GHGM) implications due to the implementation of co-generation and increased DIP pulp production in markets where the grid fuel mix is mostly based on nuclear and fossil fuel sources.

CHAPTER 3: OVERALL METHODOLOGICAL APPROACH

3.1. Objectives and hypothesis

The research hypothesis is proposed as follows:

The conventional Environmental Impact Assessment (EIA) for new process designs can be enhanced by including Life Cycle Assessment (LCA) to analyze and screen multiple design alternatives, in order to obtain a set of both techno-economically feasible and environmentally attractive designs.

The following sub-hypotheses are related to this research project that is used:

- A Multi-Criteria Decision Making (MCDM) process using Analytic Hierarchy Process (AHP) can be an effective tool to globally evaluate site-specific environmental impacts from EIA and site-generic environmental impacts from LCA.
- The new proposed methodology can be used to demonstrate that for a hypothetical integrated newsprint mill, co-generation and increase of DIP pulp production can be simultaneously cost-effective and environmentally attractive options for certain conditions. At the same time, different power costs and grid fuel mix can significantly affect the Return-On-Investment (ROI) and Greenhouse Gases Mitigation (GHGM) of these projects.

- Carbon savings at the foreground and background level obtained by the implementation of co-generation and the increase of de-inked pulp production can have a positive effect on the Return-On-Investment (ROI) of these projects if a carbon trading system was implemented.

The overall objectives of this research project are to:

- Propose a novel methodology to assess broader environmental impacts for major pulp and paper mill modernization projects by estimating LCA (or product-chain level) metrics in addition to classical EIA (or facility level) metrics for different design alternatives,
- Combine EIA (or facility-level) and LCA (or product chain-level) environmental metrics using a systematic multi-criteria decision-making (MCDM) methodology in order to calculate a single environmental index, which expresses the overall environmental performance of projects at both facility and product-chain level.
- Demonstrate the novel methodology for the implementation of increased de-inked pulp (DIP) production and co-generation at an existing integrated newsprint mill.
- Demonstrate that power cost and grid fuel mix can affect the economic and environmental performance of industrial projects oriented to increase DIP and implemented co-generation.
- Analyze future important elements such as carbon credits related to the design alternatives in order to monetize them and analyze their potential effect on projects' economic performances.

3.2. Base Case and design alternatives

This section will discuss the characteristics of current base case and as well as the design alternatives considered in this project.

Base Case description

The base case production plant is an integrated newsprint mill located in Ontario, Canada. This same base case has been used in previous LCA studies (*Salazar 2004*).

Fiber consumption: wood chips are used to produce virgin pulp in a thermo-mechanical pulping (TMP) process, which has a high yield (approximately 93%) and is very energy intensive. The refining stage in the TMP process consumes the highest amount of electricity in the newsprint mill (approximately 70%), but part of this energy is recovered as steam. The on-site sawmill provides approximately 50% of the chips necessary for the newsprint production process as well as hog fuel for the boilers, and the remainder is supplied by local sawmills. 70% of the recycled pulp produced by the de-inking pulping (DIP) process is obtained from old newspapers (ONP) and the remaining 30% is old magazines (OMG). The transportation of wastepaper to be used in the DIP process comes from Ontario or the USA to the newsprint mill by truck or rail. The yield of this process is lower than for TMP (around 85%). Part of the generated sludge (50%) can be burned in the boiler house to produce steam. The chemicals employed in the pulping process include sulphur dioxide, sodium hydroxide, sodium silicate, borol, and hydrogen peroxide

Papermaking process: The mill has an average production of 375,000 Finished Metric Tons (FMT) of newsprint per year based on 84% virgin fibre and 16% recycled fibre. The pulp produced in the TMP and DIP lines is then provided to four paper machines where water is extracted from the pulp by pressing and drying, and newsprint paper is obtained. A significant amount of steam is required for this process and most of the water extracted from the pulp is recycled within the process. Finally, the produced newsprint is distributed to newspaper printing facilities in Ontario, Quebec, and USA by truck or rail.

Energy consumption: The mill steam requirement is produced from natural gas (~55%) and biomass (~45%) (i.e., hog fuel and sludge from the DIP and effluent treatment processes). The facility has a back pressure turbine that co-generates 2.5% of the mill's electricity consumption; the difference, 97.5%, is supplied by the grid.

Emissions: The main water emissions include BOD (Biochemical Oxygen Demand), TSS (Total Suspended Solids), and nutrients (i.e. nitrogen and phosphorus). The main emissions from boiler house are TSP (Total Suspended Particles), NOx and SO_2. Solid waste generation is related to sludge produced in the effluent treatment plant, which is mixed with the sludge from the DIP process and then dewatered. A portion of the sludge (50%) is burned in the boiler house and the rest is landfilled on-site. Finally, industrial trash is generated by the DIP line and ashes are generated by the boiler house

Design alternatives

The design alternatives considered an increase of de-inked pulp (DIP) production and implementation of co-generation.

The new DIP plant design alternatives considered an increased production of recycled pulp to either 550 Air Dried Metric Tonnes/day (ADMT/day) (represents 50% of the total pulp production), or 1100 ADMT/day (represents a 100% of the total pulp production). Two DIP configurations were considered in the design of new DIP alternatives, namely, 1-loop (alkaline loop) and 2-loop configurations (alkaline and acid loops). Both technologies involve stages of screening, cleaning, flotation and dispersion of the recycled pulp (see technical flowsheets in APPENDIX 4).

The co-generation design alternatives considered the ability to increase biomass burning by the installation and/or upgrading of hog fuel boilers. Also, considered were reactivation of equipment for electricity production currently not in use and implementation of new back-pressure turbines.

A total paper production of 1100 FMT/day was assumed for these alternatives. All possible combinations of DIP and co-generation yielded a total of 18 design alternatives, and a techno-economic analysis was performed for each of these. Energy and fuel requirements for the mill vary significantly as the production of DIP is increased. This and other implications are presented in Table 3.1.

Table 3.1 Design implications related to DIP production and co-generation

Increased DIP	**Increased co-generation**
• Reduction of virgin fibre consumption, • Reduction of electricity consumption, • Increased amount of generated sludge and solid wastes • Increased transportation of ONP and OMG • Increased steam consumption due to reduced steam recovery from TMP	• Increased combustion of biomass and natural gas. • Increased amount of sludge that can be burned in the boilers • Reduction of overall landfilled material

DIP pulp design alternatives

Two DIP mill designs have been considered:

(1) 1-loop design, with a yield of 92%, and an energy demand of 450kWh/BDMT of pulp,

(2) 2-loop design, with a yield of 85%, and an energy demand of 650kWh/BDMT of pulp.

The major differences between these two configurations are that 2-loop systems consume a higher amount of electricity, chemicals and recycled fibre to produce DIP pulp. On the other hand a 2-loop system produces a higher quality pulp.

Six alternatives incorporating the above DIP designs have been evaluated and they are as follows:

- Installation of a new state-of-the-art 2-loop DIP plant to replace 50% of the TMP pulp furnish, producing an average of 550 ADMT/day of pulp.
- Installation of a new state of the art 2-loop DIP plant to replace 100% of the existing pulp furnish, producing an average of 1,100 ADMT/day of pulp.
- Installation of a new state-of-the-art 1-loop DIP plant to replace 50% of the TMP pulp furnish, producing an average of 550 ADMT/day of pulp.
- Installation of a new state-of-the-art 1-loop DIP plant to replace 100% of the existing pulp furnish, producing an average of 1,1100 ADMT/day of pulp.
- Installation of a new state-of-the-art 1-loop DIP plant to produce an average of 375 ADMT/day, replacing 50% of the TMP pulp in combination with the existing 1-loop line at 175 ADMT/day.
- Installation of a new state-of-the-art 2-loop DIP pulp plant to produce an average of 375 ADMT/day, replacing 50% of the TMP pulp in combination with the existing 1-loop line at175 ADMT/day.

Co-generation design alternatives

Three alternatives have been designed, each providing different levels of electrical generation, natural gas/hog fuel consumption. The relative merits of each of these projects have been considered with the DIP/pulp mill modifications discussed previously. A study previously executed by the mill forms the basis of technical and capital costs considered in this work. (See Technical Flowsheets in APPENDIX 4)

Co-generation system # 1 (Cogen 1)

- The existing no. 3 boiler, currently burning natural gas, is converted to a wood waste boiler.
- The existing no. 1, 2, 4, 5 and 6 boilers are unchanged
- The no. 7 turbo generator continues to be in service. Turbo generator no. 6 is reactivated and a new air-cooled condenser is installed to condense the excess steam from the no. 6 turbo generator when the capacity of the existing water-cooled condenser is exceeded.

Co-generation system # 2 (Cogen 2)

- New 900 psig wood waste boiler
- The existing no. 4, 5, and 6 boilers are converted to 900 psig operation
- The existing no. 1 and 2 boilers are unchanged
- New 900 psig no. 8 turbo generator, double extraction. Turbo generator no. 7 is not continuously used. A new air-cooled condenser is installed to condense the excess steam from no. 8 turbo generator when the capacity of the existing water-cooled condenser is exceeded

Co-generation system # 3 (Cogen 3)

- The existing no. 1, 2, 3, 4, 5 and 6 boilers are unchanged

- The no. 7 turbo generator continues to be in service. A new 35 psig condensing steam no. 8 turbo generator is added. A new air-cooled condenser is installed to condense the excess steam from the no. 6 turbo generator when the capacity of the existing water-cooled condenser is exceeded.

3.3. Proposed environmental evaluation methodology

This project combines several different tools such as (1) Techno-economic analysis, (2) Environmental Impact Assessment (EIA), (3) Life Cycle Assessment (LCA), (4) Multi-Criteria Decision Making (MCDM) in order to analyze the design alternatives from both an economic and environmental standpoint.

The aim of the proposed methodology is to assess site-generic (or facility level) environmental impacts in parallel with site-specific (or product-chain level) environmental impacts. This methodology provides an enhanced analysis of a defined set of design alternatives in order to choose the most preferable one from an environmental point of view, while maintaining economic feasibility. Additionally, a Greenhouse Gas Mitigation (GHGM) analysis is performed using Global Warming Potential results in order to identify foreground (facility level) and background (utility and fuels production) carbon savings as a consequence of the implementation of co-generation and increased DIP pulp production.

The EIA criteria consist of a set of air and water emissions and the amount of solid waste generated by design alternatives that affect the receiving environment. The LCA criteria are related to the global, regional, and local impact categories of the considered product system, of which the design alternatives are a part, as well as the entire product chain of the system.

Figure 3.1 shows two different approaches for analyzing environmental impacts. The one on the right is the proposed approach where life cycle elements are integrated in the overall environmental assessment.

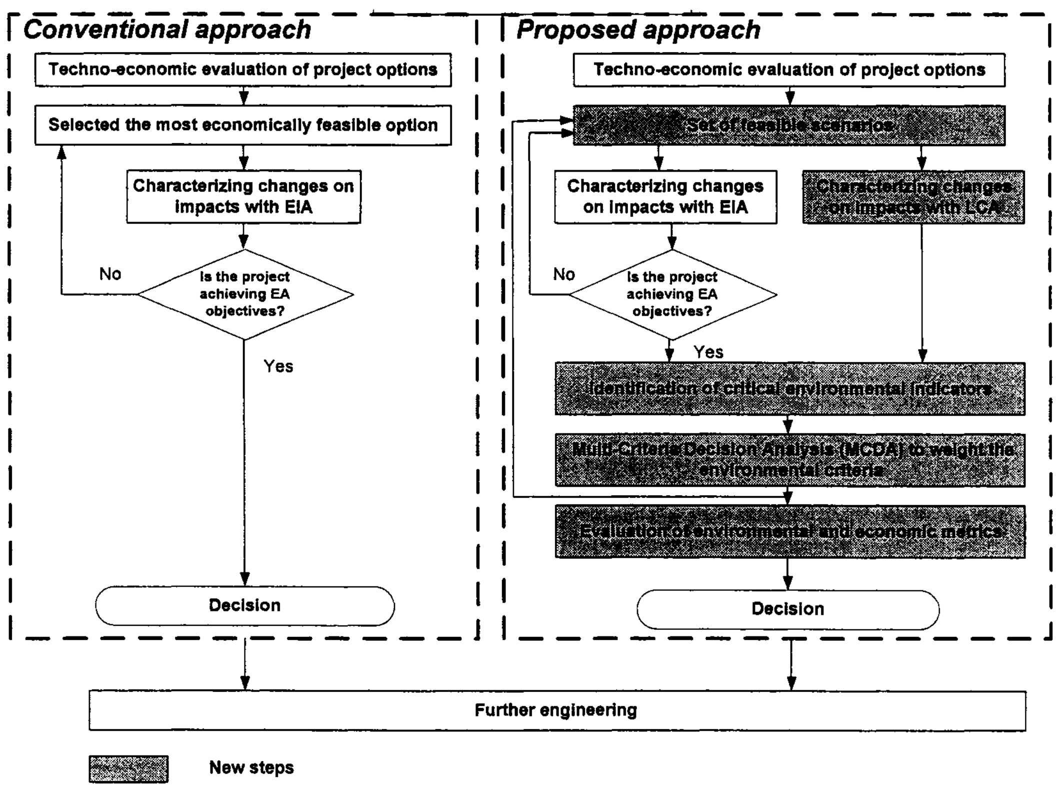


Figure 3.1 Proposed integrated methodology

By including LCA in the conventional EIA methodology, a better-informed decision can be made due to the increased completeness and broader view of the proposed methodology and consequently, its results. This section will discuss the methodologies followed to perform the techno-economic analysis, EIA, LCA and the Multi-Criteria Decision Making (MCDM) method used in this project. A design loop has been included right after the MCDM process to give engineering feedback to the design process in order to improve the current design of the alternatives based on their environmental results.

Techno-Economic methodology

The complete techno-economic analysis is presented in the APPENDIX 3. For this analysis, the following methodology *(Janssen et al. 2005)* was used:

1. A study was carried out by using available and emerging technologies, an environmental review and the gathering of necessary engineering data. Several DIP and co-generation options were identified, and changes in the other mill processes as a result of the implementation of these options were evaluate using mass and energy balances.
2. These alternatives were combined for the large-block analysis and consequently, their technological feasibility was verified. This process started with an inventory of the inputs and outputs for the different unit processes at the mill level including co-generation and De-inking process. The purpose of constructing these inventories was to devise a systematic method for gathering all the input and output data that need to be considered in the large-block analysis (Figure 3.2)

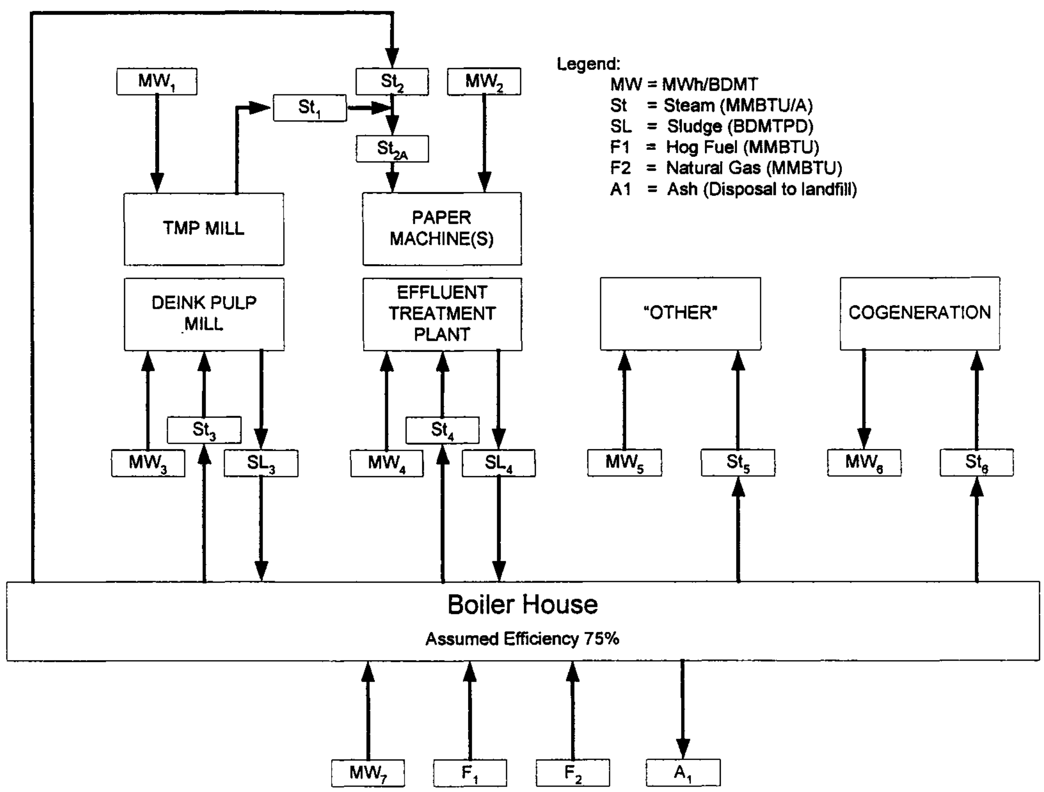


Figure 3.2 Process block diagram from a co-generation perspective (Janssen et al. 2005)

3. For each option, manufacturing and capital cost estimates were made. Based on these estimates, the Net Present Value (NPV) and Internal Rate of Return (IRR) for each of the generated alternatives were calculated.

Calculation of Net Present Value (NPV)

The Net Present Value (NPV) is used as a metric for the economic feasibility of the different design alternatives. The key investment parameters are presented in Table 3.2:

Table 3. 2 Key investment assumptions

Investment terms	10 years
Investment on Capital	8.5%
Corporate Tax rate	38.5%
Inflation rate (Constant over the years)	38.5%
Risk Premium	4%
Debt to equity	80/20

By using these assumptions, the NPV and Internal Rate of Return (IRR) were calculated and the design alternatives feasibility determined.

Environmental Impact Assessment (EIA) methodology

The EIA study includes the following:

- Identification and description of the significant air and water emission sources as well as the solid waste generation,
- Estimation of emission rates for each identified contaminant of concern due to the design modifications and comparison with base case emissions.
- Comparison of concentrations with relevant applicable environmental regulations at municipal, provincial and federal levels.

The overall methodology followed to assess air, water and solid waste generation criteria is depicted in the following Figure 3.3:

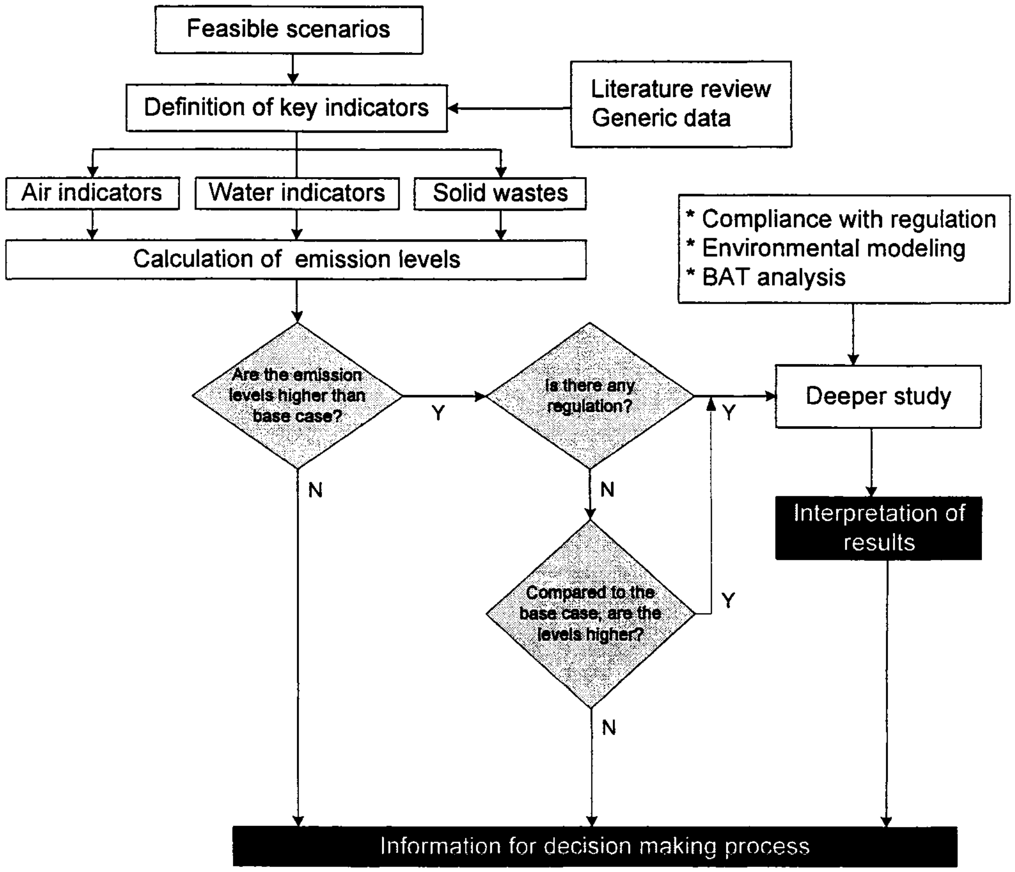


Figure 3.3 EIA Methodology followed by the project

Several Environmental Impact Statements (EIS) related to similar projects were reviewed in order to define a number of critical environmental criteria to measure future environmental performance of each design alternative. The chosen criteria are shown in Table 3.3

Table 3.3 EIA criteria

Air emissions	Total Suspended Particles (TSP) Oxide Nitrogen (NOx) Sulphur Oxide (SO_2)
Water emissions	Biological Oxygen Demand (BOD) Total Suspended Solids (TSS)
Solid waste generation	Ash Industrial trash

Nutrients and certain other discharges were not considered in this EIA study because of unchanged or reduced emission levels in the base case due to the project modifications. Furthermore, the criteria of particle matter less than 10 microns (PM_{10}) and 2.5 microns ($PM_{2.5}$) were also excluded due to a lack of regulations. The approved EIA report is presented in APPENDIX 6.

Air emissions

The methodology followed to estimate the future concentration of the selected air criteria in the receiving environment is depicted in Figure 3.4.

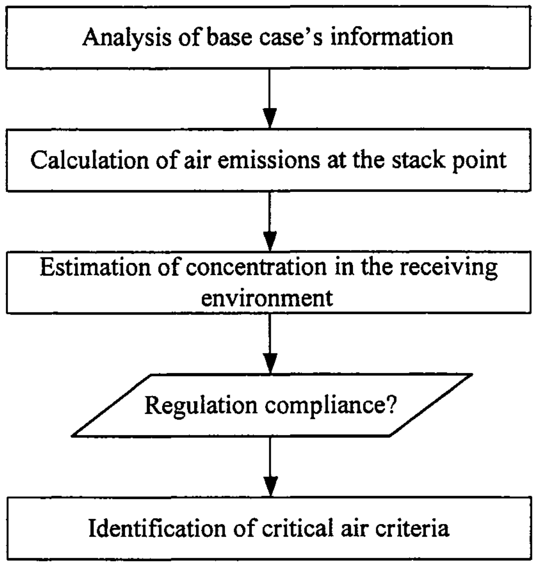


Figure 3.4 Methodology to estimate the concentration of air criteria

Current emission levels and final concentrations in the receiving environment for the selected air criteria were found by considering several mill reports and on-site data from the mill. A confidential Dispersion Modeling Report, which presents the emission release rate at the point source (stack) and the resultant final concentration in the receiving environment of current pollutants emitted for the base case, was used as the main reference.

Based on energy and mass balances, new steam requirements consumed by each design alternative were calculated and consequently, new fuel requirements were estimated (biomass, sludge, and natural gas). The new fuel consumption for the different design alternatives is converted into emission release rates by using a set of air emission factors (AP-42) for bark and natural gas boilers proposed by the Environmental Protection Agency (EPA).

Following the Proposed Guidelines for Dispersion Modeling (OME), a proportional relationship was assumed between the release rates and the resultant final concentrations in the receiving environment for each design alternative as estimated in the confidential Air Dispersion Modeling Report for the base case (*Ontario Ministry of Environment 2003*). For these calculations, it was assumed that the stacks required for the new co-generation designs would have the same dimensions as the ones already in place in order to unitize the emission rate.

Finally, to assess the importance of these emissions, legislation by the Province of Ontario was used for comparison of the calculated concentrations in the receiving environment for the different design alternatives. This legislation is the Point-Of-Impingement (POI) for air emissions. After this analysis, the critical environmental indicators were identified for the decision making step.

Water emissions

Figure 3.5 depicts the methodology followed to estimate the future concentration of the selected water emissions in the receiving environment.

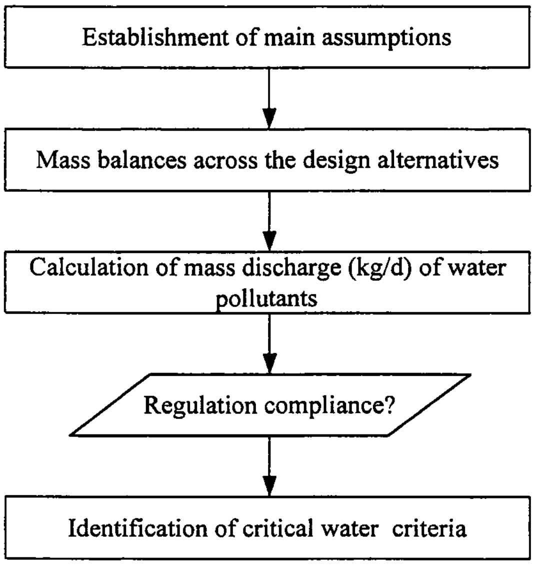


Figure 3.5 Methodology to estimate the concentration of water emissions

Water emissions from the base case were characterized using the mill's environmental reports and the mill's Environmental Profile Data Sheets (EPDS). Process experts have defined a set of sensitive water criteria that can potentially be affected by the process changes. Based on these expert reviews, the following assumptions were defined for the design alternatives:

- Current water emission levels will be strongly affected by modifications on the pulp furnish (i.e. going to 100% DIP and shutting down TMP)
- Biochemical Oxygen Demand (BOD) and Total Suspended Solids (TSS) are the main contaminants affected by project modifications.
- The current design of the effluent treatment plant will not be affected by changes in the pulp furnish because the raw waste load from the mill to the treatment will

decrease and the hydraulic load generated by the operation will remain constant at 50,000 m^3/day,

- The BOD produced by a DIP process is lower (kg/t) and more biodegradable than that produced by a TMP process. As TMP production is replaced by DIP production, the BOD levels in the effluent can be treated with lower aeration,
- The nutrient load is an effluent treatment plant design parameter based on BOD. Since the raw waste load has been set as constant, the nutrient load will not be affected significantly by the modifications mentioned.
- The following water emission levels for TSS, BOD and nutrients were assumed as follows for each DIP/TMP pulp scenario (see Table 3.4):

Table 3.4 Estimated concentrations of water emissions

Emission	**Base Case Final effluent (mg/L)**	**50% DIP alternative Final effluent (mg/L)**	**100% DIP alternative Final Effluent (mg/L)**
TSS	40	35	35
BOD5	9.0	6.0	4.0
P total	1.20	1.0	1.0
N total	4.3	4.0	4.0
Flow (m3/FMT)	45	45	45

By using the total volume of generated effluent for each design alternative (50,000 m^3/d) and the estimated water emission concentrations, the final contaminant mass loads were calculated (expressed by kg/d). The contaminant loads were compared with current levels for the base case and compared against the mill's current regulatory limits in order to define critical water criteria.

Solid waste generation

Figure 3.6 shows the methodology followed to estimate the future solid waste generation by the selected design alternatives.

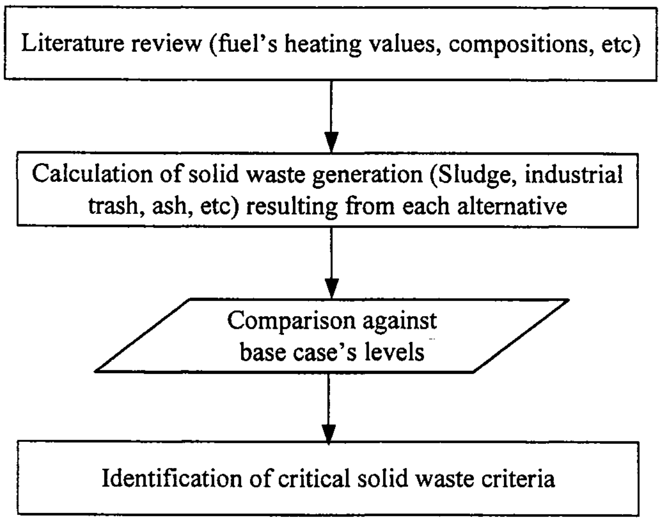


Figure 3.6 Methodology to calculate the solid waste generation

The generated solid waste emitted by the base case was characterized using information provided by the mill. Several types of solid waste were considered in this study (Table 3.5)

Table 3.5 Types of generated solid waste

Solid waste	Description
Industrial waste	Non fiber (glass, metal, sand, plastics, wires, etc) rejects removed in the early stages of the DIP pulp production.
Sludge	Sludge material from the DIP pulp production and effluent treatment plant. The main component of this waste is fiber.
Ash	By-product of the combustion of organic material from boilers.
Others	Office waste material, domestic waste, etc.

The proposed DIP alternatives generate two types of waste: industrial trash (coming from pulping and cleaning stages) and sludge (principally recycled fiber and ink rejects). Sludge and industrial trash produced in the DIP line is increased since DIP increases to 50% or 100% of the total pulp production, when compared to the base case. All of the DIP sludge in combination with all of the sludge generated from the effluent treatment plant is burned in the boilers for energy recovery. Consequently, the amount of sludge exiting the system is considered to be zero. New amounts of industrial trash from DIP lines were calculated using a factor of 1.6%, representing the fraction of industrial trash in the total material fed into the DIP line. This generation factor was kept constant across all the DIP alternatives.

Co-generation generates solid wastes as ash. As the amount of sludge and biomass burned in the boilers increases, an increased amount of ash is generated. The thermal efficiency of boilers is 75%. Several heating values and fuel compositions were obtained from literature references for wood waste and sludge composition and used in the overall calculation for solid waste generation (see Table 3.6).

Table 3.6 Heating values – literature references

	% composition					**HHV (BTU/Kg)**	**Reference**
	Organic	*Hydrogen*	*Sulphur*	*Oxygen*	*Ash*		
DIP sludge	12.10%	1.48%	0.07%	7.91%	20.22%	11,367	Kraft.D, 1993, Tappi
Mixed sludge	----	----	----	----	6.50%	17,875	Gottsching, Kraft & Frei,K.
Wood waste	50.12%	5.80%	0.10%	40.70%	3.10%	19,151	US Agriculture Depart. 1979

Finally, the solid waste generated by the proposed design alternatives was compared against the current generated levels (the base case) in order to define critical solid waste criteria.

Life Cycle Assessment (LCA) methodology

The methodology followed to perform the LCA study in each of the project alternatives has been depicted in the following Figure 3.7:

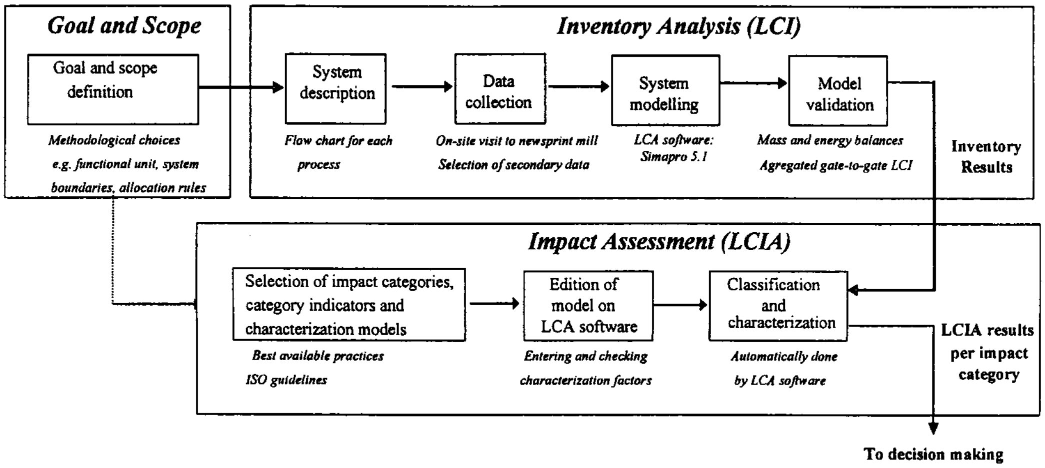


Figure 3.7 Methodology for LCA

Goal & Scope

The LCA study was based on a real mill that had been previously modelled *(Salazar 2004)*. The objective of this study is to analyze global, regional and local site-generic environmental performances of different design alternatives in comparison to a base case. The intended audience of this study is the environmental scientific community and the NSERC Environmental Design Chair in Process Integration at the Ecole Polytechnique de Montreal. The most important elements are the following:

Goal of the study: The goal of this study is to identify environmental performance of new process designs at an integrated newsprint mill.

Functional unit: The production of 1 ADMT (i.e., 1 air dried metric ton, 10% moisture content) of newsprint. The reference flow is 1 ADMT of newsprint. The reference flow and functional unit are considered same for all the design alternatives.

System boundaries: Since this LCA is a comparative study, several differences between the boundaries in previous work and the current project exist (*Salazar 2004*). The following modifications were made:

- Exclusion of the forest and sawmill from the system boundaries. At the same time, "manufacturing, maintenance and disassembly of assets have been excluded from the system since these are used for several functional units during their life cycles and their impact for one functional unit is negligible", same assumption as in previous study *(Salazar 2004).*
- Chips, recycled paper and biomass (hog fuel) are considered as elemental flows, only considering their transportation. For the elemental flows in this study, a marginal technology analysis has been carried out to demonstrate that the changes will not strongly affect the current market (*Weidema 1999*). The modification of the system boundaries was performed in order to avoid system expansion

The LCA boundaries (see Figure 3.8) considered for the environmental analysis of the different design alternatives, which include the following unit processes:

Facility level: TMP line, DIP line, boilers (Steam from hog fuel, steam from natural gas and steam from sludge), paper machines, sludge treatment plant, effluent treatment plant, landfill site and the transportation of biomass, wood chips and recycled paper (one way).

Product-chain level: electricity production, fuel production, chemical production and the transportation of the final product to the costumer (one way).

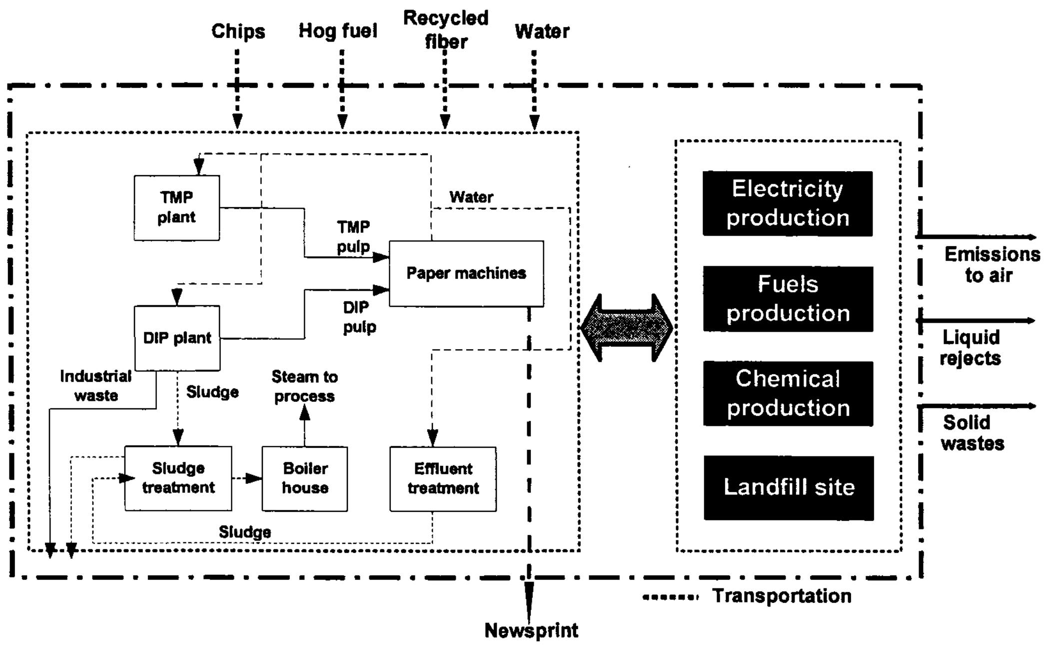


Figure 3.8 LCA system boundaries

The data quality requirements are the following: (1) Time: For the base case, the year of inventory collection is 2001. For the new design alternatives the data at the facility level are not data from 2001 but based on energy and mass balances, while for the product chain 2001 data is still used. (2) Geography: The system under study is located in Northern Ontario and therefore North American data is desirable. (3) Technology: Data based on average technology is desirable.

Treatment of data gaps: Data gaps for the different alternatives were mainly related to chemicals used at the newsprint mill. They were treated using general databases (e.g.

ETH – Organic and Inorganic Chemicals). When data gaps were identified for specific substances for a process unit (e.g. PM2.5 in natural gas production), literature review (e.g. USEPA emission factors and/or particle size distribution factors) or general databases were used.

The TRACI impact model proposed by the US Environmental Protection Agency was used to assess the environmental performance of the design alternatives. The output-related impact categories are related to different global, regional and local impact categories *(Salazar 2004)*

The limits of the LCA study are mainly related to data aggregation in the interpretation phase for the general data bases used, mostly due to their comprehensiveness (i.e. for some materials the entire life cycle is taken into account whereas for others only a fraction of the life cycle is considered). However, when comparing the design alternatives, this limitation is marginal. The absolute importance of the investigated parameters has not been assessed plus for the normalization step, a case-specific normalization approach has been used (*Hofstetter 1999*).

Life Cycle Inventory (LCI)

The sequence followed to carry out the inventory of the design alternatives is expressed by the following: System understanding → flow charts for process design →

data gathering for design alternatives → mass and energy validations → validation by experts.

Primary and secondary data sources are used to model the system. Primary data is related to the inventory at the facility level for each design alternative. This was based on energy and mass balances that calculated the consumption of recycled paper, wood chips, biomass (including sludge), new fuel requirements, cogeneration output and finally electricity requirements. Technical requirements related to the new equipment considered in the design alternatives, such as electricity consumption and chemical recipes, was specified by the manufacturer (See technical specifications APPENDIX 4).

The secondary data was estimated using general databases. The external databases considered are the following: (1) Franklin database (America averages, 95-99) to obtain data for fuel production (natural gas, gasoline and propane), transportation (trailer and locomotive) and natural resources on electricity production. (2) IVAM and BUWAL (European averages, 90-94) for most of the chemical production. (3) KCL 3.0 (Finnish average, 92) for landfill models and H_2O_2 and $NaBH_4$ production.

Life Cycle Impact Assessment (LCIA)

Since LCA analysis is used as a comparative tool to define best environmental process alternatives and the base case used for comparative reasons is taken from previous work, the same tools (SIMAPRO 5.1 and TRACI) were used to model the system.

Peer Review

A formal internal peer review of this study was carried out by an LCA expert from the Interuniversity Reference Centre for the Life Cycle Assessment, Interpretation and Management of Products, Processes and Services (CIRAIG) from the École Polytechnique de Montréal, following ISO protocols. (A report for the LCA study following ISO 14040 guidelines and a report of the critical review are presented in APPENDIX 5)

3.4. Multi-Criteria Decision Making (MCDM) methodology

In order to select the most preferred design alternative, the environmental results from the EIA and LCA were evaluated and weighted by experts in order to calculate a final environmental indicator for each design alternative.

A MCDM methodology was proposed and it consisted of 6 steps (Figure 3.9). The first 2 steps were related to the screening of project results and the last 4 steps were oriented to assign weighting factors to the environmental criteria.

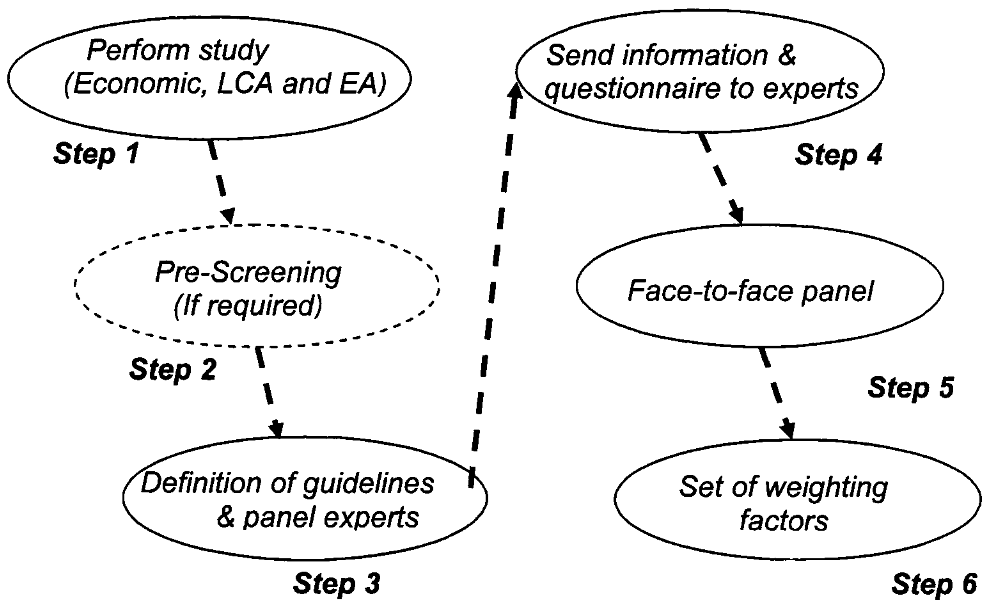


Figure 3.9 MCDM methodology

The methodology starts with the definition and screening of the critical environmental indicators to be considered during the evaluation of the expert panel.

A document called "Guidelines and Protocols" was created for the formation and execution of this panel (see APPENDIX 7). These guidelines describe the MCDM process and provide the justification for different choices, such as the selection of the number of experts, the decision making tool, etc.

An expert panel was formed to determine the weighting factors. The decision making panel consisted of five experts with diverse backgrounds and expertise in each of the following fields: pulp and paper environmental management, environmental research, environmental regulation, LCA, and EIA.

Each expert received an information package containing specific and generic information about the project, including a PowerPoint presentation, a questionnaire, and several publications as complementary literature to introduce them to the problem context before the face-to-face panel.

At the same time, targets were defined for each environmental impact criterion to help the experts assign weighting factors. For the site-specific criteria, current regulatory levels were used as targets. For the site-generic criteria (LCA criteria), the methodology for defining the site-generic targets included the following steps:

Contribution analysis ↓	The individual emissions contributing to a total of 99% of each LCA impact category were identified.
Identification of emission targets ↓	A relative Canadian reduction target was found for the emissions identified. When no reduction target was available, it was assumed that the emissions should remain constant. All the targets were relative to a reference year.
Calculation of targets relative to reference year (2001) ↓	All the targets were recalculated relative to year 2001, which corresponds to the base case, using Canada-wide emissions for that year.
Calculation of targets for impact categories	The Canadian emissions targets relative to year 2001 was applied to the base case in order to calculate targeted emissions. Characterization factors were used to transform those targeted emissions into targets for impact categories.

During the weighting panel, the pairwise comparisons were performed by elicitation to reach a final consensus. A ratio scale employing the whole numbers from 1 to 9 and their reciprocals was used. If consensus was not reached in a defined time, it was determined whether a majority of the panelists had assigned the same value to the comparison. If so, this value was used in the calculation of the weights. If a majority was not reached, then that particular comparison was placed on hold until the end of the elicitation process. As a result, either a consensus or a majority was reached among the panel members on all pairwise comparisons.

The weights were calculated using a matrix in which the criteria were compared pairwise. Only half of the matrix was required since the other half was automatically filled out by the reciprocals (e.g., 9 in a cell and 1/9 in the corresponding reciprocal cell). The AHP consistency ratio was calculated to determine the consistency of the comparisons made by the panelists. If this ratio was too high (C.R. > 10%), the comparison that was the least consistent was identified using a calculation proposed by Saaty (*2003*), and the panelists were asked to reconsider this comparison. This process was repeated until sufficient consistency was attained and there was agreement among the panelists. The consistency ratio (CR) is computed from formula (2)

$$CR = CI/RI \tag{2}$$

The CI is compared to the corresponding Random consistency Indices (RI) developed by Saaty (1980) as shown in Table 3.7.

Size of matrix (n)	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Table 3. 7. Random Consistency index (Saaty 1980)

The consistency index (CI), which is expressed as in formula (3):

$$CI = (\lambda - n) / (n - 1))\ max \quad (3)$$

Where: λ is the eigenvalue, which was calculated by a small computer program and n is the number of criteria (Saaty 1980)

Finally, aggregated environmental indicator called the Environmental Index (EI) was calculated by the following mathematical expressions (4):

$$N_{ij} = \frac{Criterion_{iSc_j}}{\text{Base case value}_{\text{Criterion}_i}}$$

(4)

Where:

N_{ij} = the normalized value for the criterion i and the design alternative j,

Criterion $_{i\,SCj}$ = the result of a defined criterion i (LCA or EIA) for design alternative j,

Base Case value$_{\text{criterion I}}$ = the value of the criterion i for the base case.

$$EI_j = \sum (N_{ij} \text{ x } W_i)$$

(5)

Where:

EI_j = the Environmental Index for the design alternative j,

W_i = the weighting factor assigned for the criterion i. with $\sum_i W_i = 1$.

Sensitivity analysis to weighting factors

"The sensitivity index (SI) is the easiest and most reliable sensitivity measure and can be calculated without detailed knowledge of the parameter distribution and without the use of random sampling schemes or large computer programs" *(Salazar 2004).* The SI was defined by Hamby (*1994*):

$$SI = \frac{D_{max} - D_{min}}{D_{max}} \tag{6}$$

where:

D_{min} and D_{max}, represent the minimum and maximum output values resulting from varying the input over its uncertainty range (*Hamby 1994*).

The inputs for this sensitivity analysis were the highest and lowest values assigned during the elicitation process through the pairwise comparisons. The matrix weights were calculated using the lowest and highest values. These were then compared with the original values, and using Hamby's SI, the sensitivity ratios for each criterion were determined

3.5. Implications of Greenhouse Gas Mitigation (GHGM)

One of the main advantages of using LCA in the current EIA of new projects is the fact that carbon savings can be easily analyzed, quantified and consequently, monetized if in the future a Carbon Trading System was implemented in Canada.

Based on the contribution analysis and LCA impact category results, an analysis of carbon savings was carried out in order to identify carbon credits at the foreground (or facility level) and background levels (or utility and fuels production). The credits are monetized by using two economic figures, a higher figure considers 50$/ $CO_{2\,eq.}$ credit and the lower one considering 10$/ $CO_{2\,eq.}$ credit *(Browne 2003)*. Finally, the effect of adding this new economic consideration to the Net Present Value (NPV) of each design alternatives was assessed. Figure 3.10 depicts the methodology used to quantify and monetize carbon savings:

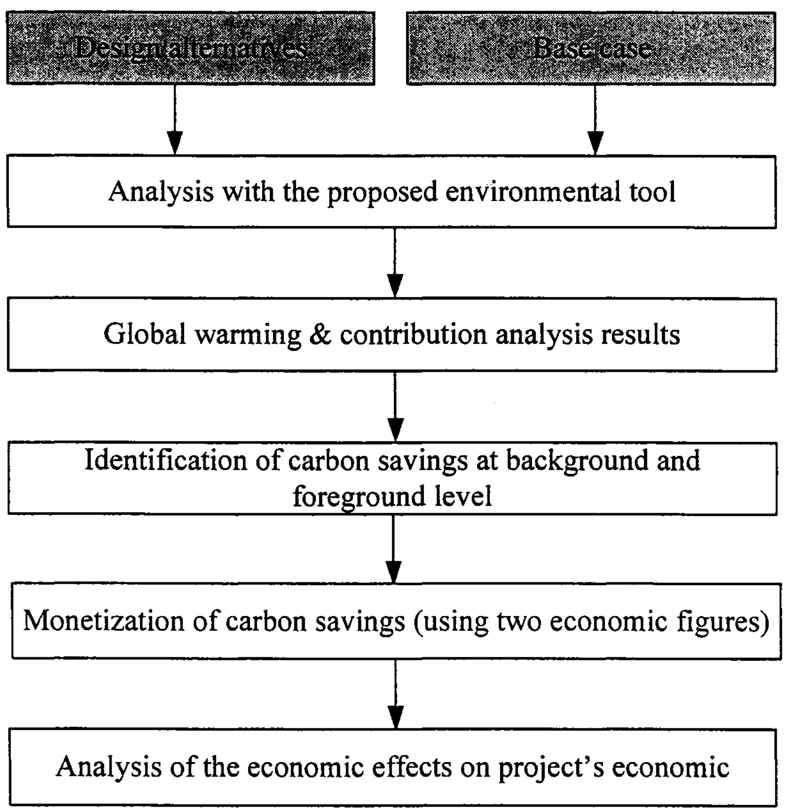


Figure 3.10 Methodology for the analysis of carbon savings

Sensitivity analysis of electricity source

A sensitivity analysis was performed on the design alternatives by changing the grid fuel mix to consider two different electricity sources with different grid fuel mixes and prices as can be seen in Table 3.8

Table 3.8 Scenarios considered for the sensitivity analysis

Scenario	Grid fuel mix	Cost Electricity ($/MW)
Ontario	33% fossil fuel, 28% hydro power, 39% nuclear power.	63.0
Energy Pool A	90% Fossil fuel, 10% hydro power, 0% nuclear power.	81.0
Energy Pool B	2% Fossil fuel, 95% hydro power, 3% nuclear power.	43.0

In order to carry out this analysis, the new grid fuel mixes (Energy Pool A and B) replaced current grid fuel mix (Ontario) in the LCA model and consequently, global warming results were calculated. Results were analyzed in order to define whether or not the environmental performance of the design alternatives changed.

New economic values for electricity cost were changed during the Techno-Economic analysis for the design alternatives. This evaluation kept all other economic parameters constant in order to analyze the change of the design alternatives' economic performance and to define whether or not the design alternatives become more or less competitive.

CHAPTER 4: SYNTHESIS OF THESIS

The details of these results are described in Appendix 1 *(Cornejo et al. 2005a),* Appendix 2 *(Cornejo et al. 2005b)* and Appendix 3 *(Janssen et al. 2005).*

4.1. Techno-economic analysis results

The design alternatives examined the increase of de-inked pulp (DIP) production and the implementation of co-generation. All combinations of 6 DIP and 3 co-generation alternatives were considered, yielding a total of 18 different design alternatives Table 4.1:

Table 4.1 Summary of the proposed design alternatives

Option	Configuration
DIP 1	Increased to 550 ADMT/day by implementing a new plant, 1-loop
DIP 2	Increased to 550 ADMT/day by implementing a new plant, 2-loop
DIP 3	Increased to 1100 ADMT/day by implementing a new plant, 1-loop
DIP 4	Increased to 1100 ADMT/day by implementing a new plant, 2-loop
DIP 5	Increased to 550 ADMT/day by adding a second line to the existing plant, 1-loop
DIP 6	Increased to 550 ADMT/day by adding a second line to the existing plant, 2-loop
Cogen 1	One natural gas boiler was converted to burn wood waste, and existing turbo-generators kept in service.
Cogen 2	New wood waste boiler (900 psig) was installed. Half the boilers were upgraded to 900 psig operation. New turbo-generator added to existing ones.
Cogen 3	New air-cooled condenser and turbo generator were installed.

Using the NPV as the measure of profitability, techno-economic results indicated that 4 out of the initial 18 design alternatives were deemed economically feasible (see Figure 4.1). The design alternative with the highest NPV is DIP 3 – Cogen 1 which combines a 40 MW co-generation facility with increased DIP production (1-loop system) to 100%. It should be noted that none of the design alternatives with a 2-loop DIP system had a positive NPV due to their higher electricity consumption (650 vs. 450 kWh/ tonne DIP for the 1-loop system), fiber (85% vs. 92% for the 1-loop system) and chemical costs (higher consumption of chemicals).

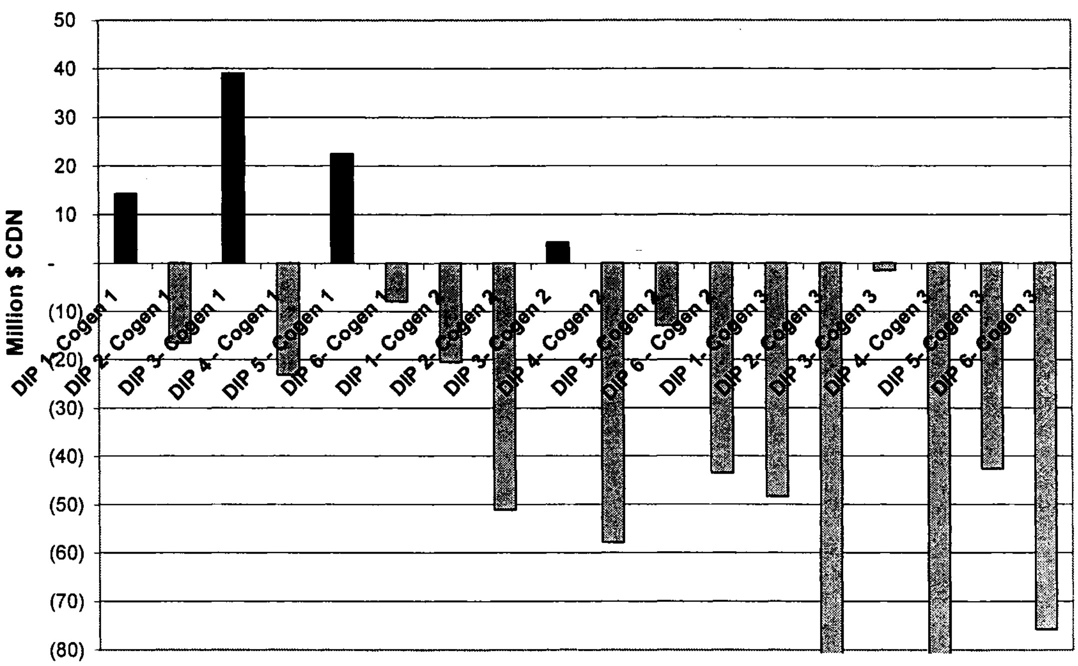


Figure 4.1 Final economic performances of the proposed alternatives

4.2. Environmental Impact Assessment (EIA) results

The following section presents the environmental results related to the EIA. Table 4.2 shows the results for the site-specific assessment.

Table 4.2 Environmental site-specific results (EIA)

Criteria		Units	Base case	DIP 3 – Cogen 1	DIP 5 – Cogen 1	DIP 1 – Cogen 1	DIP 3 – Cogen 2	Env. Regulation
Air	TSP	μg/m³	61	69	72	72	69	100
	NOx	μg/m³	50	47	52	52	59	500
	SO_2	μg/m³	227	270	251	251	269	830
Water	TSS	kg/d	2,000	1,750	2,000	1,850	1,750	9,180
	BOD_5	kg/d	424	200	400	300	200	5,830
Solid waste	Ash	t/yr	11,600	15,900	14,150	12,800	15,900	ND

For air emissions, the environmental site-specific results show that modifications in the boilers would result in a marginal increase of air emissions due to the greater amounts of biomass being burned. For this reason, electrostatic precipitators and low NO_x burners were considered in the design of the new co-generation system.

Total Suspended Particles (TSP) are the most important air contaminants identified for the proposed project modifications since their emission levels are the closest to current air emission regulation. The maximal TSP concentration in the receiving environment was approximately 72 $\mu g/m^3$ which is below POI criteria.

SO_2 and NOx levels rose due to the increased consumption of natural gas and biomass. However, they are far below regulation limits. Volatile organic compounds (VOCs) were not taken into consideration since they do not represent an important emission due to their low concentration in comparison with the current standards and regulations for Ontario.

For water emissions, BOD_5 was the main water emission criteria in the base case. This emission was reduced significantly in all design alternatives because the DIP process produces lower concentrations of more readily biodegradable BOD than the TMP plant. BOD levels were reduced by 53% at maximum, from 424 to 200 kg/day when design alternatives with 100% DIP pulp production were considered. For TSS, based on estimates, final effluent levels were lower than reported for the current facility. TSS levels show a maximum reduction of 12.5 % from current levels (from 2,000 to 1,750) due to the implementation of a brand new 100% DIP pulp production line. Comparison of TSS and BOD levels against existing regulation limits for pulp and paper effluents showed that current pollutant levels were far below the limit. It has been assumed that other contaminants such as metals and nutrients were only slightly affected by project modifications.

As for solid waste generation, since modifications of boilers allowed the process to burn larger amounts of biomass (hog fuel and sludge), the amount of ash generated from the boilers was also increased. Extra amounts of waste material would be landfilled in two landfill sites owned by the mill outside the mill premises. Since the amount of waste landfilled would only increase marginally, it has been assumed that this would not have any effect on the current landfill operation. There are no applicable regulations defined for this type of solid waste produced by pulp and paper mills. The regulations only apply to municipal landfill sites.

As can be seen in the aforementioned results, the new design alternatives do not create significant environmental impacts for the receiving environment. . Rather, the increase of DIP is beneficial with respect to water emissions, because it leads to lower concentrations of BOD and TSS in the final effluent.

4.3. Life Cycle Assessment (LCA) results

Life Cycle Assessment (LCA) results are presented in the following Table 4.3:

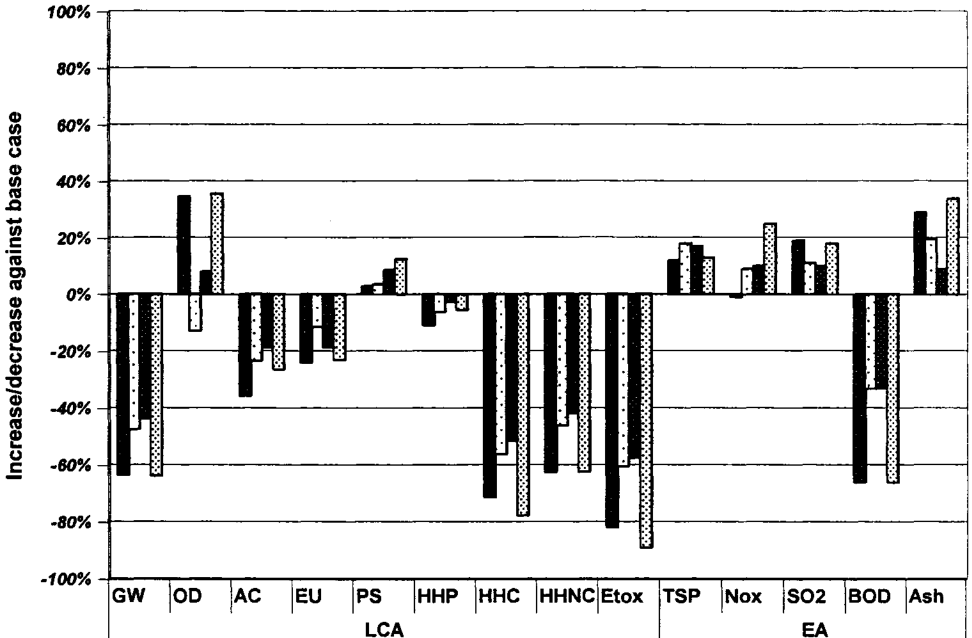
Table 4.3 Environmental site-generic results (LCA)

Impact category	**Unit**	**Base case**	**DIP 3 - Cogen 1**	**DIP 5 - Cogen 1**	**DIP 1- Cogen 1**	**DIP 3 - Cogen 2**
Global Warming	g $CO_{2\,eq}$	1,110,000	406,000	584,000	625,000	404,000
Ozone Depletion	g CFC11	0.006	0.00808	0.00522	0.00648	0.00814
Acidification	Mol H^+	297	191	228	242	219
Photo-Oxidant Formation	g NO_x/m	2.55	2.62	2.64	2.77	2.87
Eutrophication	g N	430	327	381	350	331
Ecotoxicity	g 2,4-D	3,130	566	1,240	1,230	340
Human Health Cancer	g C_6H_6	74.4	21.4	32.2	36.2	16.6
Human Health Particulates	DALY	0.000145	0.000129	0.000136	0.000141	0.000137
Human Health Non cancer	g C_7H_7	363,000	136,000	196,000	211,000	137,000

LCA results show that implementation of the design alternatives would lead to reductions on several impact categories. These environmental benefits suggest that the proposed process modifications are good environmental choices. However, there are certain exceptions, such as Ozone Depletion (OD) and Photo-Oxidant formation (PS), which present higher values for some of the proposed alternatives. The information related to the LCA, based on ISO guidelines, and the report from the critical review is presented in APPENDIX 5

4.4. Integrated environmental results

Figure 4.2 shows the integrated results from the LCA and EIA. The LCA contribution analysis has identified electricity production as the most important contributor to almost all the impact categories especially for global warming, human health related impact categories (human health cancer, human health non cancer and human health particles) and eco-toxicity. Since all the design alternatives considered a co-generation facility and the increase of DIP pulp to replace TMP pulp leading to an important electricity reduction at the mill level; all the human health impact categories and eco-toxicity were reduced as well.



	GW	OD	AC	EU	PS	HHP	HHC	HHNC	Etox	TSP	Nox	SO2	BOD	Ash
	LCA									EA				
■ DIP 3 – Cogen 1	-63%	35%	-36%	-24%	3%	-11%	-71%	-63%	-82%	12%	-1%	19%	-66%	29%
□ DIP 5 – Cogen 1	-47%	-13%	-23%	-11%	4%	-6%	-56%	-46%	-60%	18%	9%	11%	-33%	20%
■ DIP 1 – Cogen 1	-44%	8%	-19%	-19%	9%	-3%	-51%	-42%	-58%	17%	10%	10%	-33%	9%
⊡ DIP 3 – Cogen 2	-64%	36%	-26%	-23%	13%	-6%	-78%	-62%	-89%	13%	25%	18%	-66%	34%

Figure 4.2 Integrated environmental results

A new co-generation plant at the mill would marginally increase emission levels to the receiving environment, resulting in a change in the current environmental conditions. However, the LCA results show that the design alternatives would have significant environmental advantages when considering the product chain, since electricity produced at the mill is greener than electricity supplied by the grid (33% fossil fuel, 28% hydro power, 39% nuclear power). A significant reduction of the consumption of electricity from the grid (equivalent to the co-generated MWh at the facility) would result in a reduction of fossil fuel based electricity production by Ontario Power Generation (OPG) (nuclear and hydro remain constant). Thus, a reduction in electricity consumption would reduce the environmental load for the product system, which would in turn have a positive effect on the majority of the LCA impact categories. In particular, LCA local impacts such as human health cancer, human health non cancer, human health particles, and eco-toxicity would be mitigated.

4.5. Multi-Criteria Decision Making (MCDM) results

As discussed in previous sections, the aim of this MCDM step is to weight the environmental criteria using a weighting panel in order to obtain a final Environmental Index (EI).

The results of the panel show that greater weights were assigned to LCA criteria (See Table 4.4). This was discussed with the panelists, and it was noted that the EIA criteria for the 4 considered design alternatives met the current regulations. Consequently, according to the panel, LCA criteria were more important for evaluating the environmental performance of the design alternatives. It should be noted that the AHP consistency ratio at the end of the panel was 10.1%, indicating that the comparisons were near consistency according to AHP guidelines *(Saaty 1980).*

Table 4.4 Final weights assigned to the proposed environmental criteria

Criteria	**Assigned weight**
Global warming	0.202
Photo-oxidant formation	0.161
Eco-toxicity	0.109
Acidification	0.108
Ozone depletion	0.092
Human health non cancer	0.087
Eutrophication	0.061
Human health cancer	0.060
Human Health Particles	0.041
TSP	0.024
SO2	0.021
NOx	0.013
Ash	0.012
BOD	0.009

Sensitivity analysis - Weighting factors

A sensitivity analysis was performed on the weights found during the panel elicitation (see Figure 4.3), where the sensitivity of each criterion was calculated using the Sensitivity Index (SI) proposed by Hamby (1994).

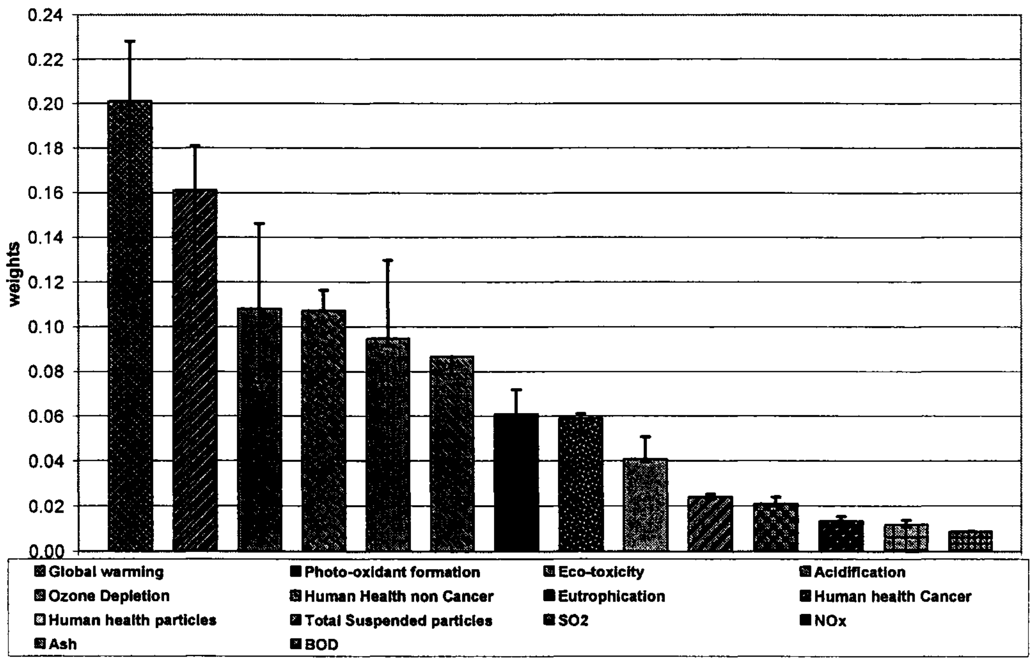


Figure 4.3 Sensitivity analysis results

Based on this analysis, it was found that EIA criteria are less sensitive than LCA criteria. The environmental criteria with the highest sensitivities were Global Warming and Eco-toxicity, while TSP exhibited the lowest sensitivity. This was discussed with the panel and the following points were highlighted:

- EIA targets are regulated and therefore are easier to evaluate regarding their importance in this decision problem, whereas the LCA targets are not regulated and as a consequence they are subject to uncertainty.
- There is ambiguity in the units used to express the final LCA impact categories results and their relevance, compared to site-specific criteria.

4.6. Economic performance vs. Environmental performance

Once the normalized results and the weights were calculated, the Environmental Index (EI) was calculated using equations (4) and (5) for each design alternative and this value was compared against their NPV. Economic versus environmental performances were plotted (see Figure 4.4). The environmental performance calculated for the project alternatives were quite similar, with DIP 3-Cogen 1 having the highest value (i.e., 0.68 pts) and DIP 1- Cogen 1 having the lowest (i.e., 0.70 pts). At the same time, from an economic perspective, DIP 3 – Cogen 1 significantly outperforms the other alternatives, suggesting that this design alternative should be considered in the detailed engineering study.

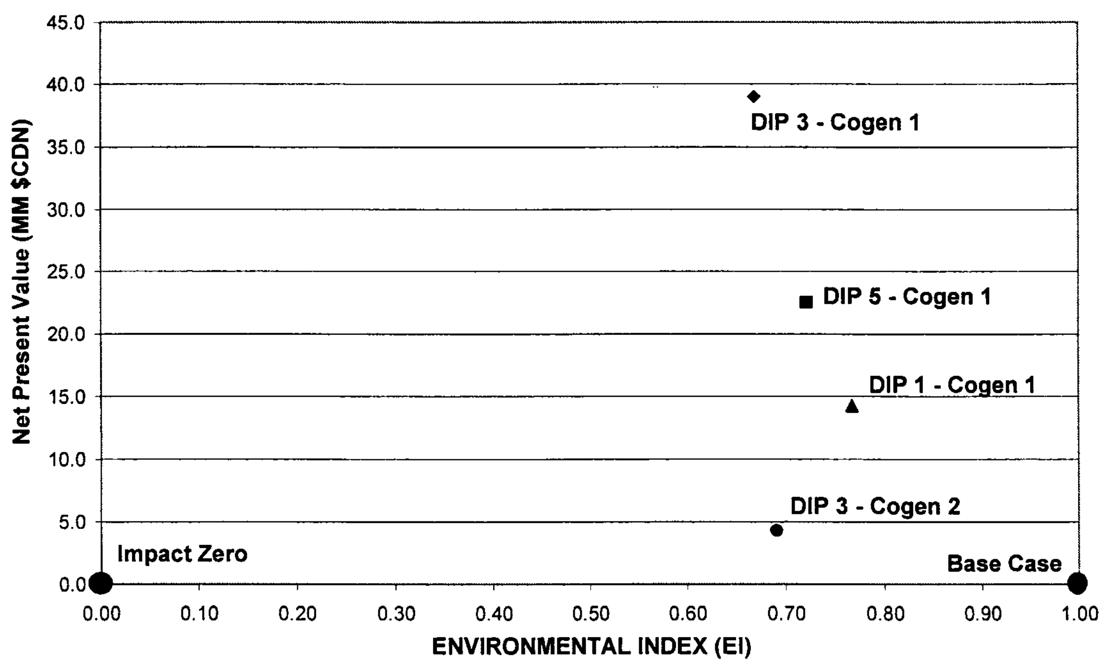


Figure 4.4 Economic vs. environmental performance

The Environmental Index (EI) has been calculated by using maximum, average, and minimum weight values. As can be seen in Table 4.5, DIP 3-Cogen 1 is still the most environmentally preferable alternative under different weighting scenarios. However, it is closely followed by DIP 3 – Cogen 2. Since the Environmental Index value for DIP 3 – Cogen 1 is the highest for all the weighting scenarios and at the same time, this design alternative has the highest NPV (DIP 3 – Cogen 2 has the lowest economic performance), DIP 3 – Cogen 1 is the most environmental and economic attractive scenario.

Table 4.5 Environmental Index results for different weighting scenarios

Scenarios		**Environmental Index (EI)**	**NPV (MM CDN)**
MAX - Weighting factors	Base case	1.000	0
	DIP 3 - Cogen 1	0.706	39.0
	DIP 3 - Cogen 2	0.727	4.3
	DIP 5 - Cogen 1	0.735	22.6
	DIP 1 - Cogen 1	0.787	14.3
AVERAGE -Weighting factors	Base case	1.000	0
	DIP 3 - Cogen 1	0.678	39.0
	DIP 3 - Cogen 2	0.699	4.3
	DIP 5 - Cogen 1	0.731	22.6
	DIP 1 - Cogen 1	0.776	14.3
MIN -Weighting factors	Base case	1.000	0
	DIP 3 - Cogen 1	0.690	39.0
	DIP 3 - Cogen 2	0.712	4.3
	DIP 5 - Cogen 1	0.742	22.6
	DIP 1 - Cogen 1	0.787	14.3

4.7. Greenhouse Gas Mitigation (GHGM) results

Since the project alternatives represent carbon savings across the product chain, carbon credits can be calculated at the foreground (or facility level) and background (utility and fuels production) levels. The following Table 4.6 shows the results related to carbon savings for each design alternative.

Table 4.6 Carbon savings for each of the design alternatives

Units (tons / year)	**Base Case**	**DIP 3 - Cogen 1**	**DIP 5 - Cogen 1**	**DIP 1 - Cogen 1**	**DIP 3 - Cogen 2**
Background $CO_{2eq.}$	343,166	72,251	143,351	152,135	50,913
Foreground $CO_{2eq.}$	86,024	84,755	82,507	89,289	105,328
TOTAL $CO_{2eq.}$ emitted	**429,190**	**157,006**	**225,858**	**241,424**	**156,241**
Carbon savings	**0**	**272,184**	**203,332**	**187,766**	**272,949**

If implemented, the four design alternatives would generate carbon savings due to their lower consumption of electricity and their production of greener electricity compared to the electricity supplied by the grid.

The alternatives oriented to increase 100% DIP production in combination with a co-generation facility (DIP 3-Cogen 1 and DIP 3-Cogen 2) have reported carbon savings by 272,000 tons $CO_{2\ eq.}$ per year. However, DIP 3 – Cogen 2 is the alternative that has increased $CO_{2\ eq.}$ emissions at the foreground level due to its higher consumption of natural gas in the boilers.

The best economic performance is reported for DIP 3 – Cogen 1 alternative with an NPV of CDN\$ 39 million and it has one of the highest carbon savings. Figure 4.5 shows the effect of monetizing the carbon savings on the NPV for the different design alternatives. The total carbon credits (including the foreground and background emissions) at 50 \$/t $CO_{2\ eq.}$, improves DIP 3 – Cogen 1 NPV by CDN\$13 million. However, by considering only the foreground (facility level) credits the NPV improvement is marginal (less than CDN\$3 million).

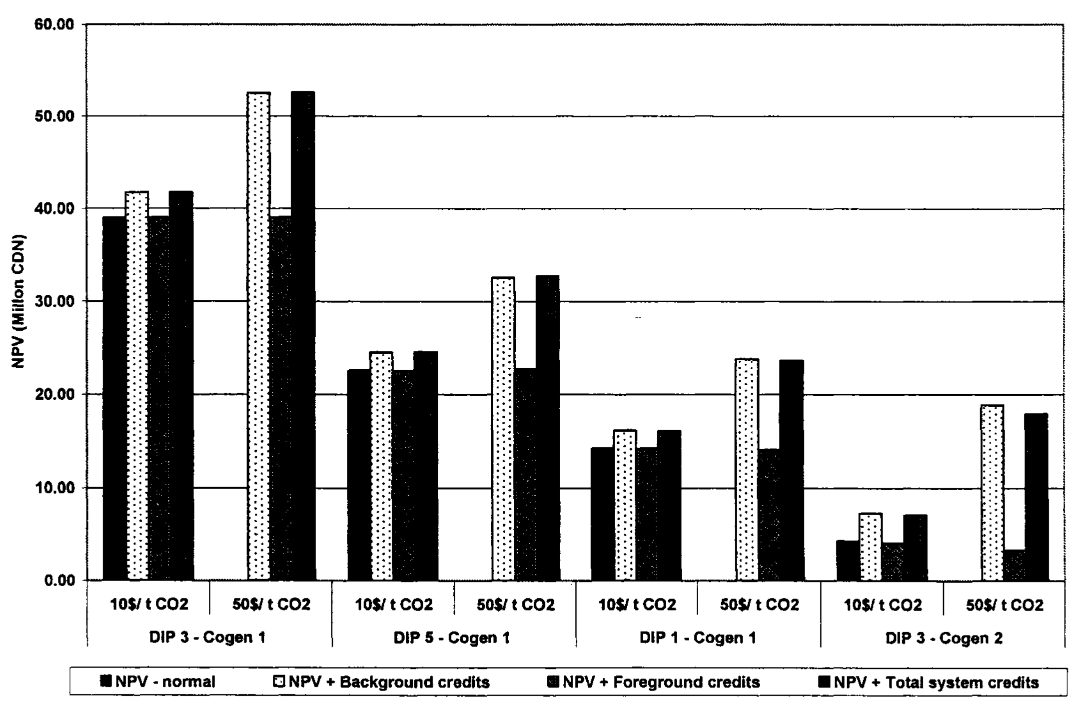


Figure 4.5 Effect of monetizing carbon credits on NPV for the design alternatives

Sensitivity analysis - $CO_{2\ eq.}$ credits

From LCA contribution analysis, electricity production was identified as the most important contributor to global warming potential and based on this finding, a sensitivity analysis was performed intended to evaluate the effect of considering different electricity scenarios with different prices and grid fuel mix within the same system boundaries. Figure 4.6 shows the NPV results for the design alternatives under the proposed electricity scenarios. The results indicate that under "Energy source A", the four design alternatives become more economically competitive since the cost to co-generate 1 MWh at the facility is lower than the cost of 1 MWh supplied by the grid ($CDN 81/MWh). Alternative DIP 3 – Cogen 1 has a maximal NPV of CDN$ 114 million under "Energy source A" in comparison with the CDN$ 39 million reported with current Energy Pool (Ontario). However, under "Energy source B", the four design alternatives become economically unattractive; since the cost for 1 MWh supplied by the grid is so low that the economic gain by implementing co-generation is negative.

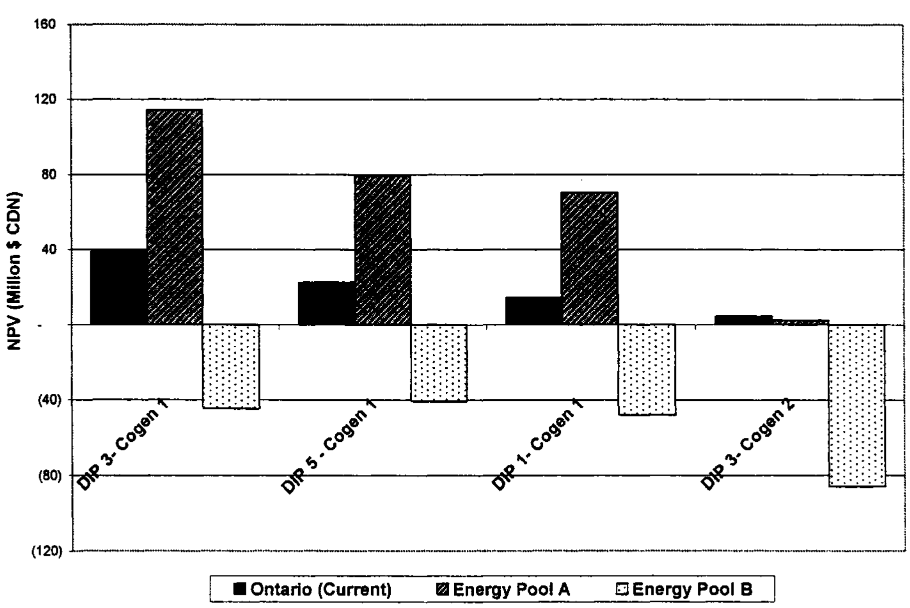


Figure 4.6 NPV for the design alternatives with different electricity prices

Figure 4.7 shows the results for global warming potential for the proposed electricity scenarios. As can be seen, the global warming potential are the lowest when the design alternatives are using electricity from a source like "Energy Pool A" compared to the base case. This is because 1 MWh produced with the proposed co-generation systems generates less greenhouse gases than an equivalent 1 MWh generated and provided by the grid. For a system that uses electricity from a source like "Energy Pool B", it is not favorable from a global warming perspective to implement the suggested design alternatives compared to the base case.

The results suggest that the considered co-generation systems are a less attractive environmental option when the electricity sources are based on hydroelectricity (Energy Pool B). However, in systems where the primary source of electricity production is based on nuclear and fossil fuels, the design alternatives are more environmentally attractive.

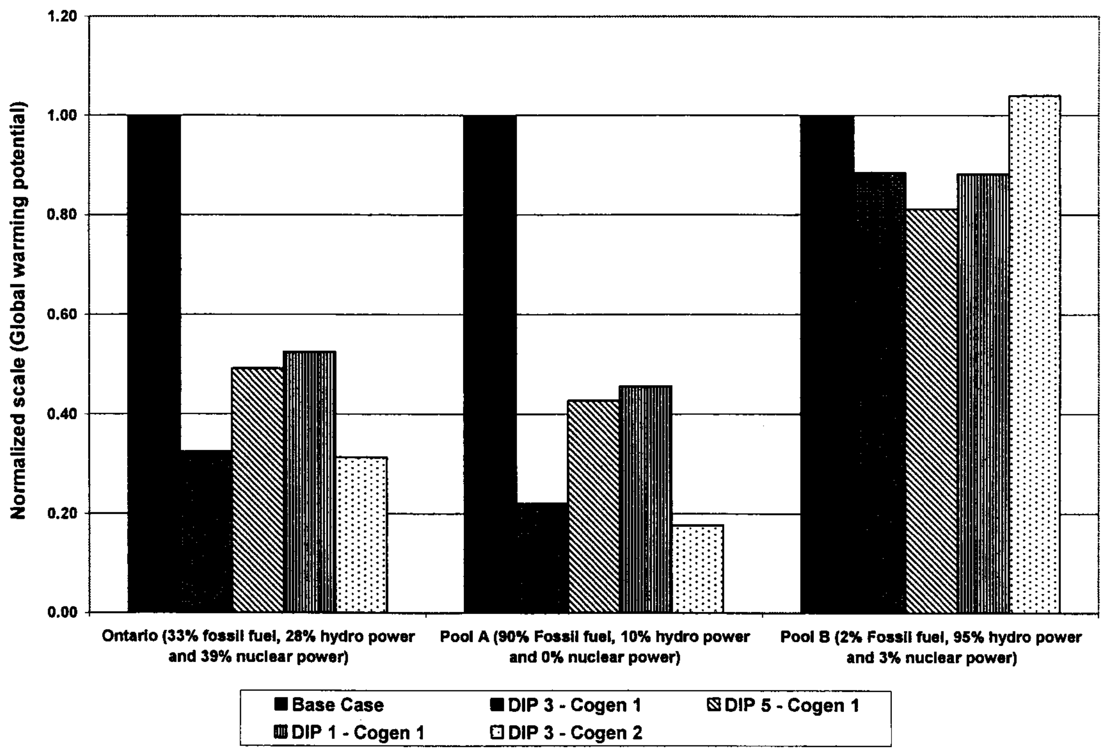


Figure 4.7 LCA scenarios using different mixed Energy Pools

CHAPTER 5: CONCLUSIONS AND CONTRIBUTION TO THE BODY OF KNOWLEDGE

The current methodology for the assessment of environmental impacts of new projects shows some shortcomings. It is generally focused on the identification of environmental impacts at the facility level or at the receiving environment without looking at broader systems such as the product-chain level or the product life cycle. In this research project a methodology has been proposed to enhance the Environmental Impact Assessment (EIA) process for major industrial projects by integrating Life Cycle Assessment (LCA) considerations and following are the main conclusions related to each step in this methodology:

- The proposed methodology gives a broader scope to the analysis of new industrial project designs. Results from this proposed tool show that environmental performances at the facility-level and product chain-level are different. Furthermore, important environmental benefits are perceived across the product chain due to the implementation of a set of economically and technically feasible alternatives oriented to the implementation of co-generation and increased DIP production.
- By performing a MCDM process using an Analytical Hierarchy Process (AHP) environmental criteria can effectively be combined into a single Environmental Index. This Environmental Index can be used to evaluate the environmental performance of different design alternatives in a project design process.

- By considering converting TMP pulp production to 100% DIP pulp production, in combination with installing a co-generation facility both the economic and overall environmental performances can be improved.
- The economic performance and the potential Greenhouse Gas Mitigation of different design alternatives oriented to increase DIP pulp production and implement co-generation are dependent on the grid fuel mix and the price of electricity.
- Monetized carbon savings can strongly affect project's economic performances Furthermore, background and foreground carbon savings need to be considered to have an important positive effect on project's ROI.

SUMMARY OF CONTRIBUTIONS TO KNOWLEDGE

The main contributions to the body of knowledge from this research project related with the initial stated main hypothesis and sub-hypothesis are:

- An enhanced methodology for the systematic evaluation of environmental impacts of new projects considering LCA and EIA. The main feature is the combination of both tools by using a normalized scale followed by a Multi-Criteria Decision Making (MCDM) tool which is used in order to weight EIA (i.e., site-specific) and LCA (i.e., site-generic) criteria to obtain a final single Environmental Index (EI) which expresses the integrated environmental performance of a set of design alternatives.

- The demonstration that the increase of DIP production capacity and the implementation of co-generation at an integrated newsprint mill are economically/technically feasible under some market and investment conditions. At the same time, the design 'alternatives represent important benefits at the product-chain level that makes them environmentally attractive.
- The illustration that fuel grid mix and electricity cost has strong influence on environmental and economic performance of new industrial projects related to the implementation of co-generation and the increase of DIP pulp production.
- The illustration of the positive economic effect of quantifying and monetizing carbon savings in projects oriented to reduce energy consumption and to co-generate greener electricity and the implications of considering either foreground and background or both.

LIMITATIONS OF AND RECOMMENDATIONS FROM THIS STUDY

The recommended data quality assessment by ISO 14043 has not been performed to the LCA inventory. At the background level; the data was the same as in a previous study which implies that the data's quality is equal to that previous work (*Salazar 2004*). Foreground inventory for the design alternatives was based on energy and mass balances, which were validated by experts. It would be beneficial to assess the quality of the foreground data by using quality indicators.

Only LCA output related impact categories have been considered in this study, the input impact categories were not included since no models for these impacts are available.

The consumption of wood chips, woodwaste and recycled wastepaper have been considered as elemental flows in the LCA modelling, future analysis of their importance should be evaluated by expanding LCA boundaries to include their markets in order to have a better assessment of the importance of these materials on the presented results.

Since this project was oriented to use LCA as a comparative tool, the main objective, of the LCA analysis, was to select the best design alternative based on life cycle impact assessment results. Only contribution analysis was performed on the LCA results of the design alternatives. Consequently, it is recommended to analyse uncertainties and sensitivities of each single alternative as future work.

No generalization of the results and consequent conclusions related to the design alternatives can be made since this study is unique due to the context considered for the assessment.

The site-generic targets proposed during the Multi-Criteria Decision making step are based on subjective elements and references, which are conventionally involved in the definition of targets. As a consequence, it is suggested to perform uncertainty and sensitivity analyses on this reference information used to define the targets in order to have a better conclusion related to their relevance.

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APPENDIX 1: USING LIFE CYCLE ASSESSMENT AS A TOOL TO ENHANCE CONVENTIONAL ENVIRONMENTAL IMPACT ASSESSMENT (EIA) OF NEW PROJECTS

Using Life Cycle Assessment (LCA) as a Tool to Enhance Environmental Impact Assessments (EIA)

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Abstract

This paper proposes a methodology to improve the Environmental Impact Assessment (EIA) process for major industrial projects by integrating Life Cycle Assessment (LCA) considerations.

Facility-based environmental impacts (site-specific) are addressed by the classical EIA methodology, whereas product-based potential environmental impacts (site-generic) are assessed by the LCA methodology. Design alternatives may influence the environmental impact of a project in the product chain due to activities upstream and downstream of the process. In this context, incorporating LCA considerations in an EIA may provide significant opportunities for the comparison of different design alternatives, for both green field and retrofit design. The relative importance of the values of the different environmental metrics resulting from the two techniques can be evaluated by a panel of experts using a Multi-Criteria Decision Making (MCDM) methodology, where the experts evaluate and weight the different EIA and LCA metrics based on distance-to-target criteria.

This proposed methodology is illustrated by means of a case study for an integrated newsprint mill considering a major modernization project including increased deinked pulp (DIP) production and the implementation of cogeneration. The benefits of the methodology are demonstrated by evaluation and quantification of otherwise hidden environmental credits and/or impacts, estimated for a set of project alternatives. A sensitivity analysis was performed on the MCDM panel results, and it indicated that the site-generic impact categories were more sensitive than the site-specific criteria. This can be explained by the fact that for the latter set of criteria, current regulatory levels were used as reference targets, allowing experts to have greater confidence in the weight attributed to each criterion.

Introduction

"The growing concerns about a wide range of environmental issues being identified through public opinion, political bodies, non-governmental organizations (NGOs), and industry must be carefully addressed by companies considering major projects. These broad concerns may be related to the sustainability of the available resource base, impacts on human health, or the well-being of the natural environment. Whatever the reasons for these concerns, they may result in actions such as the implementation of new environmental regulations, to which industry must adapt" (Baulmann *et al.*, 2004).

In the conventional approach for assessing new design projects, typically only the most economically feasible option identified in a techno-economic study undergoes an environmental evaluation. This classical methodology does not allow for an early and systematic analysis of environmental impacts and benefits resulting from a number of still economically attractive, but possibly more environmentally sound, design alternatives.

Due to the site-specific nature of EIA, the scope and boundaries of an environmental assessment are restricted to the environmental impacts on the local receiving environment only. Several authors (Tukker *et al.*, 1999; Bruhn-Tysk *et al.*, 2002) have pointed out that EIA does not consider important site-generic impacts such as global warming, or the environmental impacts at the product-chain level, all of which could be of critical importance. Life Cycle Assessment (LCA) covers many of the environmental impacts associated with a product or a process by using a "cradle-to-grave" approach, meaning that environmental impacts are quantified from the extraction of the raw materials to the final disposal of the manufactured product (De Haes *et al.*, 2002). This paper proposes a methodology that combines EIA and LCA for the evaluation of major industrial projects, resulting in a broader environmental analysis to address the above issues.

Environmental Impact Assessment (EIA)

In general, environmental impact assessment (EIA) is a tool used to predict the environmental effects of proposed initiatives before they are carried out (Canter, 1998) (Figure 1). Environmental assessments are performed to minimize or avoid adverse environmental effects before they occur, and to incorporate environmental factors into decision making.

Governments use EIAs to ensure that the adverse environmental effects of proposed industrial projects are identified and mitigated where possible, by employing a methodology that incorporates an evaluation of the Best Available Technology (BAT). Ideally, the assessment of environmental effects and provision for their mitigation are an integral part of the project planning and design process. In Canada, the formal EIA process is based on the Canadian Impact Assessment Act established in 1992. EIA has the following goals:

a) to identify possible environmental effects,
b) to propose measures that mitigate those adverse effects, and
c) to predict whether there will be significant adverse environmental effects after the mitigation has been implemented.

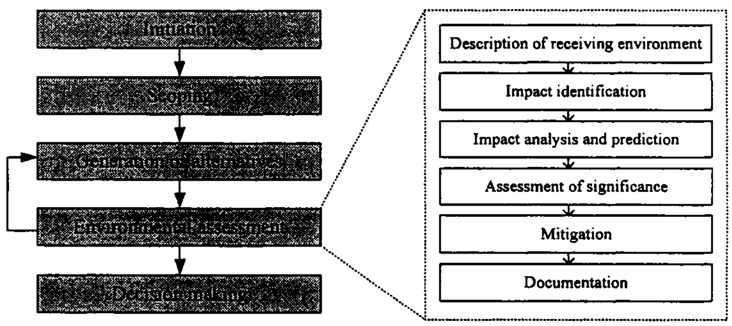

Figure 1. EIA methodology (Canter, 1998)

Life Cycle Assessment (LCA)

LCA is a method that assesses the potential environmental impacts associated with a product, process, or service throughout its entire life cycle from resource extraction to ultimate disposal (i.e., cradle-to-grave). The LCA methodology was recently standardized in the International Organization for Standardization (ISO) 14040 series (ISO 14041, 1997), and consists of the following phases: goal and scope definition, inventory analysis (LCI), impact assessment (LCIA), and interpretation. Figure 2 shows the relationship between these four phases and general LCA applications. The double arrows illustrate the iterative nature of the methodology.

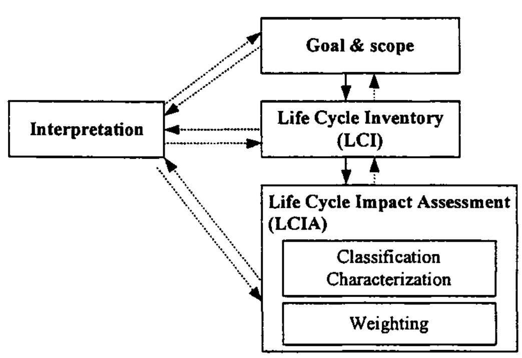

Figure 2. LCA methodology (Baulmann *et al.*, 2002)

Integrated Environmental Evaluation Methodology

The goal of the integrated methodology addressed in this study is to assess product-chain (site-generic) environmental impacts using LCA, along with facility-oriented (site-specific) environmental impacts using EIA. The proposed methodology aims to provide a better analysis of the environmental impacts for a defined set of design alternatives, in order to have the information necessary to choose the most beneficial project scenario using combined environmental and economic perspectives.

Figure 3 contrasts the conventional and proposed approaches. The diagram on the right represents the proposed approach evaluated in this study, where LCA is integrated into the overall environmental assessment.

This paper investigates whether a better informed decision can be made due to the enhanced completeness and broader view of the proposed methodology due to the inclusion of LCA in the conventional EIA methodology.

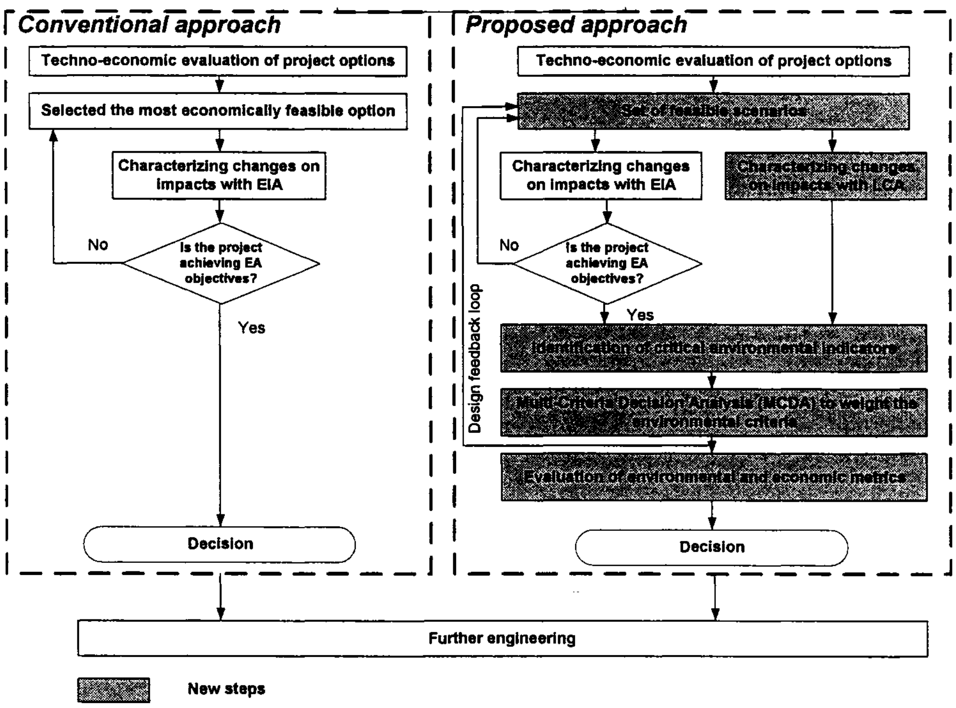

Figure 3. Conventional and proposed approaches

Description of Major Mill Modernization Project

Base case

The base case production plant is an integrated newsprint mill located in Ontario, Canada. It has an average production of 375,000 Finished Metric Tons (FMT) of newsprint per year based on 80% virgin pulp and 20% recycled pulp. The virgin pulp is produced from wood chips supplied by a sawmill owned by the mill, and several external sawmills in the vicinity. Recycled paper is transported from urban locations such as New York, Chicago, and Toronto, as well as from smaller communities near the mill location, and consists of 20% old magazines (OMG) and 80% old newsprint (ONP).

The boilers produce an average of 6700 MMBTU of steam per day. A small fraction of the produced steam is sent to a back pressure turbine that co-generates 2.5% of the total electricity used to run the mill. Natural gas is currently used as the main fuel in the boiler house. Secondary fuel sources include biomass and 50% of the sludge produced in the Deinked Pulp (DIP) mill and wastewater treatment plant operations. The rest of the sludge is landfilled outside the mill complex in two sites that are owned by the mill.

Project Alternatives

The goal of the project was to increase de-inked pulp (DIP) production and to implement cogeneration at the integrated newsprint mill. Some of the key process design implications are summarized in Table 1.

Table 1. Process design implications related to implementation of de-inked pulp production and cogeneration

Increasing DIP Production	Cogeneration
• Reduction of virgin fibre consumption • Reduction of electricity requirements at the facility level (less TMP) • Increase in the amount of generated sludge and solid wastes (mainly from increased DIP) • Increase in transportation	• Consumption of greater quantities of biomass and natural gas • Sludge generated by DIP can be burned in the boilers • Reduction of landfilled material

Eighteen different design alternatives were proposed by combining different DIP and cogeneration configurations. A techno-economic analysis was performed, and it was determined that only 4 out of 18 alternatives were economically feasible under current market conditions (Janssen *et al.* 2005). These four project alternatives from the techno-economic study are summarized in Table 2.

Table 2. Summary of promising project alternatives

	Units	Base case	Option 1	Option 2	Option 3	Option 4
Fibre consumption						
Virgin fibre	%	80	0	50	50	0
Recycled fibre	%	20	100	50	50	100
Fuel consumption						
Natural gas	MM m3/yr	28.3	25.8	29.3	30.1	35.2
Wood waste	BDMT/yr	93,500	187,000	187,000	187,000	187,000
Sludge	BDMT/yr	23,300	47,200	39,750	34,650	47,235
Overall electricity consumption	MWh/yr	1,087,000	450,230	826,650	828,872	450,733
Cogeneration (%)	%	2.50%	78.0%	59.5%	59.0%	94.5%
Purchased from grid (%)	%	97.50%	22.0%	40.5%	41.0%	5.5%

Evaluation of Site-Specific Environmental Impacts

A community is located 200 m north from the facility area and the population is approximately 10,000 inhabitants.

The simplified EIA study included:

a) identification and description of the significant air and water emission sources as well as solid waste generation,

b) estimation of emission rates for each identified contaminant of concern for the base case and modernized mill configurations, and

c) comparison of concentrations with relevant applicable environmental regulations at the municipal, provincial, and federal levels.

Other Environmental Impact Statements (EIS) for similar projects were reviewed in order to identify the most critical environmental criteria to evaluate. The key emissions expected to increase compared to the base case were the following:

- Air emissions: Total Suspended Particles (TSP), oxide nitrogen (NOx), sulphur oxide (SO_2).
- Water emissions: Biological Oxygen Demand (BOD)
- Solid waste generation: Ash

Nutrients and certain other discharges were not considered in this EIA study because of unchanged or reduced emission levels in the base case due to the project modifications. Furthermore, the criteria of particle matter less than 10 microns (PM_{10}) and 2.5 microns ($PM_{2.5}$) were also excluded due to a lack of regulations.

Legislation set by the province of Ontario was used for comparison of the calculated concentrations in the receiving environment related to the different design alternatives. The regulations used were "Point of Impingement (POI)" for air emissions and loading limits (in kg/t) set in "Effluent Regulation for Pulp and Paper Mills" for water emissions. The four economically feasible project alternatives were analyzed using this conventional approach. Table 3 shows the results for the emissions considered.

Table 3. Contaminant emission rates for the proposed project alternatives

Criteria		Units	Base case	Option 1	Option 2	Option 3	Option 4	Regulation
Air	TSP	µg/m3	61	69	72	72	69	100
	NO_x	µg/m3	50	47	52	52	59	500
	SO_2	µg/m3	227	270	251	251	269	830
Water	TSS	kg/d	2,000	1,750	2,000	1,750	1,750	9,180
	BOD_5	kg/d	424	200	400	300	200	5,830
Solid waste	Ash	t/yr	11,600	15,900	14,150	12,800	15,900	ND

Evaluation of Site-Generic and Product-Based Environmental Impacts

The methodology used to perform the LCA study followed ISO 14040 guidelines and then was peer-reviewed by LCA experts (Figure 4). The functional unit used for the assessment was 1 Air Dry Metric Ton (ADMT) of newsprint. The data inventory was based on primary data and engineering calculations such as energy and mass balances, and secondary data such as external databases, emission factors, etc. The system was modeled using the LCA software SIMAPRO 5.1. Relevant impact categories were selected based on SETAC guidelines, using the characterization factors developed by the USEPA (i.e., TRACI impact assessment method) in order to characterize the emissions from the system (Salazar *et al.* 2005).

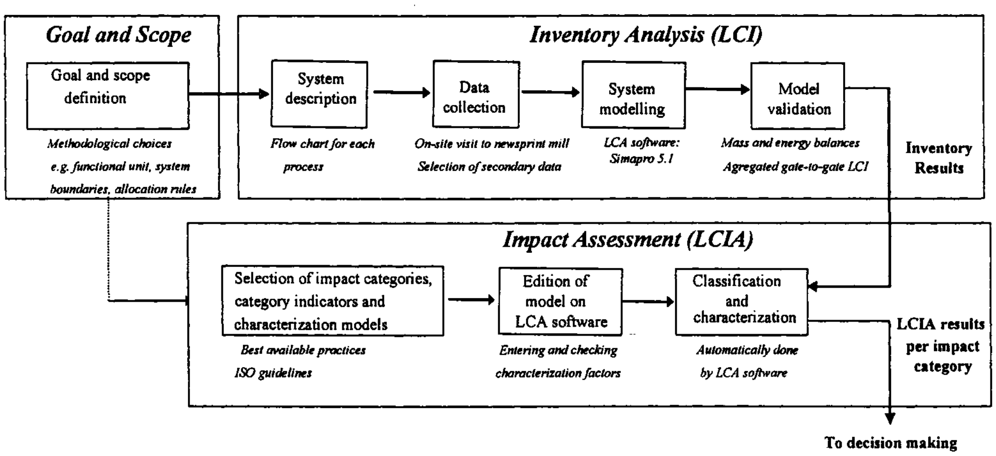

Figure 4. Overall methodology used for the LCA analysis of the design scenarios

The LCA boundaries (Figure 5) considered for the environmental analysis of the different project alternatives included unit processes for the production of electricity, fuels, chemicals, as well as transportation of the final product for delivery to the customer. In addition, the transportation of the different raw materials used for manufacturing the final product was considered.

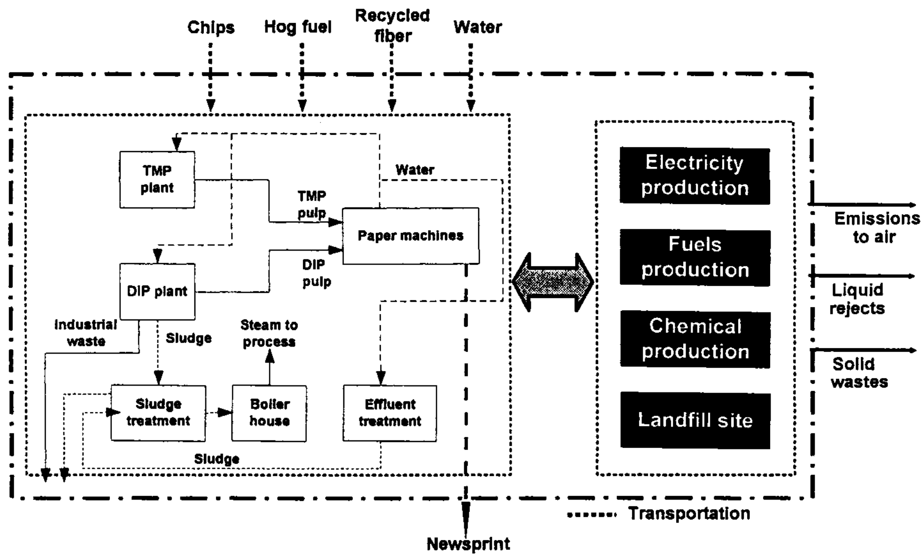

Figure 5. LCA system boundaries

Table 4 presents the selected impact categories, indicators, and models for the LCA. The results for the different project alternatives are summarized in Table 5.

Table 4. Life cycle impact categories considered

Impact Categories	Scale	Category Indicators	Characterization Models
Climate change	Global	g CO_{2eq}	IPCC
Ozone depletion		g $CFC11_{eq}$	WMO
Acidification	Regional	mol $H+_{eq}$	TRACI – Michigan
Eutrophication		g N_{eq}	TRACI – Michigan
Photo-oxidant formation		g NO_{xeq}/m	TRACI – Michigan
Eco-toxicity	Local	g $2,4D_{eq}$	TRACI – USA
Human health-cancer		g C_6H_{6eq}	TRACI – USA
Human health-non cancer		g C_7H_{7eq}	TRACI – USA
Human health criteria pollutants		DALY	TRACI – Michigan

Table 5. LCIA results for the proposed alternatives

Impact category	Unit	Base case	Option 1	Option 2	Option 3	Option 4
Global Warming	g CO_2	1,110,000	406,000	584,000	625,000	404,000
Ozone Depletion	g CFC11	0.006	0.00808	0.00522	0.00648	0.00814
Acidification	Mol H^+	297	191	228	242	219
Photo-Oxidant Formation	g NO_x/m	2.55	2.62	2.64	2.77	2.87
Eutrophication	g N	430	327	381	350	331
Ecotoxicity	g 2,4-D	3,130	566	1,240	1,230	340
Human Health Cancer	g C_6H_6	74.4	21.4	32.2	36.2	16.6
Human Health Particulates	DALY	0.000145	0.000129	0.000136	0.000141	0.000137
Human Health Non cancer	g C_7H_7	363,000	136,000	196,000	211,000	137,000

Weighting of Critical Environmental Metrics Using Multi-Criteria Decision Making (MCDM)

In order to select a preferred project option, the environmental results from the EIA and LCA should be evaluated and weighted by experts, and then aggregated so that a final environmental indicator can be calculated for each project option. Targets were defined for each environmental impact criterion to help the experts assign weighting factors. The Analytic Hierarchy Process (AHP) (Saaty, 1980) was used for the weighting of the different criteria for final decision making. AHP was selected primarily due to its wide application. AHP is based on pairwise comparisons and contains indicators that measure the consistency of these comparisons. This feature makes AHP an optimal choice for the panel evaluation (Saaty, 1980). The indicators to measure this consistency are calculated with the following formulas:

- Consistency Index (CI):

$$CI = \frac{\lambda_{\max} - n}{(n-1)} \qquad (1)$$

where:

λ_{max} = eigenvalue of the comparison matrix

n = number of decision criteria

- Consistency Ratio (CR):

$$CR = \frac{CI}{RI} \tag{2}$$

where:
RI: Random Index
Table 6 presents the random index which is defined by the number of criteria (N) used during the panel elicitation (Saaty, 1980).

Table 6. Random Index table

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.52	1.54	1.56	1.58	1.59

If CR is higher than 10%, the elicitation should be performed again until a ratio lower or equal than 10% is reached (Saaty, 1980).
For the site-specific criteria, current regulatory levels were used as targets. For the site-generic criteria (LCA criteria), the methodology for defining the targets included the following steps:

Contribution analysis	The individual emissions contributing to a total of 99% of each LCA impact category were identified.
↓ *Identification of emission targets*	A relative Canadian reduction target was found for the emissions identified. When no reduction target was available, it was assumed that the emissions should remain constant. All the targets were relative to a reference year.
↓ *Calculation of targets relative to reference year (2001)*	All the targets were recalculated relative to year 2001, which corresponds to the base case, using Canada-wide emissions for that year.
↓ *Calculation of targets for impact categories*	The Canadian emissions targets relative to year 2001 have been applied to the base case in order to calculate targeted emissions. Characterization factors have been used to transform those targeted emissions into targets for impact categories.

Finally, the Environmental Index (EI) was calculated by the following mathematical expressions:

$$N_{ij} = \frac{Criterion_{\ iSc_j}}{\text{Base case value}_{Criterion_i}} \tag{3}$$

where:
N_{ij} = the normalized value for the criterion i and the design alternative j,
Criterion $_{i\,SCj}$ = the result of a defined criterion i (LCA or EIA) for design alternative j,

Base Case $value_{criterion\ I}$ = the value of the criterion i for the base case.

$$EI_j = \sum (N_{ij} \times W_i) \quad (4)$$

where:
EI_j = the Environmental Index for the design alternative j,
W_i = the weighting factor assigned for the criterion i. with $\sum_i W_i = 1$.

Panel Results and Implications

The decision making panel consisted of five experts with diverse backgrounds and expertise in each of the following fields: pulp and paper environmental management, environmental research, environmental regulation, LCA, and EIA. To elicit the different pairwise comparisons, a ratio scale employing the whole numbers from 1 to 9 and their reciprocals was used.

The pairwise comparisons were carried out by elicitation to reach a final consensus. If consensus was not reached by a defined time, it was determined whether a majority of the panelists had assigned the same value to the comparison. If so, this value was used in the calculation of the weights. If a majority was not reached, then that particular comparison was placed on hold until the end of the elicitation process. As a result, either a consensus or a majority was reached among the panel members on all pairwise comparisons. This information was used to calculate the weights using the method proposed by Saaty (1980), using a matrix in which the criteria were compared pairwise. Only half of the matrix was required since the other half is automatically filled out by their reciprocals (e.g., 9 in a cell and 1/9 in the corresponding reciprocal cell).

In addition, the AHP consistency ratio was calculated to determine the consistency of the comparisons made by the panelists. If this ratio was too high (C.R. > 10%), the comparison that was the least consistent was identified using a calculation proposed by Saaty (2003), and the panelists were asked to reconsider this comparison. This process was repeated until sufficient consistency was attained and there was agreement among the panelists.

The results of the panel show that greater weights were assigned to LCA criteria (Figure 7). This was discussed with the panelists, and it was noted that the EIA criteria for the 4 considered design alternatives met the current regulations. Consequently, according to the panel, LCA criteria were more important for evaluating the environmental performance for the options.

It should be noted that the AHP consistency ratio at the end of the panel was 10.1%, indicating that the comparisons were near consistency according to AHP guidelines (Saaty, 1980). Due to the large number (i.e., 15) of criteria considered in this decision making problem, the achieved consistency ratio was sufficient to represent consistency of the comparisons.

Discussion of panel results and sensitivity analysis

A sensitivity analysis was performed (Figure 6), where the sensitivity of each criterion was calculated using a Sensitivity Index (SI). The sensitivity index (SI) is the easiest and most reliable sensitivity measure and can be calculated without detailed knowledge of the parameter distribution and without the use of random sampling schemes or large computer programs. The SI is defined as follows:

$$SI = \frac{D_{max} - D_{min}}{D_{max}} \quad (5)$$

where:

D_{min} and D_{max}, represent the minimum and maximum output values resulting from varying the input over its uncertainty range (Hamby, 1994).

The inputs for this sensitivity analysis were the highest and lowest values assigned during the elicitation process through the pairwise comparisons. The matrix calculated weights using the lowest and highest values. Based on that, these weights were compared against the original values, and the sensitivity ratios for each criterion were determined using Hamby's SI (see Formula 5).

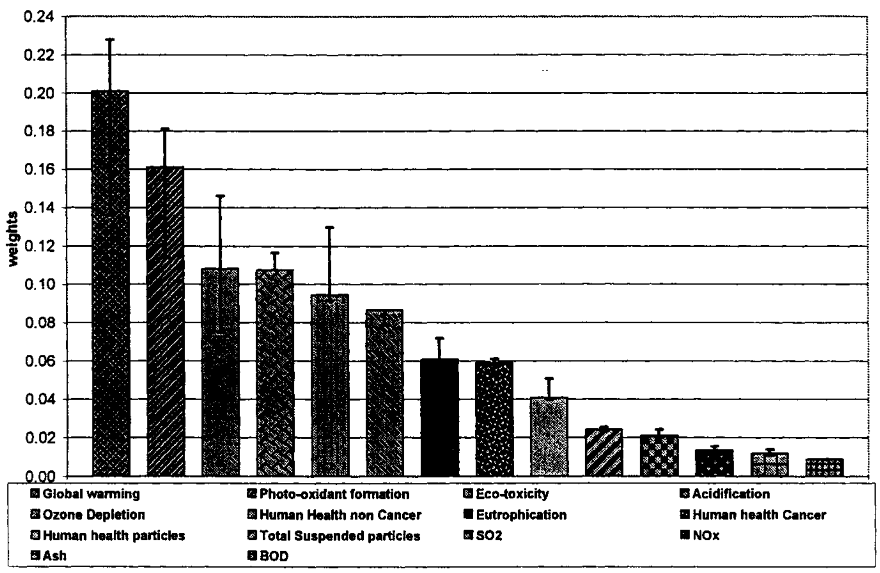

Figure 6. Sensitivity analysis on panel results

Based on this analysis, it was found that site-specific criteria are less sensitive than site-generic criteria. The criteria with the highest sensitivities were Global Warming (GW) and Eco-toxicity (Etox), while Total Suspended Particles (TSP) exhibited the lowest sensitivity. This was discussed with the panel and the following points were highlighted:

- EIA targets are regulated and therefore their importance is easier to evaluate in this decision problem, whereas the LCA targets are not regulated, and as a consequence, they are subject to uncertainty.
- There is ambiguity in the units used to express the final LCA impact categories results and their relevance, compared to the units for the site-specific criteria.

Evaluation of Integrated Environmental Evaluation Methodology

Figure 7 summarizes the overall results of the LCA and EIA assessments. They are presented using a normalized scale, meaning that the environmental results of the design alternatives were compared against the environmental performance of the base case. A positive percentage means a higher emission or impact due to the new design alternative, while a negative percentage means an environmental benefit.

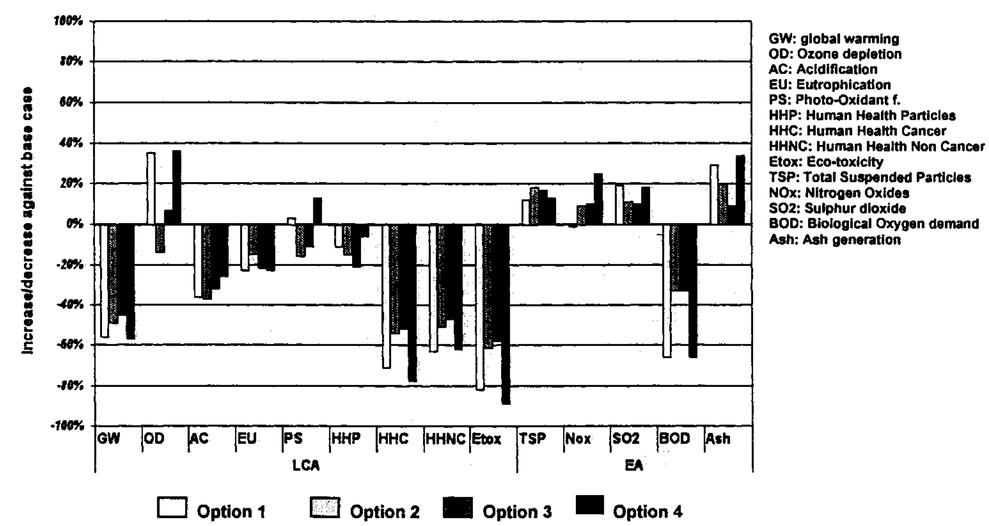

Figure 7. Overall environmental results from the panel

Figure 7 shows two different trends for the EIA and LCA results. A new cogeneration plant at the mill would increase emission levels to the receiving environment, resulting in a change in the current environmental conditions. However, the LCA results show that the proposed design alternatives would have significant environmental advantages when considering the product chain, since electricity produced at the mill (~80% bark and 20% of natural gas) is greener than electricity supplied by the grid (39% fossil fuel, 28% hydro power, 39% nuclear power).

Option 1 achieves a reduction of Green House Gas (GHG) emissions of approximately 63% (Figure 8) when compared to the base case. This represents an environmental

credit that can be monetized and would increase the financial performance of Option 1 if a Canadian over-the-counter $CO_{2\,eq.}$ credits market were implemented in the future. At the same time, a replacement of the thermo-mechanical pulp (TMP) production by recycled pulp production (DIP) will significantly reduce the amount of electricity consumed by the mill (the TMP chip refiners are responsible for 70% of the current total electricity consumption of the mill). This reduction is as high as 50% for the alternatives considering an increase of DIP production, which would lead to the shutdown of the TMP plant (100% DIP production, i.e., Options 1 and 4 in Table 2).
A contribution analysis has been performed for each single LCA impact category considered in this evaluation in order to have a better assessment of each option. Figure 8 depicts the contribution analysis carried out for the Global Warming Potential (GWP) impact category indicator using the LCA results of the system.

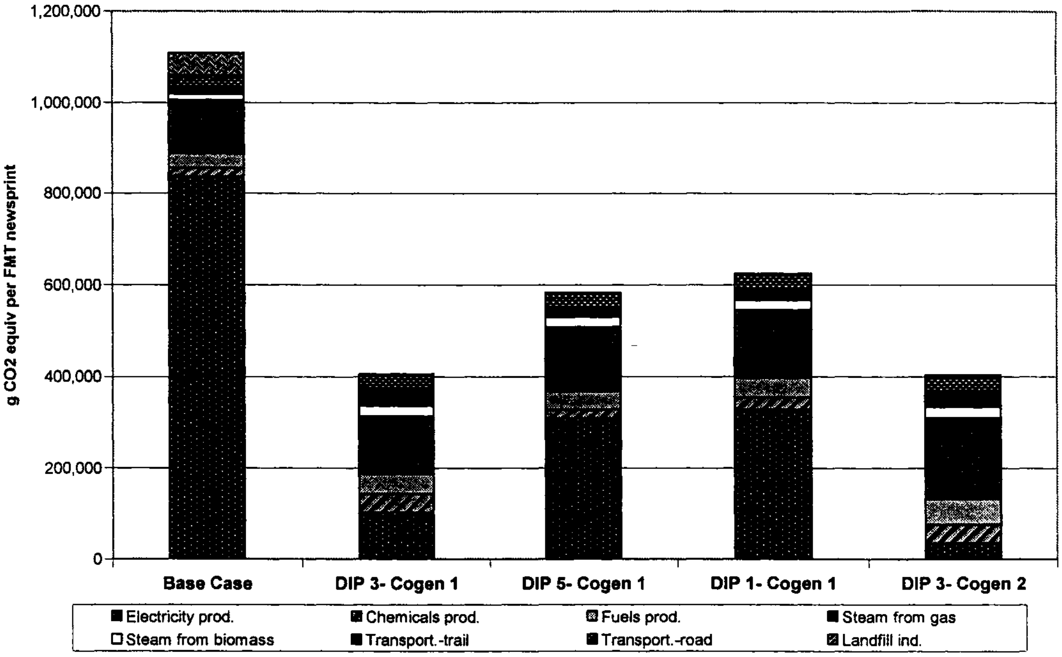

Figure 8. Global warming contribution analysis

From an LCA point of view, this significant reduction of the consumption of electricity from the grid (which is equivalent to the co-generated MWh at the facility) would result in a reduction of fossil fuel-based electricity production by Ontario Power Generation (OPG) (nuclear and hydro remain constant). Thus, a reduction in electricity consumption would reduce the environmental load of the product system, which would in turn have a positive effect on the majority of the LCA impact categories. In particular, LCA local impacts such as human health cancer, human health non-cancer, human health particles, and eco-toxicity would be mitigated. Furthermore, the

reduction of electricity consumed from the grid would positively impact nearly all other impact categories including acidification and photo-oxidant formation (Figure 7). The increased consumption of natural gas and biomass at the facility level for Options 1 and 4 (100% DIP production scenarios) increases photo-oxidant formation levels by 3% and 13% respectively when compared to the base case. This is due to increased emissions of NO_x, CO, and non-methane VOC emissions at the boiler house. Moreover, ozone depletion levels increase in Options 1, 3 and 4 (new DIP lines), and are higher than the base case levels by 35, 8, and 36% respectively, due to their increased consumption of chemicals at the facility level.
Finally, once the normalized results and the weighting factors have been calculated, the Environmental Index (EI) was found using equations (1) and (2) for each design alternative, and this value was compared against their Net Present Value (NPV) (calculated in Janssen *et al.* (2005)) (Figure 9).

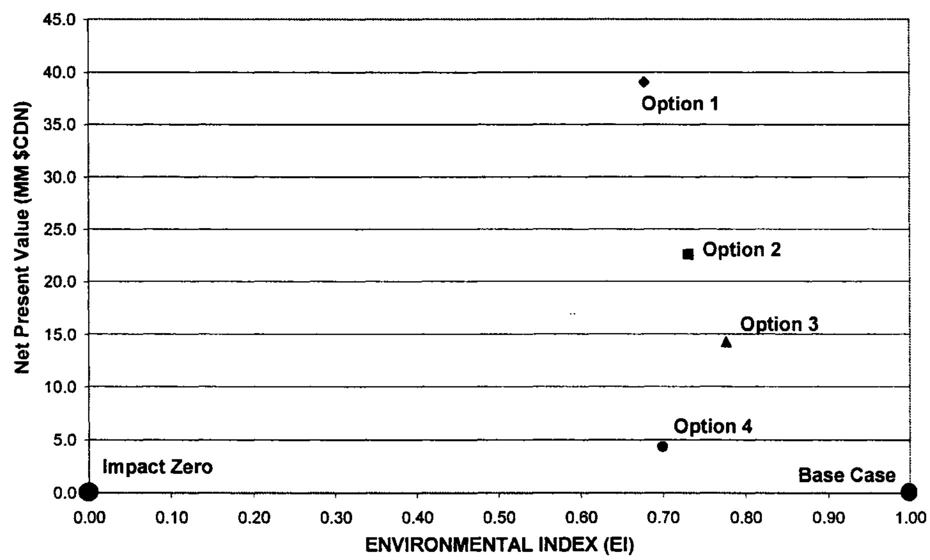

Figure 9. Economic vs. environmental performance of each project option

The best environmental performance is related to the Option 1 (i.e., 0.68 pts) showing that other project alternatives are in a closer range. However, from an economic perspective, Option 1 significantly outperforms the other alternatives, suggesting that this alternative should be considered in a subsequent detailed engineering study. The conventional EIA (Table 3) shows that all the legal environmental requirements are met for this option. Furthermore, the proposed methodology shows that Option 1 is the most environmentally competitive alternative (Figure 9), which suggests that good economics often coincide with a positive environmental performance.
The proposed methodology allows for analysis of the environmental impact of the product chain and a systematic combination of site-specific with site-generic criteria in

order to express the environmental performance in one single indicator (Environmental Index).
Table 7 shows the Environmental Index (EI) results calculated by using maximum, average, and minimum weighting factor values. As can be seen, Option 1 is still the most environmentally preferable scenario under different weighting scenarios. However, it is closely followed by Option 4 (i.e., 0.70 pts).

Table 7. Environmental position of scenarios under different weighting scenarios

Scenarios		Environmental Index (EI)	NPV (MM CDN)
MAX - Weighting factors	Base case	1.000	0
	Option 1	0.706	39.0
	Option 4	0.727	4.3
	Option 2	0.735	22.6
	Option 3	0.787	14.3
AVERAGE - Weighting factors	Base case	1.000	0
	Option 1	0.678	39.0
	Option 4	0.699	4.3
	Option 2	0.731	22.6
	Option 3	0.776	14.3
MIN -Weighting factors	Base case	1.000	0
	Option 1	0.690	39.0
	Option 4	0.712	4.3
	Option 2	0.742	22.6
	Option 3	0.787	14.3

The aforementioned results highlight several advantages of using this proposed methodology, as expressed by the following:

- Since environmental performances at the facility-level and product chain-level can be different, a need exists for integrating LCA into conventional EIA so that both perspectives are taken into account, resulting in an enhanced and well-informed decision making process.

- At the same time, by analyzing the both LCA and EIA criteria results, a panel of experts should assign importance weights to the selected criteria; the weights should be different depending on the type of project.
- Including LCA in the overall EIA evaluation can help to clarify current paradigms and debates related to $CO_{2\ eq.}$ credits and their allocation in a defined system, an issue that is currently important from both a national and international point of view, due to international agreements such as the Kyoto Protocol. This issue is also significant at the project level, since $CO_{2\ eq.}$ credits can represent a potential economic benefit in the future.
- Based on the contribution analysis (Figure 9) and the normalized scale (Figure 8), the communication process is improved by using the proposed methodology to show the results and to allow the public to see the trends of both site-specific and site-generic impacts.

Conclusions

An integrated tool using EIA and LCA has been proposed that aims to assess the site-specific and site-generic environmental impacts of major project modifications at an integrated newsprint mill. The results show the following:

- Conventional EIA metrics can be effectively combined with LCA metrics using a multi-criteria decision-making methodology,
- The greatest subjectivity involved in the proposed methodology is related to setting LCA targets. These targets lack objectivity, since setting targets at the national level is always influenced by social perspectives and political points of view.
- The sensitivity analysis performed on the panel results indicates that site-generic impact categories are more sensitive than site-specific criteria, most likely due to the nature of the reference targets. It is difficult to compare two LCA targets, whereas comparing a regulated target with another target yields fewer problems.
- The consistency ratio was 10.1%, indicating that the comparisons of the panel members were reasonably consistent. However, the high number of criteria (15) was a constraint to reaching the desired consistency ratio.
- The methodology showed that when conventional site-specific parameters are well within regulated limits, LCA parameters become of greatest concern to a panel of experts.
- When considering EIA metrics only, the environmental performance assessment was restricted to the site-specific level, and suggested that Option 1 would increase the air emission levels in the receiving environment. However, the change in these emissions was always below current regulation limits. When EIA metrics were

combined with LCA metrics, it was found that Option 1 could lead to an increasing load of contaminants at the facility-level, whereas at the product-chain level, this same option resulted in important environmental credits, in the form of reducing current levels for global, regional, and local LCA impact categories.

- The selected alternative, Option 1, has the best economic performance, as expressed by the Net Present Value, and it also meets the environmental regulations. Furthermore, this scenario has the best environmental performance at the facility level and product-chain level showing great benefits such as the reduction of greenhouse gases, and also with respect to human health related impact categories and several other global and regional impact categories.

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APPENDIX 2: GREENHOUSE GASES MITIGATION (GHGM) IMPLICATIONS OF IMPLEMENTING CO-GENERATION AND INCREASING DE-INKED PULP PRODUCTION AT AN INTEGRATED NEWSPRINT MILL

Greenhouse Gases Mitigation (GHGM) implications due to the implementation of co-generation and increasing recycled paper production at an integrated newsprint mill

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ABSTRACT

This paper examines greenhouse gas mitigation (GHGM) implications due to different process design alternatives, resulting from the implementation of co-generation and increased de-inked pulp production at an integrated newsprint mill. Co-generation using biomass represents an important means for the pulp and paper industry to achieve reductions in fossil fuel use. De-inked pulp (DIP) production requires only about a quarter of the total energy needed for thermo-mechanical pulp (TMP) production. These two major projects represent a potentially important economic opportunity for integrated newsprint mills, to reduce operating costs while achieving carbon savings using both facility and product chain perspectives.
In this paper, a techno-economic analysis is performed for various process design alternatives for the implementation of co-generation and DIP production, in order to identify those opportunities which are economically viable at an integrated newsprint mill. Using an LCA-based methodology, foreground (facility level) and background (utility and fuels production) carbon savings are quantified for the feasible design alternatives. The economic implications of monetizing these carbon savings in a future Carbon Trading System are analyzed, considering a range of carbon credit values (between 10 and 50 \$/t CO2). Finally, an analysis of these projects is made considering the GHGM achieved using facility (foreground) and product (background) perspectives.
Results show that under current market conditions the design alternative with the best financial performance provides an NPV of CDN\$39 million, and includes an increase in DIP production to 1,100t/d and a 40 MW co-generation facility. A contribution analysis of the life cycle assessment (LCA) results shows that electricity produced at the mill (from approximately 80% bark and 20% and natural gas) is cleaner than electricity supplied by the grid (from approximately 39% fossil fuel, 28% hydro power, 39% nuclear power), and that GHG emissions are consequently reduced by 63% or about 272,000 tonnes CO2equiv/year with this project alternative. By monetizing the total carbon credits (including the foreground and background emissions) at 50 \$/t CO2, an improvement in the project NPV of CDN\$13 million is realized. However, by considering only the foreground credits the NPV improvement is marginal (less than CDN\$3 million). This result illustrates the importance of how GHGM is to be considered in future carbon trading activity.

KEY WORDS

Life Cycle Assessment (LCA), Environmental Impact Assessment (EIA), integrated newsprint mill, Thermo-Mechanical Pulp (TMP), De-inked Pulp (DIP), Multi-Criteria Decision Making (MCDM), Analytic Hierarchy Process (AHP), Global Warming Potential (GWP), carbon savings, Net Present Value (NPV)

INTRODUCTION

With the Kyoto Protocol, the Canadian pulp and paper sector is currently promoting energy efficiency and increased used of biomass based energy sources in order to respond to the future challenges related to this international agreement. Since the pulp and paper industry is energy-intensive and energy costs typically comprise an important percentage of the total production costs, energy projects such as fuel savings or fuel switching technologies, that is, switching from more GHG-intensive fuels to less GHG-intensive and even CO2 neutral fuels (biomass based) could represent a measure to achieve cost reduction. The ability to switch fuels is dependent, among other things, on the availability of alternative fuel supplies.
According to the Kyoto Protocol, Canada has to reduce its CO2 eq. emissions to 6% below the 1990 levels *(Canada Climate Change, 2005, Lynch 2005, Grant 1999)*. At this moment, the Canadian Pulp and Paper sector has already reduced its CO2 eq. emissions by 28% in comparison with 1990 levels which suggests that the pulp and paper sector has been implementing in a fairly high number projects oriented to reduce energy consumption by improving energy efficiency in their mills over the last 15 years. *(Lynch 2005)*
"Canadian Pulp and Paper (SIC 271) sector experts have identified increased use of conventional co-generation as a means of achieving a reduction in energy use and in CO_2 emissions" *(NRCan, 1999)*. Biomass is an accepted form of renewable energy and is seen as a means of helping to reduce global warming by displacing the use of fossil fuels. The use of renewable energy sources is becoming increasingly necessary due to international agreements like the Kyoto Protocol.
"Energy consumption and reduction are widely discussed in the literature for mechanical pulp mills and de-inking pulp mills. One reason is that recycled pulp mills typically have only 25-27% of the gross energy consumption of thermo-mechanical pulp (TMP) mills" *(Dessureault, 2001)*. Consequently, by increasing de-inked pulp production and implementing co-generation, several economic and environmental benefits can be achieved.
Additionally, current electricity costs are uncertain, due to the high volatility of fossil fuel prices which could have a positive effect on future economic feasibility of co-generation projects using bio-fuels.

This paper considers these issues by analyzing carbon savings and their economic and environmental implications in projects oriented to implement co-generation and increased DIP pulp production at an integrated newsprint mill.

BASE CASE DESCRIPTION

The base case production plant is an integrated newsprint mill located in Ontario, Canada. It has an average production of 375,000 Finished Metric Tons (FMT) of newsprint per year based on 86% virgin pulp and 14% recycled pulp. The virgin pulp is produced from wood chips supplied by a sawmill owned by the mill, and several external sawmills in the vicinity. Recycled paper is transported from urban locations such as New York, Chicago and Toronto, as well as from smaller communities near the mill location, and consists of 20% old magazines (OMG) and 80% old newsprint (ONP).
The boilers produce an average of 6700 MMBTU of steam per day. A small fraction of the produced steam is sent to a back pressure turbine that co-generates 2.5% of the total electricity used to run the mill. Natural gas is currently used as the main fuel in the boiler house. Secondary fuel sources include biomass and 50% of the sludge produced in the De-inked Pulp (DIP) mill and wastewater treatment plant operations. The rest of the sludge is landfilled outside the mill complex in two sites that are owned by the mill.

MILL MAJOR MODERNIZATION PROJECTS

The design alternatives look at increased the de-inked pulp (DIP) production and to the implementation of biomass-based co-generation.
The technological DIP configurations considered in this study are related to 1-loop system (alkaline loop) and 2-loop systems (alkaline and acid loops); the co-generation configuration considers the replacement and/or upgrading of idle equipment such as boilers and turbines.
The newsprint production basis has been considered the same across the different process design alternatives (1100 admt/day). A combination of 6 DIP and 3 co-generation scenarios has been proposed obtaining a final number of 18 different scenarios. Table 1 lists the design alternatives considered:

Option	Configuration
DIP 1	Increase to 550 admt/day by implementing a new plant, 1-loop
DIP 2	Increase to 550 admt/day by implementing a new plant, 2-loop
DIP 3	Increase to 1100 admt/day by implementing a new plant, 1-loop
DIP 4	Increase to 1100 admt/day by implementing a new plant, 2-loop
DIP 5	Increase to 550 admt/day by adding a second line to the existing plant, 1-loop
DIP 6	Increase to 550 admt/day by adding a second line to the existing plant, 2-loop
Cogen 1	One natural gas boiler is converted to burn wood waste, and existing turbo-generators kept in service.
Cogen 2	New wood waste boiler (at 900 psig) is installed. Half the boilers are upgraded to 900 psig operation. New turbo-generator added to existing ones.
Cogen 3	New air-cooled condenser and turbo generator are installed.

Table 1 Considered technological scenarios

However, the implementation of the aforementioned alternatives entails several design implications which are summarized in Table 2:

DIP Production	Co-generation
• Reduction of virgin fibre consumption • Reduction of electricity requirements at the facility level (less TMP) • Increase in the amount of generated sludge and solid wastes (mainly from increased DIP) • Increase in transportation	• Consumption of greater quantities of biomass and natural gas • Sludge generated by DIP can be burned in the boilers • Reduction of landfilled material

Table 2 Process design implications related to implementation of de-inked pulp production and co-generation

TECHNO-ECONOMIC ANALYSIS OF THE DESIGN ALTERNATIVES

Figure 1 shows the manufacturing costs of the 18 proposed scenarios. It can be seen that the manufacturing costs are varied each process design option. The differences in the cost of fibre and purchased electricity (including electricity price) had the biggest impact on the overall manufacturing cost for each option; the cost of purchased electricity was clearly reduced in all options when compared to the base case. This reduction depended on:

1. The amount of TMP pulp produced, and/ or replaced by recycled pulp,
2. The increased use of co-generation at the mill,
3. The amount of sludge generated by the DIP and effluent treatment plant,
4. The amount of available hog fuel,
5. The amount of steam regenerated in the Heat Recovery Unit (HRU) of the TMP plant.

The 2-loop system configuration has a higher specific electricity consumption than 1-loop system (650 vs. 450 kWh/ tonne DIP) and its yield is lower (85% vs. 92% for the 1-loop system). At the same time, more chemicals are used in a 2-loop system than in a 1-loop system.

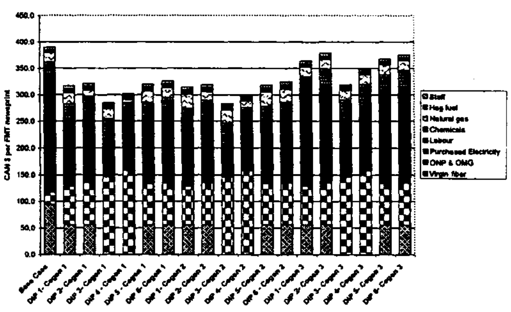

Figure 1 Manufacturing costs graph

Figure 2 shows the economic results for the proposed set of scenarios, showing that only four out of the eighteen design alternatives are economically feasible. *(Janssen et al. 2005)*

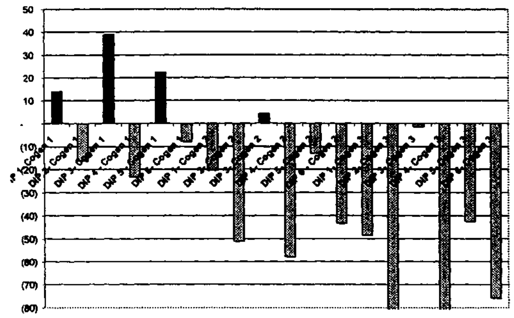

Figure 1 Economic performances of design alternatives

The table 3 shows some important elements of the data inventory based on energy and mass balances at the facility level. Fuel, fibre and electricity consumptions are shown for each of the feasible scenarios:

	Units	Base case	DIP 3 – Cogen 1	DIP 5 – Cogen 1	DIP 1 – Cogen 1	DIP 3 – Cogen 2
'ibre consumption						
'irgin fibre	%	80	0	50	50	0
'ecycled fibre	%	20	100	50	50	100
'uel consumption						
'atural gas	MM m3/yr	28.3	25.8	29.3	30.1	35.2
'ood waste	BDMT/yr	93,500	187,000	187,000	187,000	187,000
'ludge	BDMT/yr	23,300	47,200	39,750	34,650	47,235
)verall electricity onsumption	MWh/yr	1,087,000	450,230	826,650	828,872	450,733
'o-generation (%)	%	2.50%	78.0%	59.5%	59.0%	94.5%
'urchased from grid (%)	%	97.50%	22.0%	40.5%	41.0%	5.5%

'ase Case: 20% DIP (1 loop system) + co-generation 2.5%
'IP 3 - Cogen 1: 100% DIP (new 1-loop system) + Co-generation 78%
'IP 5 - Cogen 1: 50% DIP (new 1-loop system) + Co-generation 60%
'IP 1 - Cogen 1: 50% DIP (retrofit, 1-loop system) + Co-generation 59%
'IP 3 - Cogen 2: 100% DIP (new 2-loop system) + Co-generation 95%

Table 1 Summary of promising project alternatives

ENVIRONMENTAL EVALUATION METHODOLOGY

The economically feasible design alternatives have been analyzed by an integrated environmental tool proposed by Cornejo (2005) where Life Cycle Assessment (LCA) is integrated in conventional Environmental Impact Assessment (EIA) studies of new industrial projects.
The environmental criteria considered to measure the performance of each design alternative are presented in table 4.

	Impact Categories	Scale
EIA	**Air emissions** Total Suspended Particles (TSP) Oxide Nitrogen (NOx) Sulphur Oxide (SO_2)	Facility
	Water emissions Biological Oxygen Demand (BOD)	
	Solid waste generation Ash generation	
LCA	Climate change Ozone depletion	Global
	Acidification Eutrophication Photo-oxidant formation	Regional
	Eco-toxicity Human health-cancer Human health-non cancer Human health criteria pollutants	Local

Table 2 Considered environmental criteria used in the environmental evaluation

Results have shown two different trends for the EIA (site-specific) and LCA (site-generic) results suggesting that proposed design alternatives would marginally increase air emission levels to the receiving environment. However, their LCA results show that these would have significant environmental advantages when considering the product chain, since electricity produced at the mill (~80% bark and 20% of natural gas) will be cleaner than electricity supplied by the grid (33% fossil fuel, 28% hydro power, 39% nuclear power).
At the same time, a replacement of the thermo-mechanical pulp (TMP) production by recycled pulp production (DIP) will significantly reduce the amount of electricity consumed by the mill (the TMP chip refiners are responsible for 70% of the current total electricity consumption of the mill). This reduction is as high as 50% for the alternatives considering an increase of DIP production, which would lead to the shutdown of the TMP plant and 100% DIP production. (i.e., DIP 3-Cogen1 and DIP 3-Cogen2 in Table 1). This reduction on electricity will positively impact on almost all the LCA impact categories.
The environmental criteria results were normalized against the base case and weighting factors were defined by using a panel of experts in order to calculate an Environmental Index (EI) which expresses the overall environmental performance of each design alternative*)*. Finally, EIs are compared against alternative's economic performances showing that scenario considering 100% increased DIP production in combination with a 40 MW co-generation (DIP 3 - Cogen 1) is the best from an economic and environmental point of view, suggesting that this alternative should be considered in a subsequent detailed engineering study *(Cornejo et al. 2005)*.

IMPLICATIONS OF CARBON SAVINGS

LCA contribution analysis related to Global Warming Potential (GWP) impact category indicator (figure 3) have used in this study to analyze the carbon savings generated by the different design alternatives. The results on the figure are expressed by grams of CO_{2equiv} generated by the production of 1 Finished Metric Ton of newsprint.

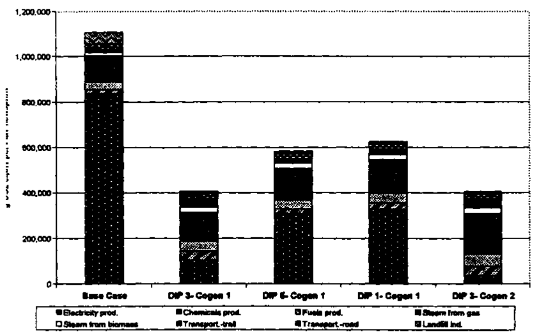

Figure 1 Global warming contribution analysis results

Results from GWP contribution analyses show as major contributor of the unit processes to Electricity Production and natural gas used to generate steam at the facility level. Since the new design alternatives generate cleaner electricity and increased DIP pulp production reducing overall electricity consumption, carbon credits can be perceived at the foreground (facility) and background (Utility an fuels production) level (See table 5) . In addition, landfill emissions contributing to global warming are reduced to almost zero since sludge produced at the mill is being burned in the boiler house.

Units (tons / year)	Base Case	DIP 3 - Cogen 1	DIP 5 - Cogen 1	DIP 1 - Cogen 1	DIP 3 - Cogen 2
Background CO_{2equiv}	343,166	72,251	143,351	152,135	50,913
Foreground CO_{2equiv}	86,024	84,755	82,507	89,289	105,328
TOTAL CO_{2equiv} emitted	**429,190**	**157,006**	**225,858**	**241,424**	**156,241**
Carbon savings	**0**	**272,184**	**203,332**	**187,766**	**272,949**

Table 1 Carbon savings from design alternatives

Table 5 shows that feasible design alternatives represent carbon savings at the background and foreground level (except for alternative DIP 3 – Cogen 2). DIP 3 – Cogen 1 which considers 100 % DIP pulp production in combination with a 40 MW co-generation facility presents one of the highest carbon savings (around 272,000 tons per year) because it represents less electricity consumption (credits at the background level) and production of cleaner electricity (credits at foreground level).
Lowest carbon savings are reported by DIP 1 – Cogen 1 (which considers an increased of 50% DIP pulp production and a co-generation facility) because for this scenario, TMP refiners are still running to produce the other 50% virgin pulp to produce newsprint.
Browne (2003) reported that Government economists have estimated that prices of $CO_{2\ equiv}$ credits will likely range from $10 to 50$ per ton of $CO_{2\ equiv}$, with the lower figure being more probable. Foreground and background carbon savings have been monetized using this predicted range and added into the overall economic evaluation expressed by the Net Present Value (NPV), results are depicted in figure 4.

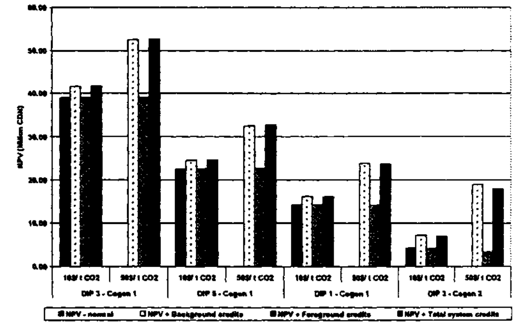

Figure 2 Effect of carbon savings on project's economic performance

As can be seen in figure 4, the NPV of all the design alternatives is positively affected by adding the monetized carbon savings suggesting that carbon savings could potentially enhance economic competitiveness of new projects.
The design alternative with the best financial performance (i.e., DIP 3 – Cogen 1) provides an NPV of CDN$39 million, and includes an increase in DIP production to 100% DIP (1,100t/d) and a 40 MW co-generation facility. By monetizing the total carbon credits (including the foreground and background emissions) at 50 $/t CO2, an improvement in the project NPV of CDN$13 million is realized. However, by considering only the foreground credits the NPV improvement is marginal (less than CDN$3 million), similar economic improvements can be seen for the other suggested design alternatives.

GEOGRAPHICAL SCENARIOS

Since Electricity Production was identified as the most important contributor to Global Warming Potential (GWP) which defines carbon savings due to new projects and, electricity price was a key element on the economic analysis. A sensitivity analysis is performed to the design alternatives changing the current electricity production (33% fossil, 39% nuclear, 28% hydro at 63$/MWh) by two other different electricity pools (See table 6).

Scenario	Energy pool breakdown	Cost Electricity ($/MW)
Ontario	33% fossil fuel, 28% hydro power, 39% nuclear power.	63.0
Energy Pool A	90% Fossil fuel, 10% hydro power, 0% nuclear power.	81.0
Energy Pool B	2% Fossil fuel, 95% hydro power, 3% nuclear power.	43.0

Table 1 Electricity scenarios considered in the sensitivity analysis

Figure 5 shows the NPV variation of the design alternatives under the two proposed electricity pool scenarios. If design alternatives were implemented in a geographical context where the electricity supplied by the grid would be similar to "Energy pool A", the economic competitiveness of these projects would be higher compared to the currently reported. However, under scenario "Energy pool B", the design alternatives become non-economically competitive since the cost per MWh supplied by the grid is lower enough to consider to not implementing these projects.

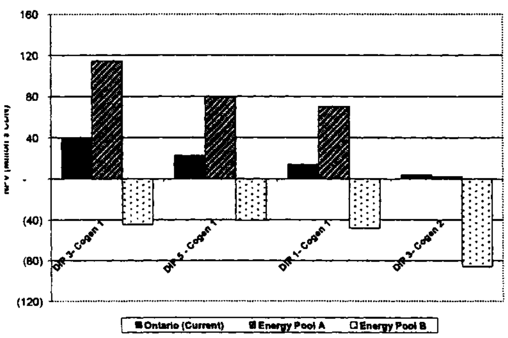

Figure 1 Economic performances under different electricity prices

Figure 6 depicts the LCA-GWP results under the two proposed electricity pool scenarios. The highest reduction of global warming potential can be achieved if the design alternatives were implemented in markets with similar electricity characteristics as in "Energy pool A". This could be explained due to the fact that producing 1 MWh (~80% based on biomass) with the proposed co-generation systems could be cleaner than 1 MWh generated and provided by the grid (90% based on fossil fuel).

However, in electricity markets with similar characteristics to "Energy pool B", the considered design alternatives are not a good environmental choice (from a global warming perspective) since the electricity supplied by the grid is almost entirely based on hydropower and the implementation of a co-generation system based on (~80% biomass and 20% natural gas) would represent higher carbon emissions at the process life cycle level.

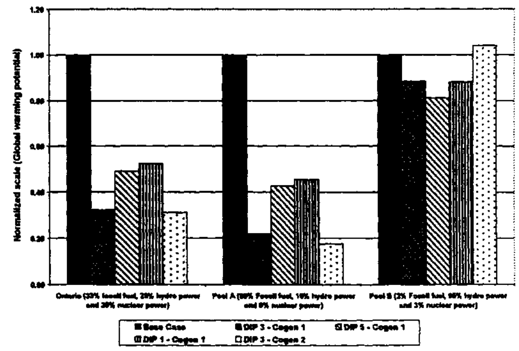

Figure 2 LCA scenarios using different mixed energy pools

CONCLUSION

The following conclusions are drawn from this paper:

1. This study analyzes Greenhouse Gas Mitigation (GHGM) implications due to the implementation of co-generation and increased de-inked pulp production at an integrated newsprint mill.
2. The major contributor to LCA's Global Warming Potential (GWP) is the electricity production, since the system's energy breakdown is based on 33% fossil fuel, 28% hydropower and 39% nuclear power, this allows to generating a considerable amount of carbon savings at the background level by considering the proposed design alternatives. On the other hand, since the co-generation alternatives use mainly biomass, this allows generating carbon savings at the foreground level when compared to the base case.
3. The alternative which considers the implementation of co-generation and increased 100% de-inked pulp (DIP) production *(DIP 3- Cogen 1)* generates one of the highest carbon savings at the foreground and background level, around 272,000 tons CO_{2equiv} per year because of its much lower consumption of electricity (around 50% less) and its production of cleaner electricity (~80% bark and 20% of natural gas) which replaces electricity supplied by the grid.
4. By monetizing the total carbon credits (including the foreground and background emissions) at 50 $/t CO2, an improvement in the project NPV of CDN$13 million is realized. However, by considering only the foreground credits the NPV improvement is marginal (less than CDN$3 million) which demonstrates the importance of considering Greenhouse Gas Mitigation (GHGM) effects on project's economic analysis.

Sensitivity analysis has shown that the energy source breakdown of electricity production has an important influence on projects oriented to reduce energy consumption and/or producing electricity by the fact that alternatives presented a much better economic performance in combination with higher carbon savings if they were implemented in markets where electricity would be based on fossil fuels. However, in markets where the electricity

1. would be based on hydropower, the design alternatives were non-feasible and presented higher global warming levels when compared to the base case.

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APPENDIX 3: TECHNO-ECONOMIC CONSIDERATIONS FOR DIP PRODUCTION INCREASE AND IMPLEMENTATION OF COGENERATION AT AN INTEGRATED NEWSPRINT MIL

TECHNO-ECONOMIC CONSIDERATIONS FOR DIP PRODUCTION INCREASE AND IMPLEMENTATION OF COGENERATION AT AN INTEGRATED NEWSPRINT MILL

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ABSTRACT

Techno-economic considerations for the implementation of cogeneration and increased deinked pulp (DIP) production at a hypothetical integrated newsprint mill have been considered in this paper. "Large-block" pre-feasibility engineering estimates were completed, followed by an economic analysis using Net Present Value (NPV). As expected, the study showed that 2-loop DIP technology was generally not economically attractive. A risk analysis demonstrated that conditions required for the economic attractiveness of a 2-loop DIP design are related especially to significantly higher electricity prices. The likely decrease in the quality of recycled paper and likely increase in energy costs in the future may eventually induce a move to 2-loop DIP systems in North America, where 1-loop systems have historically been the selected technology.

BACKGROUND

Conventional pre-feasibility design studies in the pulp and paper industry, either for greenfield or retrofit projects, involve methodologies that can result in a limited number of process design options being taken into account for further economic analysis. The cost estimates for the process design options under study are typically based on the knowledge and expertise of the engineering team, including risk analysis considerations related to future economic scenarios.

"Large-block" analysis involves a more systematic search of possible process design options than is typically undertaken, and complements the expertise of the engineering team. A large-block analysis is based on the representation of different process systems by the overall mass and energy balances of these process systems. This approach results in a larger number of process design options being explored as candidates for more detailed engineering.

Integrated newsprint mill energy considerations

Newsprint production requires large amounts of electricity and steam. Steam is typically generated by burning fossil fuel or biomass in the boiler house. Sludge from the effluent treatment plant can also be burned, but in the best cases, only at marginal energy recovery rates due to its high moisture content. The refiners in the TMP plant are the largest consumers of electricity mill-wide (typically > 2 MWh/bdmt). Heat recovery (i.e., recovery of generated steam from the TMP refiners) is an essential part of the TMP plant at most mills in order to increase the overall energy efficiency of the operation.

Although a number of techniques are available for reducing TMP energy consumption, they yield only marginal reductions when compared to the implementation of de-inked pulp (DIP) production to replace TMP (for a constant newsprint production rate). Such modifications have a dramatic affect on mill-wide energy consumption. By decreasing TMP production, the production of steam from the TMP plant (required principally for paper drying operations) is reduced. The mill must compensate for this loss of steam by increasing the steam production in the boiler house. Consequently, this increase can give rise to opportunities for changes in steam production, and potentially an enhanced opportunity for cogeneration at the mill. Cogeneration is the combined production of electrical (or mechanical) and useful thermal energy from the same primary energy source [2].

Study objectives

The objectives of the present study are:

1. To characterize a "base case" process design and process design options for the implementation of increased deinked pulp production and cogeneration system at an integrated newsprint mill,
2. To analyze the economic feasibility of each option based on a large-block analysis,
3. To further analyze the financial results based on risk analysis.

Although the problem definition and constraints are based on an operating integrated newsprint mill, adjustments have been made to create a hypothetical mill scenario. The design problem presented is an example of the approach a similar integrated mill could take in order to analyze DIP and cogeneration project options.

TECHNO-ECONOMIC STUDY

Methodology

The following methodology was used for the techno-economic study (Figure 1):

- A study was made of available and emerging technologies, an environmental review, and the gathering of necessary engineering data. Several DIP and cogeneration options were identified, and changes in the other mill processes as a result of the implementation of these options were evaluated using mass and energy balances.
- These options were combined for the large-block analysis and their technological feasibility verified. For this purpose, an inventory of the inputs and outputs was constructed.
- For each option, manufacturing and capital cost estimates were made. Based on these estimates, the NPV for each of the generated options was calculated.

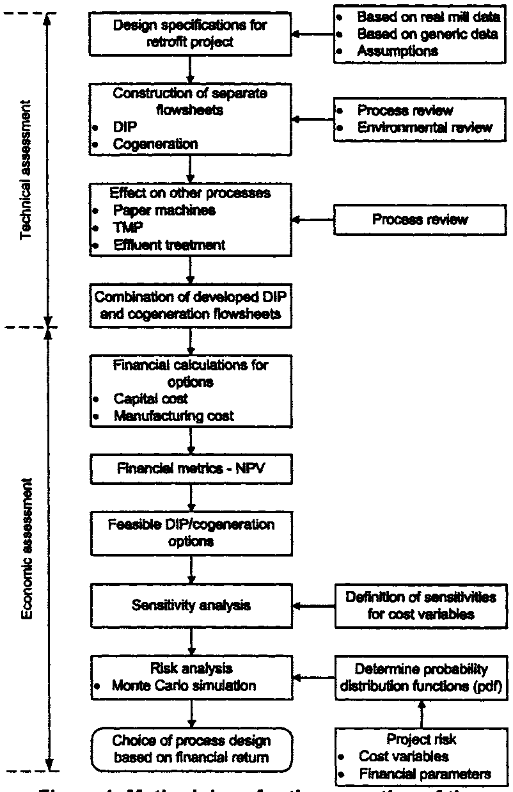

Figure 1: Methodology for the execution of the techno-economic analysis in this study

- The calculated NPVs were used to evaluate the feasibility of the options. All process options with a positive NPV were retained for further analysis.
- A risk analysis was performed to assess the project risk for each process design option based on the uncertainty of certain manufacturing cost variables and financial parameters. Probability distribution functions (pdf's) were determined based on historical data to quantify this uncertainty. Monte Carlo simulation was used for incorporating the pdf's into the calculation of the NPV.

Assumptions and choices

Critical choices and assumptions that were made during the execution of this study are summarized in Table 1.

Base case configuration

The base case mill can be described by the following:

1. 4 newsprint machines have an average production of 1100 fmt/day,
2. 2 TMP lines that produce 925 admt/day,
3. DIP plant that produces 175 admt/day,

TABLE 1: DESIGN STUDY ASSUMPTIONS

Assumptions
Implemented technologies meet environmental regulations
Boilers have a net thermal efficiency of 75%
No extra electricity generated by using condensing turbines
Total investment is completed at time t = 0 and financial parameters are constant over the project lifetime
Choices
Market considerations are not taken into account[1]
Incremental de-bottlenecking is not considered[2]
Fluidized bed boilers are not considered[3]

[1] New process design options are compared with a base case
[2] This would render the problem at hand too complex
[3] Dryness of the hog fuel is high enough to use conventional boilers

4. 70% of the wastepaper used is old newspaper (ONP) and 30% is old magazine paper (OMG),
5. The activated sludge treatment plant treats approximately 50,000 m3/day of wastewater,

The existing boiler plant produces approximately 6,700 MMBtu/day of steam.

Options for DIP and cogeneration plant

The options for the DIP and cogeneration plant were selected because they decreased overall mill energy costs. The techno-economic analysis methodology combined the reduced manufacturing costs and capital expenditures, by calculation of NPV. Other financial criteria are typically also considered, including total installed capital cost. In total, 18 options were analyzed in the large-block analysis by considering all combinations of the DIP and cogeneration possible. The combinations of 6 DIP and 3 cogeneration options were named according to the following method: Option {DIP Option 1, 2, ...6}-{Cogeneration Option A, B, or C}.

The DIP plant process design options considered in the study (summarized in Table 2) considered increasing the DIP production to either 550 admt/day which represents 50% of the total pulp production, or to 1100 admt/day which is 100%. A 1-loop DIP configuration is the conventional technology used in North America. However, a 2-loop configuration can compensate for lower recycled paper quality, expected in the coming years [1].

The cogeneration plant options considered the following (Table 3):

1. Ability to increase biomass burning by the installation of hog fuel boilers,

TABLE 2: CONFIGURATION OF THE DIP PLANT OPTIONS

Option	Configuration
1	New 550 admt/day DIP plant, 1-loop
2	New 550 admt/day DIP plant, 2-loop
3	New 1100 admt/day DIP plant, 1-loop
4	New 1100 admt/day DIP plant, 2-loop
5	Increase DIP to 550 admt/day by adding a second line to the existing DIP plant, 1-loop
6	Increase DIP to 550 admt/day by adding a second line to the existing DIP plant, 2-loop

TABLE 3: CONFIGURATION OF THE COGENERATION OPTIONS

Option	Configuration
A	One natural gas boiler is converted to burn wood waste, and existing turbo-generators kept in service.
B	New wood waste boiler is installed. Half the boilers are upgraded to higher pressure operation. New turbo-generator added to existing ones.
C	New air-cooled condenser and turbo generator are installed.

1. Reactivation of turbines to increase electrical output, and implementation of new back-pressure turbines.

Process block diagram for "large block" analysis

A process block diagram from a cogeneration perspective was developed for each of the 18 options as per Figure 2. The energy consumption of the entire mill was calculated using this diagram, and the results were used in the calculation of manufacturing costs.

Cost modeling

Capital cost estimates

It is generally recognized that the precision of cost estimates falls within bounds which satisfy different purposes (e.g., project screening, project appropriation, construction, etc.). Since this evaluation was developed to screen multiple design options and system configurations, it employed an order-of-magnitude/pre-feasibility engineering precision (i.e., that required to evaluate and compare the costs and economic benefits). Any decision to proceed would require further estimate/analysis work to be done. The estimates for both the DIP and cogeneration configurations were derived from a variety of sources including similar estimates. Cost ratios were employed to suit new production capacities, year of construction, etc.

For the capital cost estimate of the DIP system, an allowance for modifications of the paper machines was included to allow for the effects of using larger proportions of DIP in newsprint. Also, a contingency cost of 10% was included. This contingency cost compensated for the items not directly included in the capital cost estimate and was an approximation for the costs about which there was no information. No changes to the effluent treatment plant were anticipated under any of the new scenarios.

Manufacturing cost estimates

For each combined option, the manufacturing cost per finished metric tonne of newspaper was computed using the following cost items:

- Purchased electricity,
- ONP and OMG,
- Wood chips,
- Process chemicals,
- Natural gas,
- Hog fuel,
- Labour and staff.

Costs that remained constant for all options were not considered, since a comparison was being made to the base case design (e.g., newsprint transportation costs did not change between options since it was assumed that the end product and customer base were constant).

The manufacturing costs varied with the process design option. The differences in the cost of fibre and the cost of purchased electricity had the biggest impact on the overall manufacturing cost for each option. The cost of purchased electricity was clearly reduced in all the analyzed options when compared to the base case. This reduction depended on:

- The increased use of cogeneration at the mill,

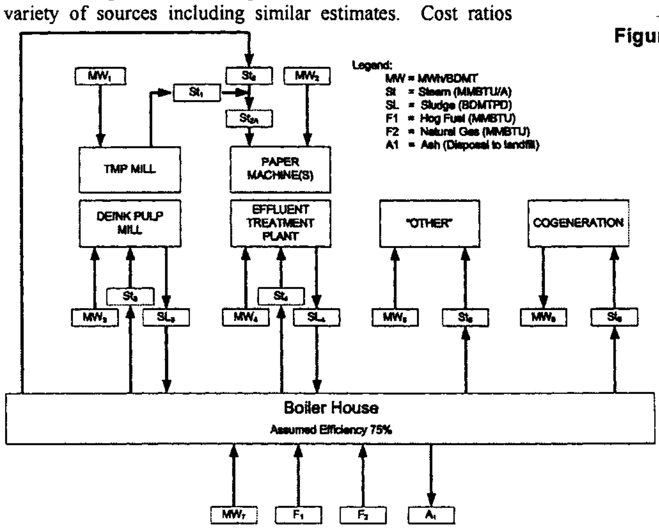

Figure 2: Process block diagram from a energy perspective

1. The amount of sludge generated by the DIP and effluent treatment plant,
2. The amount of available hog fuel,
3. The amount of TMP pulp produced, and
4. The amount of steam regenerated in the Heat Recovery Unit (HRU) of the TMP plant.

The cost of fibre (ONP, OMG, and virgin fibre) was higher for all options compared to the base case, because the cost of ONP and OMG was higher than the cost of chips for producing TMP. The cost of chemicals also increased for each option when compared to the base case, since the use of chemicals per tonne of DIP pulp produced was higher than would be required in a TMP plant. The cost of labour varied mainly because of the amount of man hours used for ash landfill and sludge handling. The cost of staff was reduced in the 100% DIP options only, since in these options staff was no longer necessary for the TMP plant. The manufacturing costs for the options with a 2-loop configuration were all higher than the corresponding 1-loop design options. This was caused by:

- Higher electricity costs: 2-loop system has a higher specific energy (650 vs. 450 kWh/ tonne DIP),
- Higher fibre costs: the yield of the 2-loop system is lower (85% vs. 92% for the 1-loop system),
- Higher chemical costs: more chemicals are used in a 2-loop system than in a 1-loop system.

The natural gas cost varied per option based on the amount of sludge that was generated in-process. For cogeneration configurations A and B, the natural gas cost was lower for the 2-loop options than for the 1-loop options, because the former systems produced more sludge.

Recommendations from the large block analysis

The manufacturing cost and the capital cost were used as the basis for the calculation of the NPV for each of the process design options to determine their economic feasibility. The NPV was used as a screening tool to select options that had a positive NPV after 20 years. According to this criterion, 4 economically viable process options were retained: 1-A, 3-A, 5-A, and 3-B (Table 4). Option 3-A, a 1-loop DIP configuration, had the highest return after 20 years (40.4 M$). It should be noted that none of the options with a 2-loop DIP system had a positive NPV after 20 years. The reason for this negative outcome is that these options incur higher manufacturing costs and require a higher capital investment for implementation than those with a 1-loop system. However, due to the projected decrease in recycled paper quality over time, DIP plants may need to be upgraded to a 2-loop system, which is a more rigorous recycling technology.

TABLE 4: NPV FOR THE ECONOMICALLY FEASIBLE PROCESS DESIGN OPTIONS

Option[1]	NPV (million $ CDN)
1-A	15.4
3-A	40.4
5-A	23.5
3-B	6.1

[1] See Tables 2 and 3 for design option descriptions

RISK ANALYSIS

Analysis of retained design options

Risk analysis is the analysis of risks associated with the values of key project variables and parameters, and therefore associated with the overall project result. Quantitative risk analysis considers the range of probable values for key variables and parameters and defines a probability distribution function (pdf) for describing these uncertain variables and parameters. Combination of these pdf's may lead to an overall probability indicating that the project is unacceptable. A Monte Carlo simulation can be used to obtain this overall probability. A Monte Carlo simulation is a method that uses a pseudo-random generator for sampling to approximate a probability distribution. When deciding on a particular project or a portfolio of projects, decision-makers should take into account not only the expected value of the NPV, but also the risk that the project's NPV will be negative. Therefore, a risk analysis using Monte Carlo simulation was carried out for the 4 options with a positive NPV.

First, the probability distribution functions (pdf's) for the price changes over time (volatility) were determined for the different variables and parameters based on data from Statistics Canada (Statistics Canada, 2004). These variables and parameters included the inflation rate, as well as the cost of virgin and recycled fibre, electricity, chemicals, wood waste, and natural gas. Data from the time period 1993-2003 were used. It was assumed that the distributions for labour and staff costs had the same characteristics as the pdf for the inflation rate. For the investment term, a triangular distribution with a median of 10 years, a minimum of 5 years, a maximum of 15 years was assumed and for the total capital investment, a triangular distribution with a median of 0%, a minimum of -25% and a maximum of +25% was assumed. Also, it was assumed that the interest on capital, the corporate tax rate, the risk premium, and the debt to equity ratio remained constant over the project's lifetime. Then, the Monte Carlo simulation was executed using $1 \cdot 10^4$ iterations to obtain credible results (Table 5).

Although option 3-A still had the highest average NPV ($44.9 million CDN), the risk of obtaining a negative NPV (16.4%) was higher than that for option 5-A (12.0%), which had an average NPV of 28.2 million dollars (2nd highest). There is a trade-off between the value of the NPV and the risk to reach that NPV. This indicates that there are some drawbacks in considering the NPV as the sole measure of profitability for an investment, and that possibly other indicators should be used as well.

Using the Monte Carlo simulation, tornado graphs were generated (Figure 3), depicting the simultaneous sensitivity of the NPV towards the different parameters and variables that

TABLE 5: RESULTS FROM THE MONTE CARLO SIMULATION FOR THE RETAINED OPTIONS

Option	Mean [10^6 $CDN]	P(NPV ≤ 0) [%]
1-A	20.4	20.3
3-A	44.9	16.4
5-A	28.2	12.0
3-B	10.9	41.4

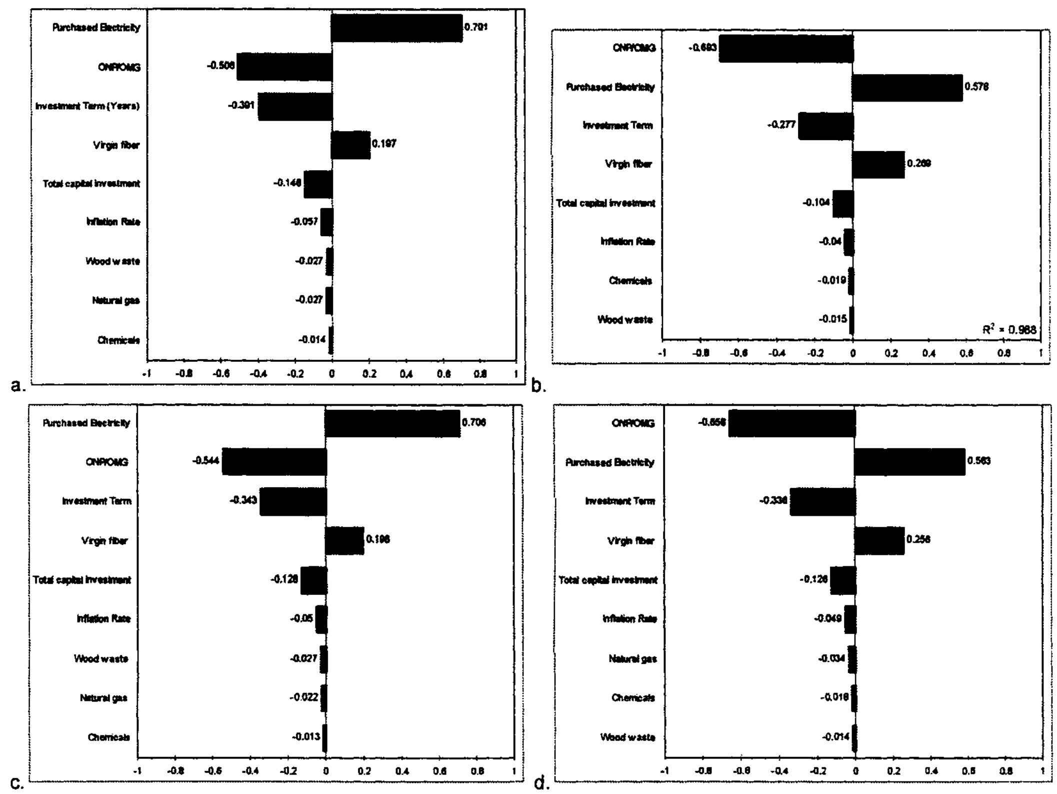

Figure 3: Tornado graphs for: a. option 1-A; b. option 3-A, c. option 5-A, d. option 3-B

were taken into account in the simulation. As such, the tornado graphs represent a more realistic view of the sensitivity of the NPV, since the variables and parameters are taken into consideration simultaneously instead of one-by-one. The tornado graphs show that the cost of purchased electricity and recycled fibre had the highest impact on the NPV. They indicate that when the mill is transformed to a 100% DIP mill (options 3-A and 3-B), the recycled fibre cost has the highest (negative) impact on the NPV. Furthermore, they show that the cost of purchased electricity and the cost of virgin fibre have a positive impact on the outcome of the NPV in all cases. In the risk and risk sensitivity analysis, the investment term and the total capital invested were also taken into account. While both have a significant impact on the NPV, they were not as critical as electricity and recycled fibre prices.

Two-loop systems

Scenarios were run in order to investigate the effect of changes in the price of recycled fibre and electricity on the financial return of the 2-loop DIP system (Table 6), to determine the conditions under which a 2-loop system would become profitable. These particular cost changes were selected because fibre and electricity prices are expected to increase in the future, and because these costs had the greatest impact on the NPV. The same pdf's used previously were assumed for parameters other than electricity and fibre costs.

An increase in the price of electricity had a positive effect on the resulting NPV of the options. Still, the risk of the investment also needs to be taken into account by examining P(NPV $\leq$ 0) (Table 7). Clearly, option 6-A would be the best design to choose for scenarios I and II, since it has the lowest risk and a near maximum or a maximum NPV, respectively. In the case of a doubling of the electricity price, P(NPV $\leq$ 0) even reached zero for option 6-A. Although option 4-A (highest NPV) had a higher risk, this risk was so small that this would be the preferred option under scenario III. This shows that the increase in the electricity price may influence the choice of the preferred process design option.

TABLE 6: SCENARIO ANALYSIS FOR 2-LOOP SYSTEMS

Scenario	Cost change	
	Electricity	Fibre
I	50%	10%
II	50%	50%
III	200%	0%

TABLE 7: RESULTS FROM THE MONTE CARLO SIMULATION FOR THE 3 BEST OPTIONS UNDER SCENARIOS I, II AND III

	Option	Mean [10^6 $CDN]	P(NPV ≤ 0) [%]
Scenario I	2-A	60.4	2.35
	4-A	70.7	11.0
	6-A	69.7	1.18
Scenario II	2-A	46.9	9.26
	4-A	39.6	27.2
	6-A	56.3	5.54
Scenario III	4-A	170.4	0.50
	6-A	142.0	0.00
	4-B	151.1	0.83

An increase in the price of fibre had a negative effect on the NPV of the options, as shown in scenario II (when comparing with scenario I). For each of these options, the average NPV decreased and the risk increased (Table 7). It is also clear that the increase in the cost of electricity had a larger impact on the NPV than the increase in the cost of recycled fibre (results not shown).

These results imply that deregulation of the electricity market, which is expected to lead to an increase in prices, may result in the implementation of more 2-loop de-ink systems in Canada, since with such an increase, the profitability of 2-loop systems increases. If these modifications were to be made, measures to minimize the cost of fibre would have to be taken, such as increasing the efficiency of the process. Furthermore, since a 2-loop system requires a higher capital expenditure, the necessary capital would have to be available for investment.

CONCLUSIONS

In this study, the implementation of increased deink pulp production and cogeneration was considered at a hypothetical integrated newsprint mill.

The capital and manufacturing costs were calculated by considering the effect the implementation of different process options would have on the rest of the mill. The process options with the 2-loop DIP technology were generally negative because of higher capital and manufacturing costs compared to the corresponding 1-loop DIP options.

A risk analysis demonstrated that the risk of a negative NPV can be taken into account in selecting a process option, and that the inclusion of uncertainty in the analysis of process options may reveal valuable information for decision making. The risk analysis showed that with increasing electricity and recycled fibre prices, the 2-loop DIP technology options may become profitable.

ACKNOWLEDGEMENTS

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APPENDIX 4: TECHNICAL INFORMATION RELATED TO THE DESIGN ALTERNATIVES

Unit Process	Specific Energy (kWh/t)
Slushing Pulper	10 – 40
Drum Pulper / Screening	15 – 20 / 40
Deflaking	20 – 60
Screening	5 – 20
Tailing Screening	20 – 40
Washing	1.5 – 20
Dissolved Air Flotation (DAF)	10 – 20
Flotation (selective)	20 – 50
Centrifugal Cleaners	4 – 8
Thickening	1 – 10
Dewatering, Screw Press	10 – 15
Dewatering, Double Wire Press	2 – 4
Dispersing	30 – 150
Refining LC (per SR Unit)	3 – 25
Refining HC (per SR Unit)	10 – 60
Storage	0.02 – 0.1
Mixing	0.2 – 0.5

Ref: "Recycled Fibre and De-inked" ISBN 952-5216-07-1 (Book 7 of: Papermaking Science and Technology)
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Total Specific Energy

Existing system:	0.41MWh/BDMT
1 Loop System:	0.45MWh/BDMT
2-Loop System:	0.65MWh/BDMT

DEINK CHEMICAL APPLICATION

1-Loop System

Item	Unit	Quantity
Consumption Based Waste Paper Feed		
H_2O_2	kg/BDMT	11.22
NaOH	kg/BDMT	7.38
Sodium Silicate	kg/BDMT	15.36
Surfactant	kg/BDMT	7.50
Flocculent	kg/BDMT	0.47
Coagulant	kg/BDMT	1.72
Calcium Chloride	kg/BDMT	1.18
Consumption Based on Pulp Produced		
Sulphuric Acid	kg/BDMT	12.50
Bleach (Borol)	kg/BDMT	0.90
Biocide	Kg/BDMT	0.50

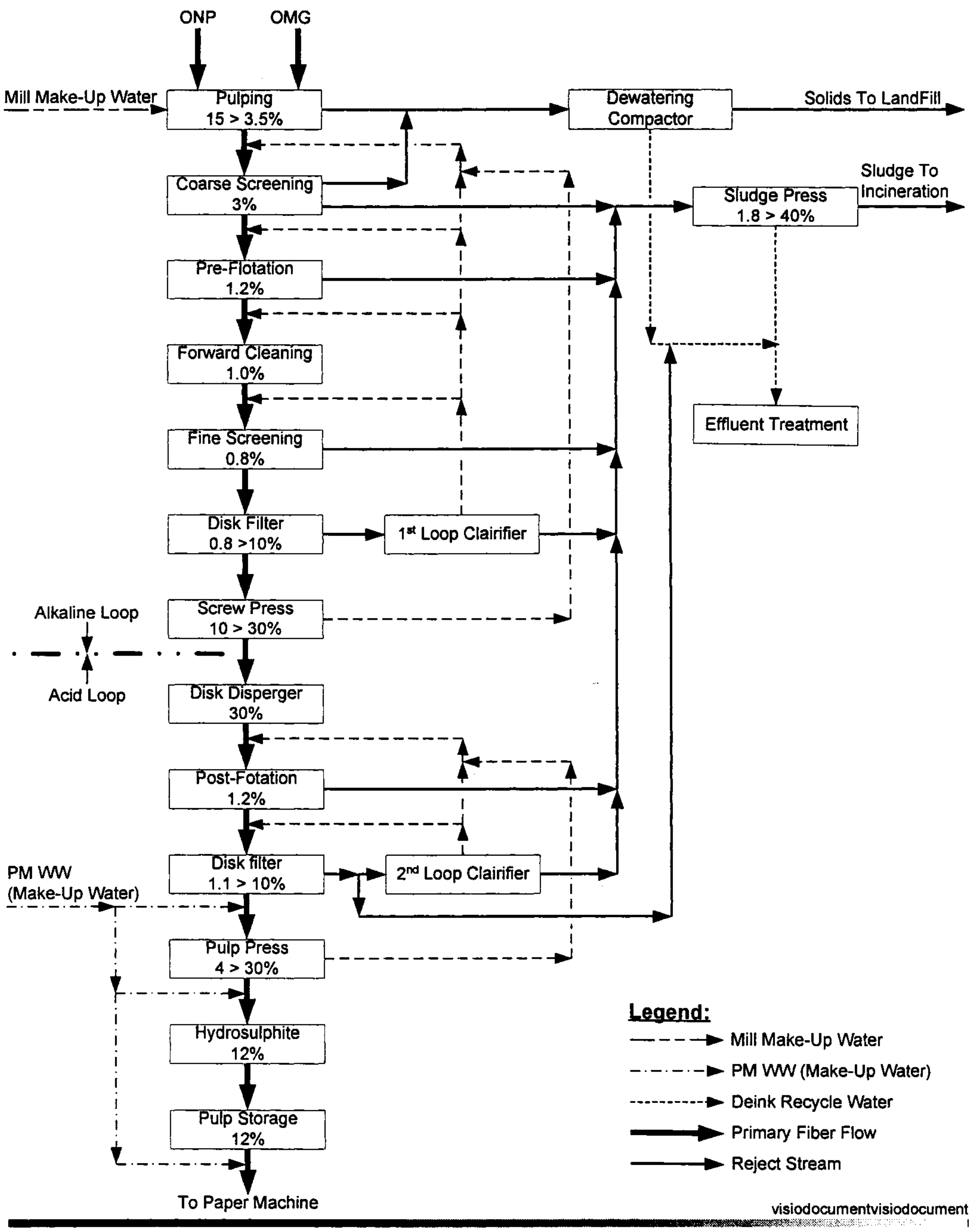
2-Loop System

Item	Unit	Quantity
Consumption Based Waste Paper Feed		
H_2O_2	kg/BDMT	12.15
NaOH	kg/BDMT	8.00
Sodium Silicate	kg/BDMT	16.62
Surfactant	kg/BDMT	7.50
Flocculent	kg/BDMT	0.47
Coagulant	kg/BDMT	1.72
Calcium Chloride	kg/BDMT	1.18
Consumption Based on Pulp Produced		
Sulphuric Acid	kg/BDMT	22.50
Bleach (Borol)	kg/BDMT	0.90
Biocide	Kg/BDMT	0.50

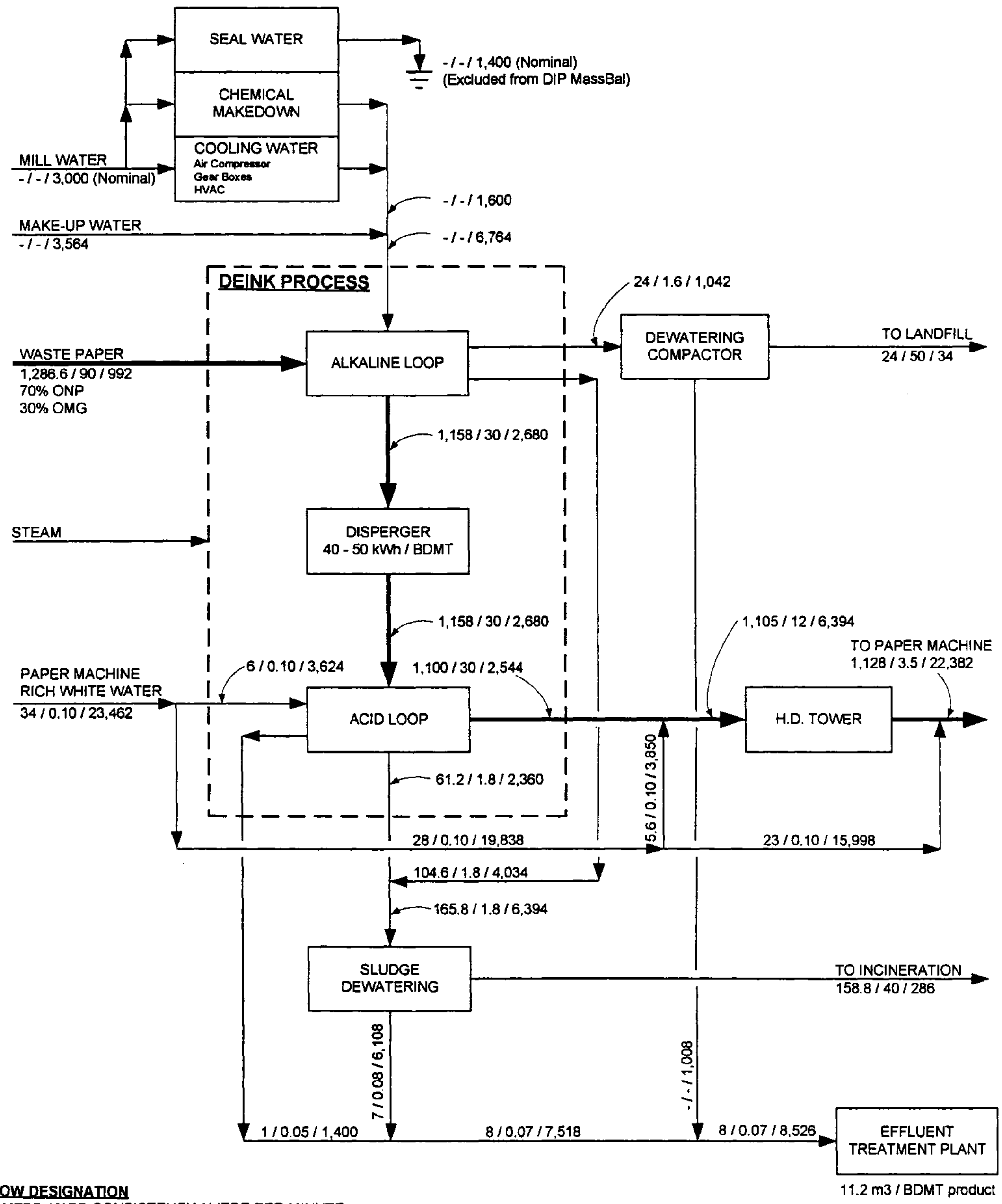
CHEMICAL LIST AND FUNCTION

Chemical	Function
Caustic (Sodium Hydroxide)	Caustic is added at the pulper to aid in repulping the recovered paper and to remove ink from the fibres. The alkaline environment created by addition of caustic is necessary for fibre swelling which facilitates detachment of ink from the fibre.
Hydrogen Peroxide	Addition of caustic at the pulper will result in alkaline darkening of the mechanical pulp. Addition of peroxide at the pulper will prevent this darkening effect.
Sodium Silicate	The presence of metal ions in the pulp/water mixture will cause hydrogen peroxide to decompose. Sodium silicate aids in stabilizing the hydrogen peroxide by deactivating these metals and by pH buffering. In addition, silicate also acts as a dispersant, emulsifier and anti-re deposition (of ink on fibre) agent.
Hydro-Sulphite Bleach	Hydro-sulphite bleach is the final agent used to increase pulp brightness to target levels. Hydro-sulphite is a reductive bleach and will remove color from dyed papers (i.e., directory grades).
DTPA	DTPA is a chelant that is added to sequester metal ions that cause decomposition of hydrogen peroxide. Chelants tie up metal ions by forming complexes with the ions, thereby preventing them from reacting with the hydrogen peroxide.
Sulphuric Acid	Sulphuric Acid is used for adjusting the pH of the pulp to slightly acidic conditions prior to storage and bleaching with sodium hydro-sulphite. Acidic conditions are optimum for sodium hydro-sulphite bleaching.
Surfactant	Addition of a surfactant prior to flotation is required in order to generate the inky foam for removal in the flotation cell. Surfactants may be 'natural (i.e. fatty acids or soaps) or synthetic (displectors). The surfactant is necessary to form a stable ink/air bubble formation that can be removed by flotation.
Clarification Polymers	Polymers are required at the DAF clarifiers to coagulate and/or flocculate the suspended solids so they are easier to remove.
Sludge Press Polymers	Polymers are required for the sludge press to coagulate/flocculate suspended solids to improve the discharge consistency from the press.
Talc	Talc may be used to act as a pitch collector and de-tackifier to minimize equipment fouling.

DEINK BLOCK-FLOW DIAGRAM: 2 - LOOP SYSTEM



DEINK PLANT 1,100BDMTPD, 2 - LOOP GREENFIELD OPTION



FLOW DESIGNATION
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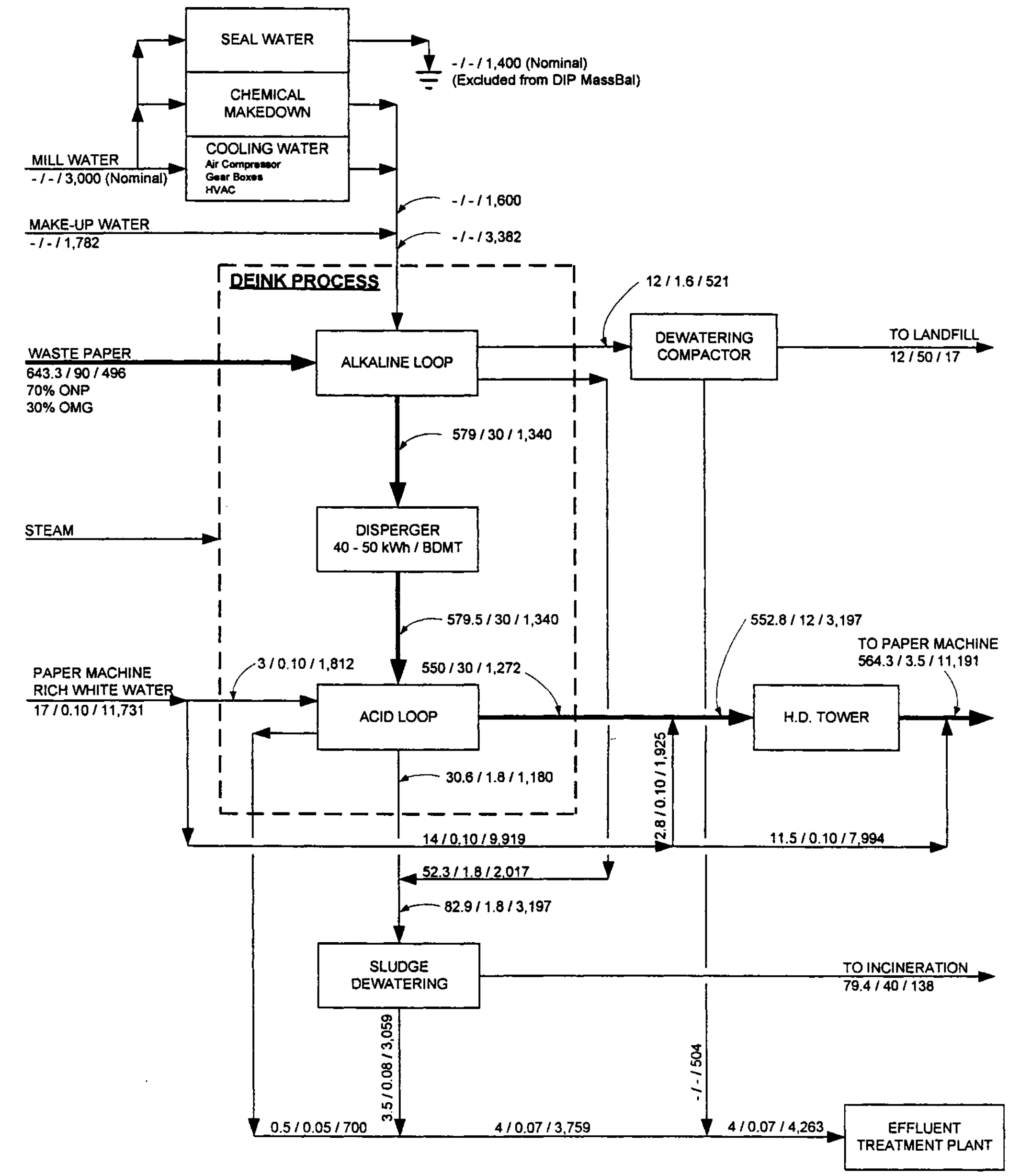
DEINK PLANT 550BDMTPD, 2 - LOOP GREENFIELD OPTION



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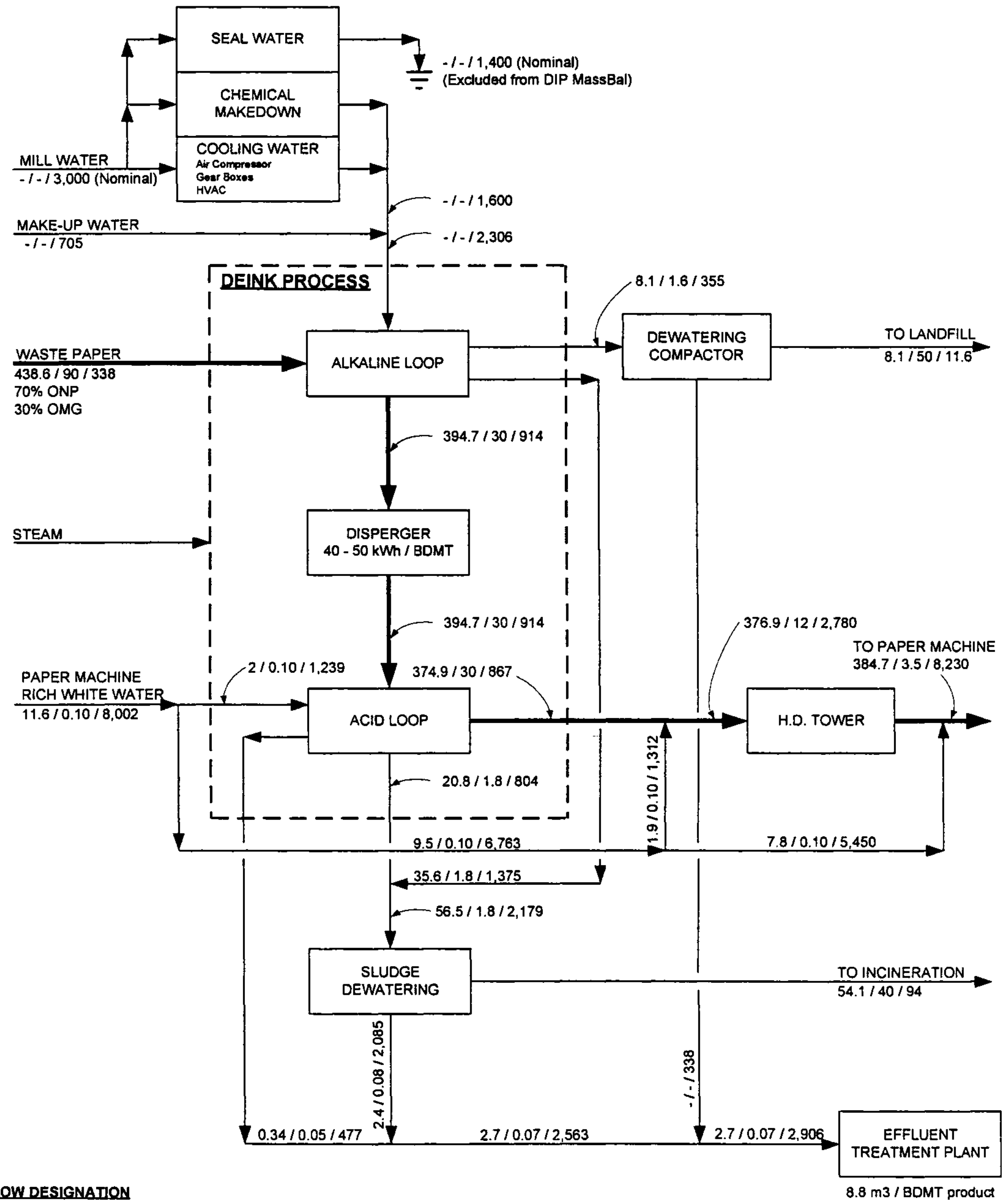
DEINK PLANT 375BDMTPD, 2 - LOOP GREENFIELD OPTION



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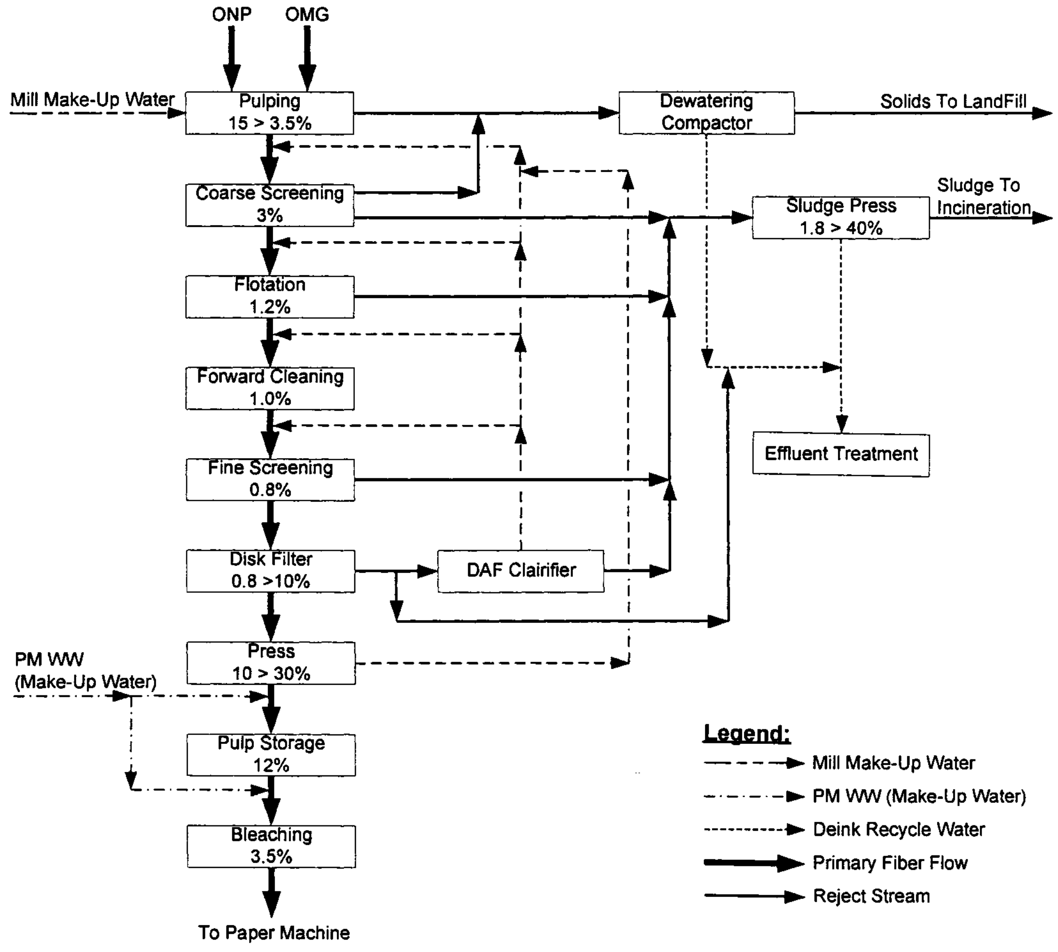
DEINK BLOCK-FLOW DIAGRAM: 1 - LOOP SYSTEM



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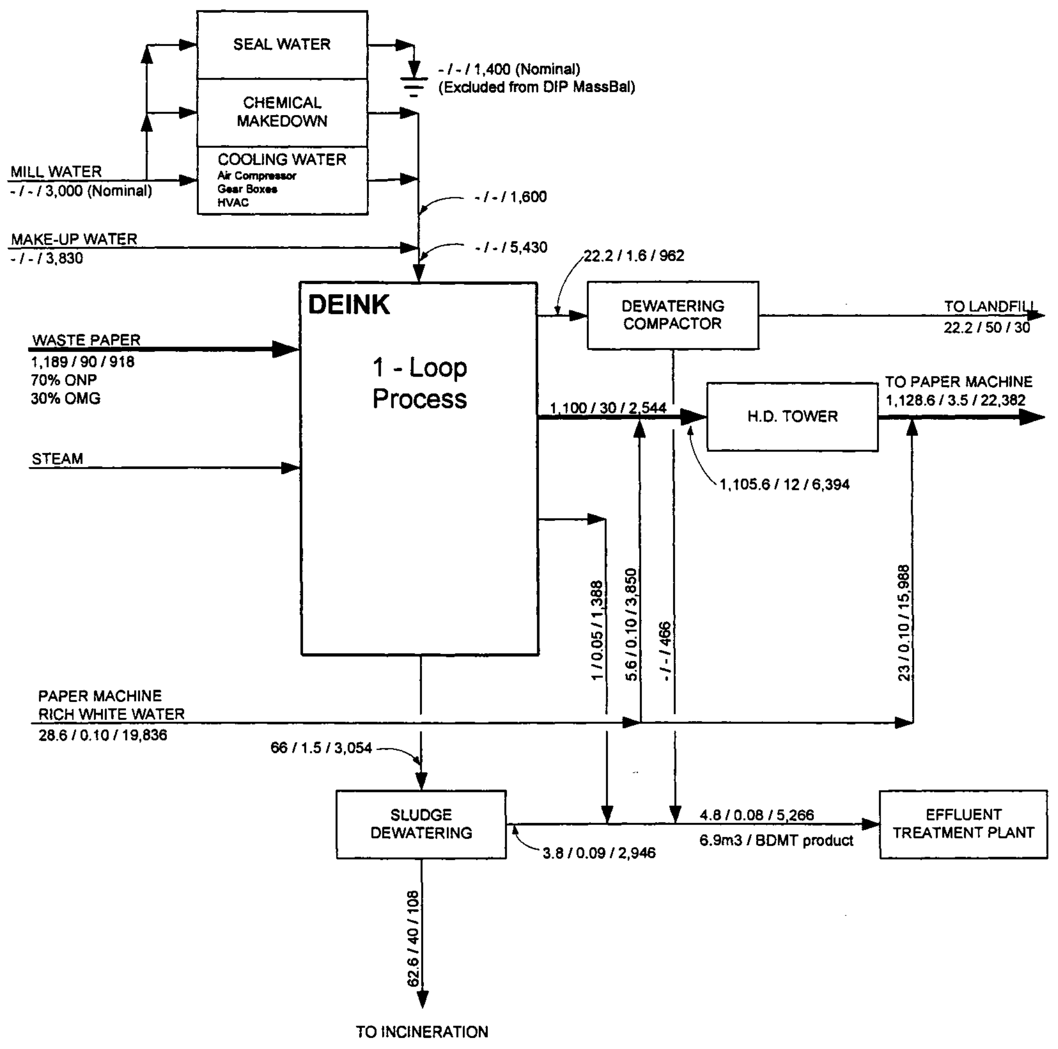
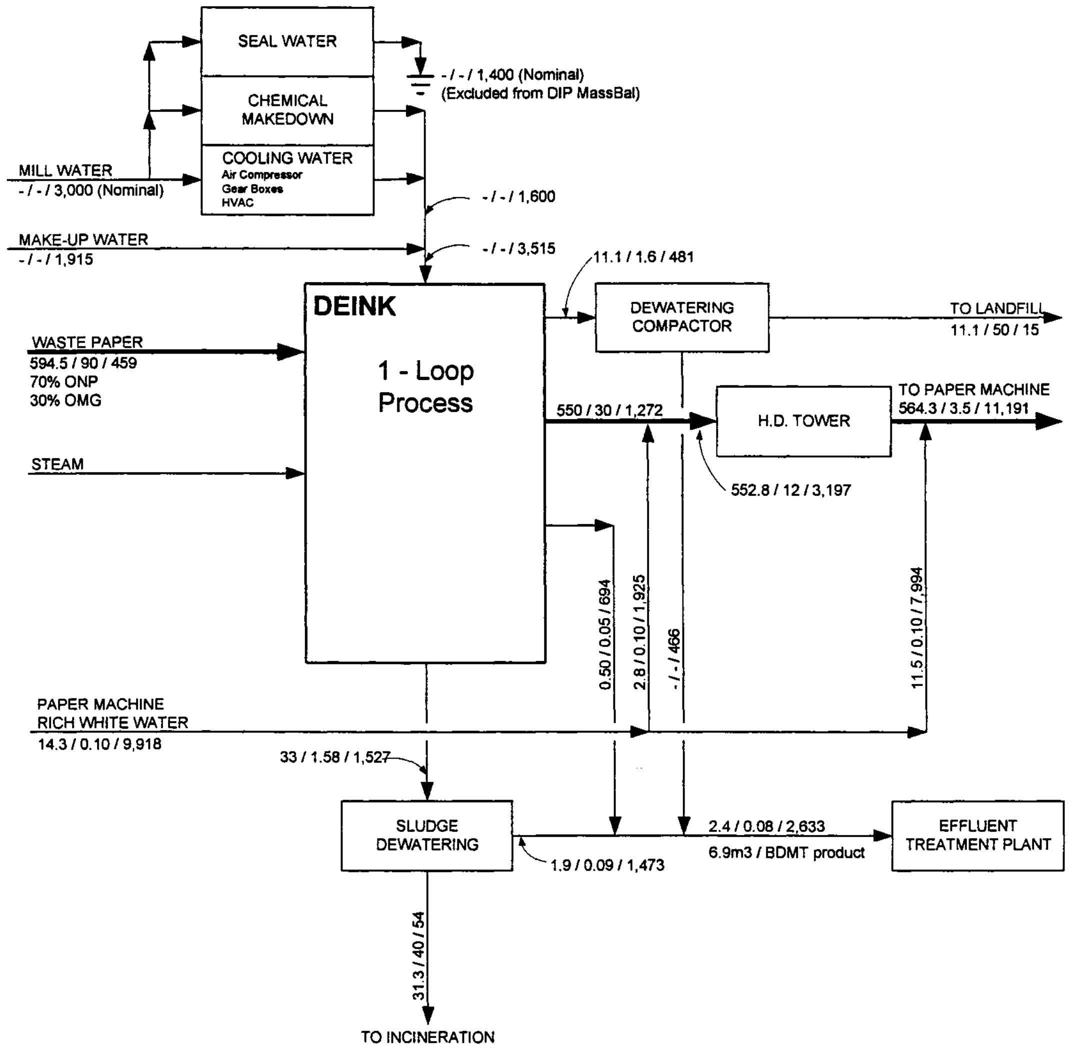


FLOW DESIGNATION
BDMTPD / %BD CONSISTENCY / LITRE PER MINUTE

Refer: DEINK BLOCK-FLOW DIAGRAM, 1 - LOOP SYSTEM; for equipment configuration visiodocumentvisiodocument

DEINK PLANT 550BDMTPD, 1 - LOOP GREENFIELD OPTION



FLOW DESIGNATION
BDMTPD / %BD CONSISTENCY / LITRE PER MINUTE

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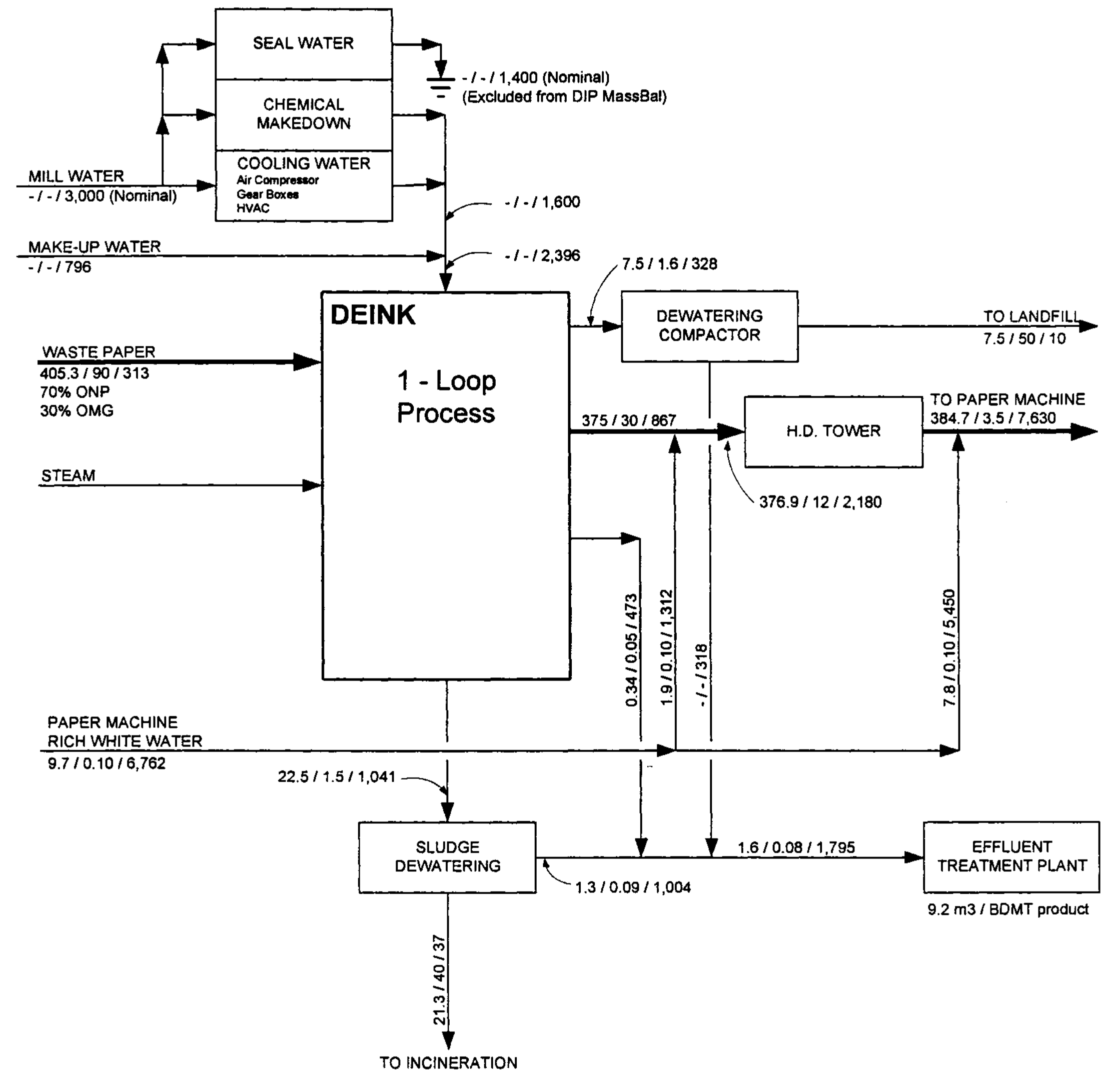
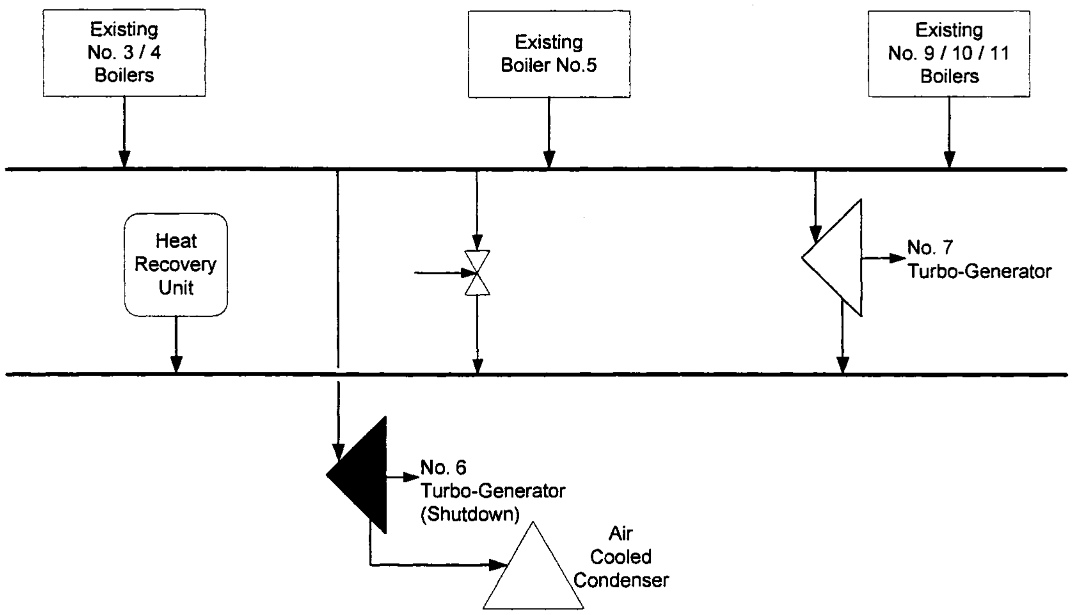
DEINK PLANT 375BDMTPD, 1 - LOOP GREENFIELD OPTION



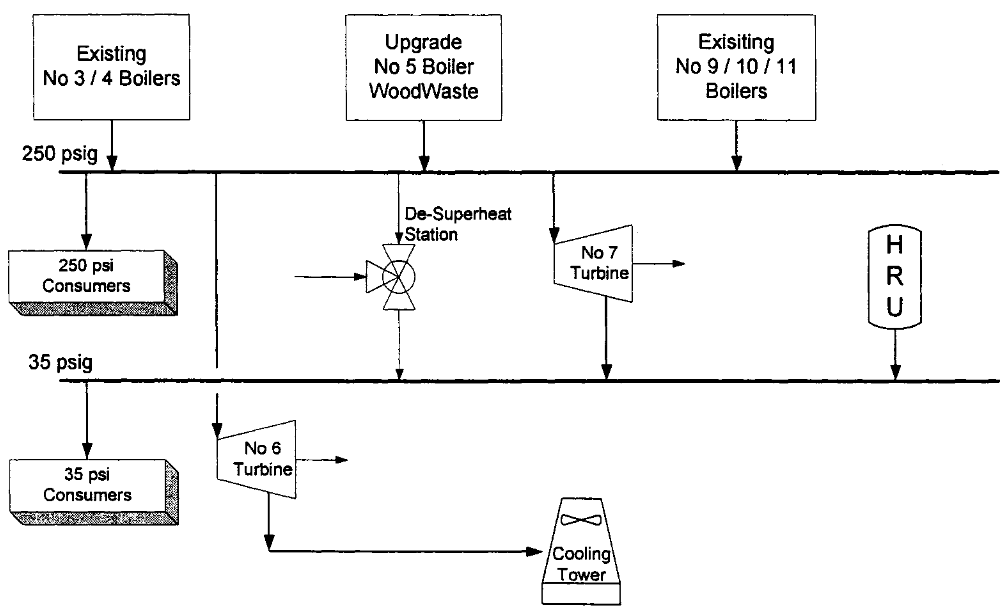
FLOW DESIGNATION
BDMTPD / %BD CONSISTENCY / LITRE PER MINUTE

Refer: DEINK BLOCK-FLOW DIAGRAM, 1 - LOOP SYSTEM; for equipment configuration visiodocumentvisiodocument

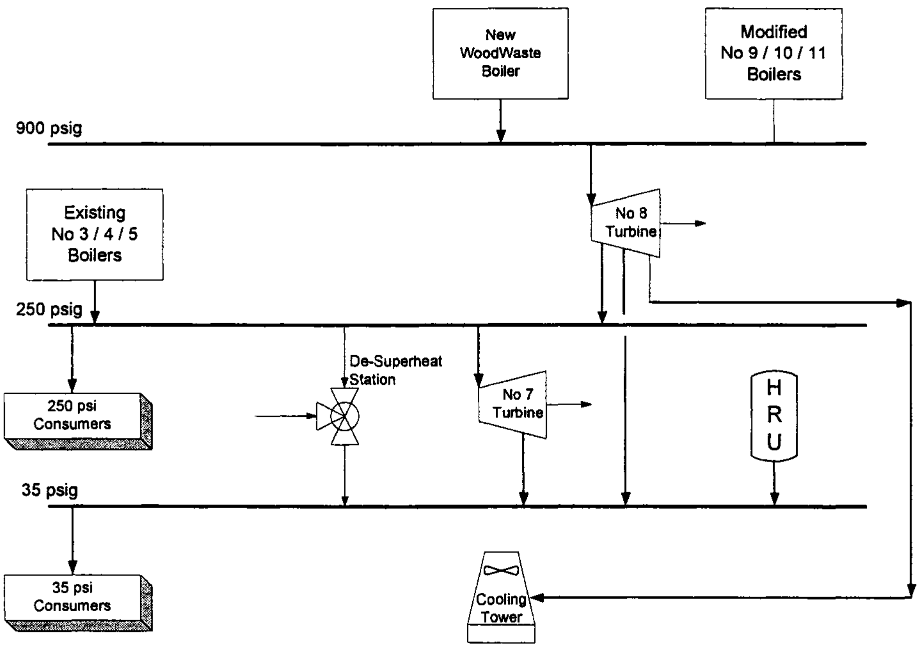
BASE CASE:



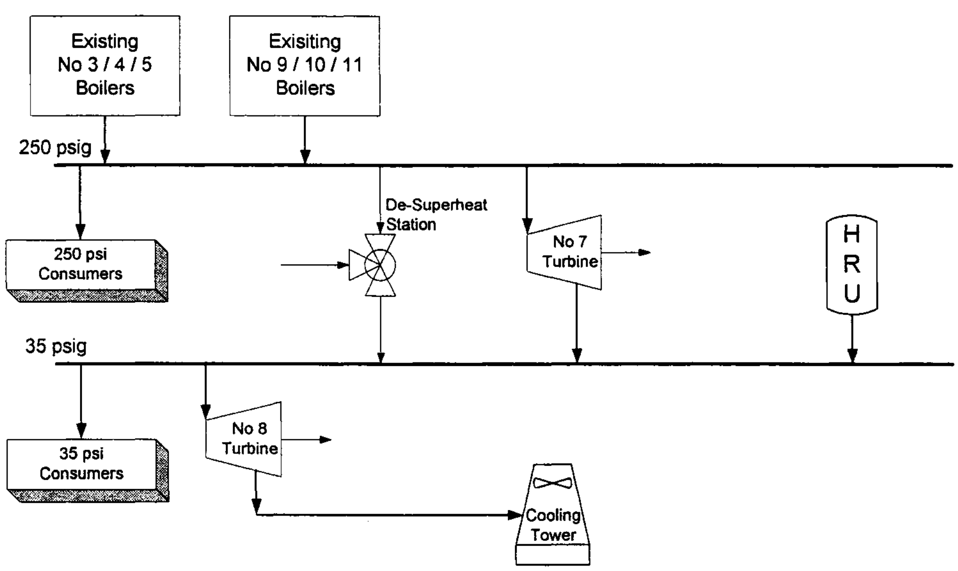
COGENERATION DESIGN ALTERNATIVE No. 1:



COGENERATION DESIGN ALTERNATIVE No. 2:



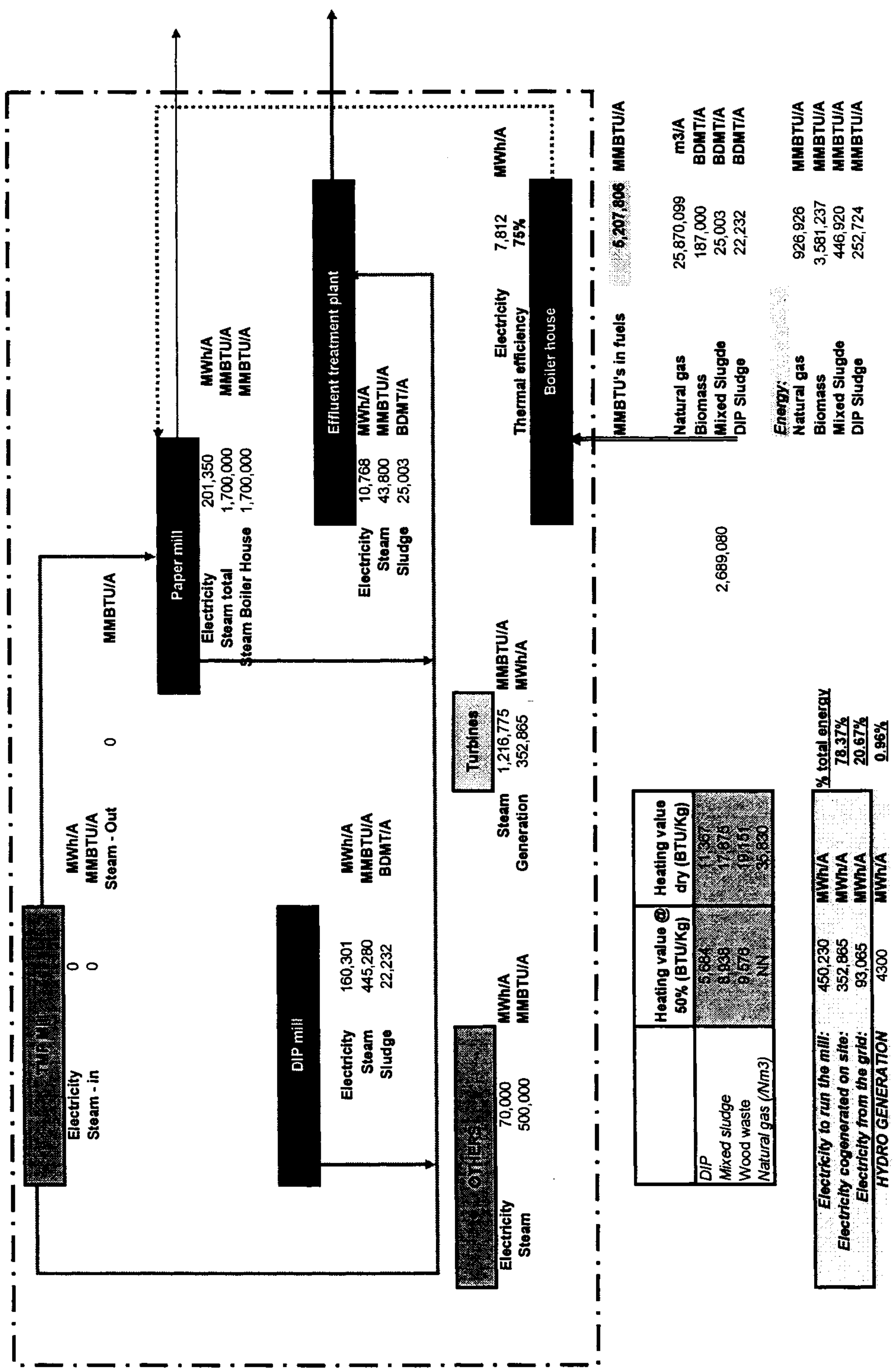
COGENERATION DESIGN ALTERNATIVE No. 3:



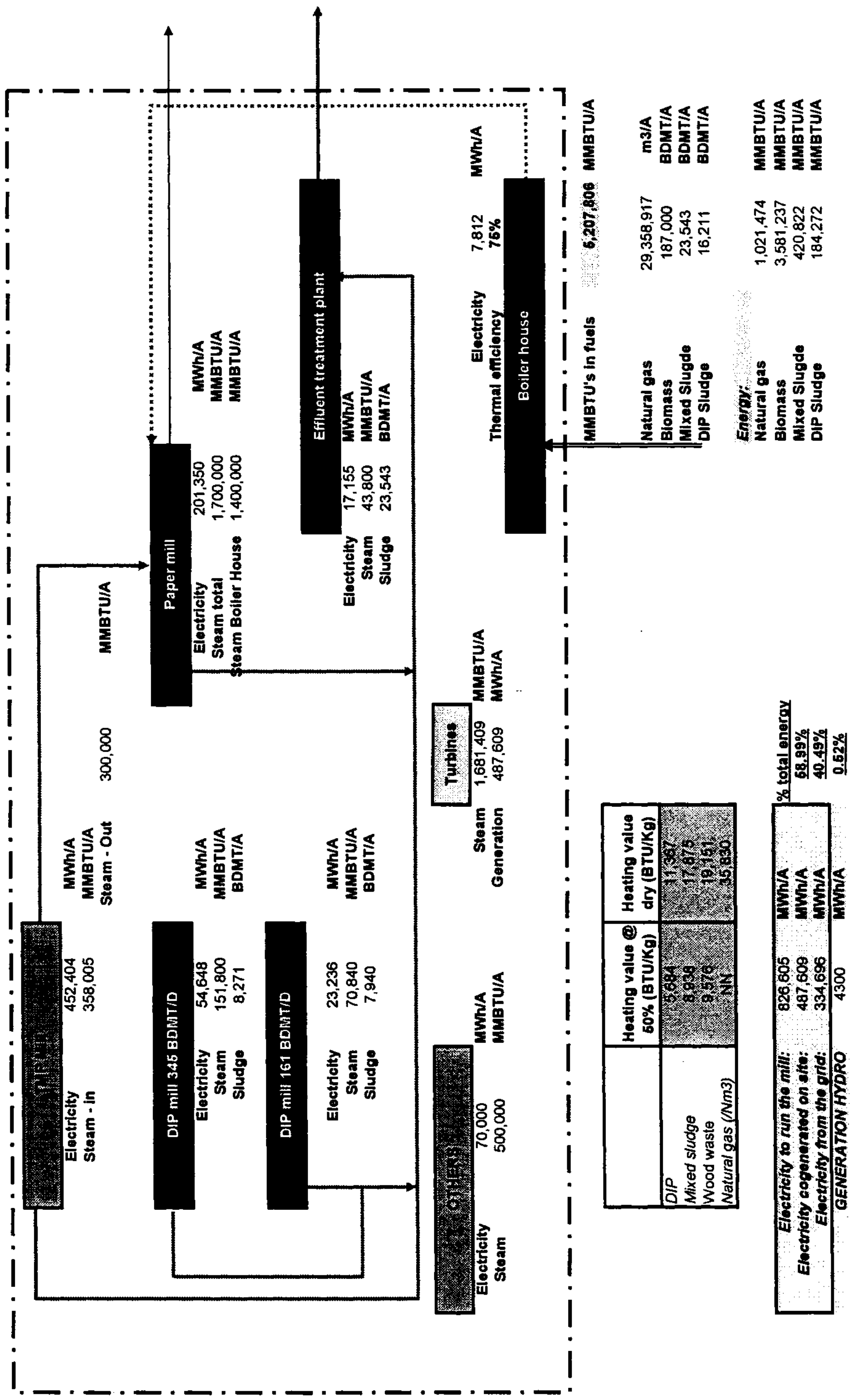
Production Summary

Newsprint furnish fiber balances	DIP 3 - Cogen 1	DIP 5 - Cogen 1	DIP 1 - Cogen 1	DIP 3 - Cogen 2	Units
Average annual recycled newsprint production	387,200.00	387,200.00	387,200.00	387,200.00	FMT/year
Operating period	352.00	352.00	352.00	352.00	days
Moisture at reel	0.92	0.92	0.92	0.92	%
Average newsprint daily production	1,100.00	1,100.00	1,100.00	1,100.00	FMT/d
Sewer loss (allowance)	31.22	36.74	30.10	31.22	ADMT/d
Average daily newsprint furnace requirement					
DIP furnace New line	418,594.59	143,095.65	209,297.30	418,594.59	ADMT/y
DIP furnace Old Line	0.00	72,884.71	0.00	0.00	
TMP furnace	0.00	208,172.04	208,172.04	0.00	ADMT/y
deink plant annual production (pulp)	387,200.00	131,648.00	193,600.00	387,200.00	ADMT/y
Operating period	352.00	352.00	352.00	352.00	Days
Average daily production	1,100.00	374.00	550.00	1,100.00	ADMT/d
Plant availability	1.75	0.59	0.87	1.75	%
Peak deink plant production (design)	630.00	630.00	630.00	630.00	ADMT/d
Furnish					
ONP	70.00%	70.00%	70.00%	70.00%	%
OMG	30.00%	30.00%	30.00%	30.00%	%
Brightness @ HD tower (Unreverted)	60-61	60-61	60-61	60-61	ISO brightness
Dirt (>200 um) or Tappi	30-40	30-40	30-40	30-40	ppm
Ink (10-200 um) optest scanner	4,600.00	4,600.00	4,600.00	4,600.00	ppm
Stickies 0.004 inch. Slot 96 gms	5 to 10	5 to 10	5 to 10	5 to 10	ppm
Freeness	140 -160	140 -160	140 -160	140 -160	ml CSF
Ash content (900°C)	2 to 3	2 to 3	2 to 3	2 to 3	%
Chemical carry over (TDS)	16.00	16.00	16.00	16.00	Lb/BDST
Chemical carry over (TDS) %	80.00%	80.00%	80.00%	80.00%	%
Deink mill yield old line	0.00%	85.00%	0.00%	0.00%	%
Deink mill yield new line	92.50%	92.00%	92.50%	92.50%	%
System yield loss	82.05	29.92	41.03	82.05	BDMT/d
System yield loss	0.08	0.08	0.08	0.08	%
Industrial trash production	18.89	6.42	9.45	18.89	BDMT/d
System sludge production	63.16	23.50	31.58	63.16	BDMT/d

DIP 3 – Cogen 1


Electricity 0 MWh/A
Steam - in 0 MMBTU/A
Steam - Out 0 MMBTU/A
Paper mill
Electricity 201,350 MWh/A
Steam total 1,700,000 MMBTU/A
Steam Boiler House 1,700,000 MMBTU/A
DIP mill
Electricity 160,301 MWh/A
Steam 445,280 MMBTU/A
Sludge 22,232 BDMT/A
Effluent treatment plant
Electricity 10,768 MWh/A
Steam 43,800 MMBTU/A
Sludge 25,003 BDMT/A
OTHERS
Electricity 70,000 MWh/A
Steam 500,000 MMBTU/A
Turbines
Steam 1,216,775 MMBTU/A
Generation 352,865 MWh/A
Electricity 7,812 MWh/A
Thermal efficiency 75%
Boiler house
MMBTU's in fuels 5,207,806 MMBTU/A
Natural gas 25,870,099 m3/A
Biomass 187,000 BDMT/A
Mixed Slugde 25,003 BDMT/A
DIP Sludge 22,232 BDMT/A
2,689,080
Energy:
Natural gas 926,926 MMBTU/A
Biomass 3,581,237 MMBTU/A
Mixed Slugde 446,920 MMBTU/A
DIP Sludge 252,724 MMBTU/A
Heating value @ 50% (BTU/Kg)
Heating value dry (BTU/Kg)
DIP 5,684 11,367
Mixed sludge 8,938 17,876
Wood waste 9,576 19,151
Natural gas (/Nm3) NN 35,830
Electricity to run the mill: 450,230 MWh/A
Electricity cogenerated on site: 352,865 MWh/A 78.37%
Electricity from the grid: 93,065 MWh/A 20.67%
HYDRO GENERATION 4300 MWh/A 0.96%
% total energy

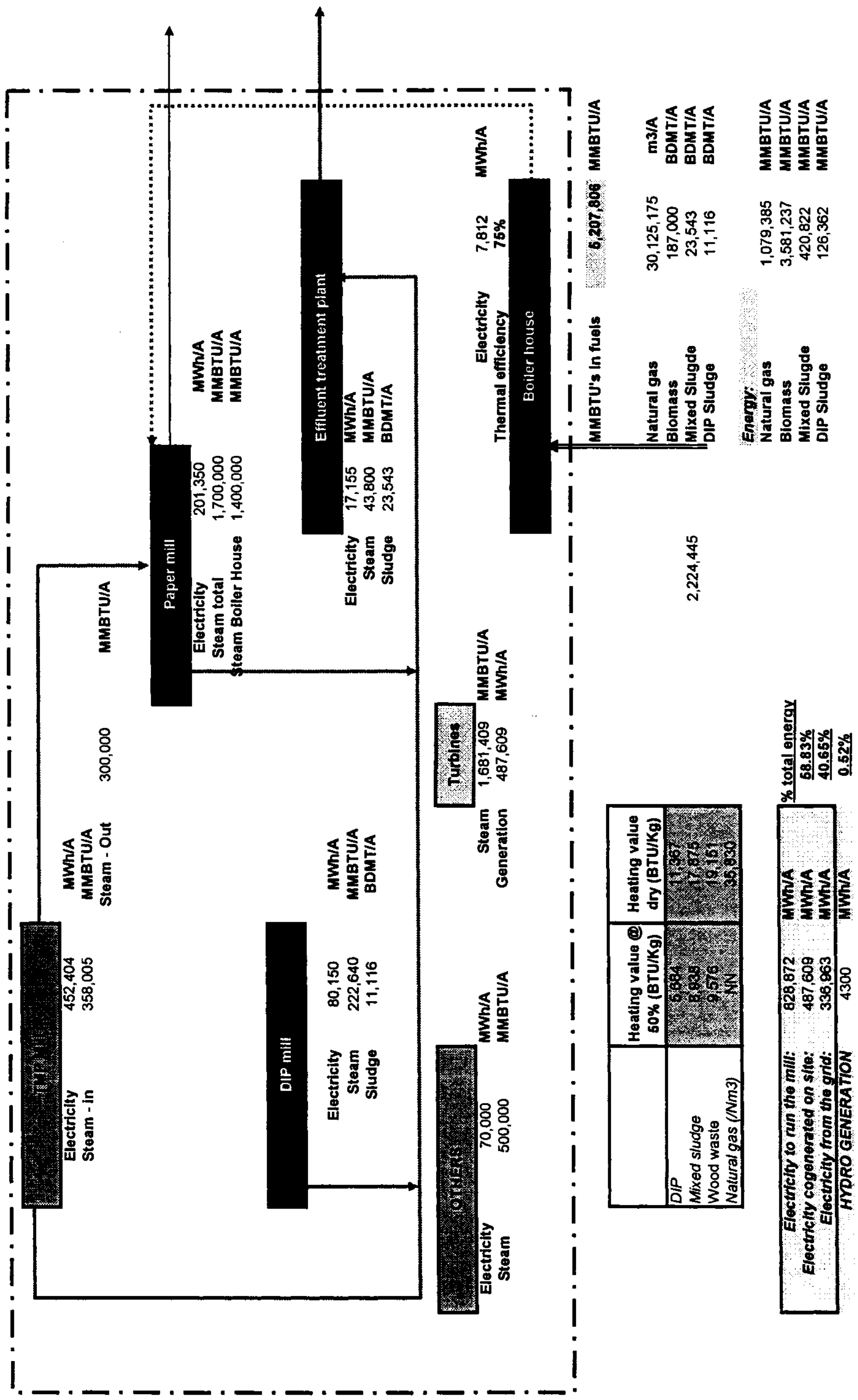
DIP 5 – Cogen 1



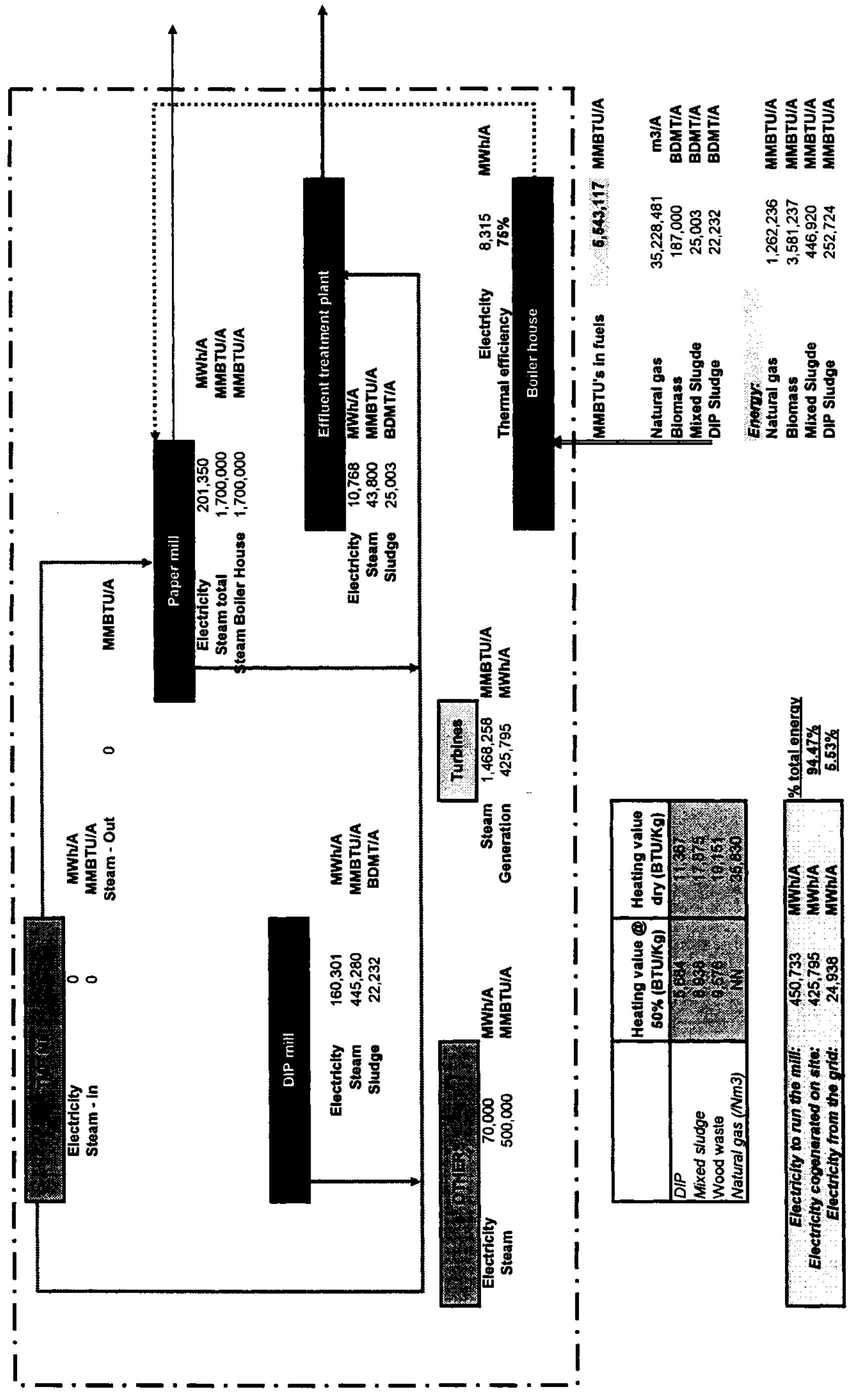
	Heating value @ 50% (BTU/Kg)	Heating value dry (BTU/Kg)
DIP	5,684	11,367
Mixed sludge	8,938	17,875
Wood waste	9,576	19,151
Natural gas (/Nm3)	NN	35,830

			% total energy
Electricity to run the mill:	826,605	MWh/A	
Electricity cogenerated on site:	487,609	MWh/A	58.99%
Electricity from the grid:	334,696	MWh/A	40.49%
GENERATION HYDRO	4300	MWh/A	0.52%

DIP 1 – Cogen 1


Electricity 452,404 MWh/A
Steam - in 358,005 MMBTU/A
Steam - Out 300,000 MMBTU/A
Paper mill
Electricity 201,350 MWh/A
Steam total 1,700,000 MMBTU/A
Steam Boiler House 1,400,000 MMBTU/A
Effluent treatment plant
Electricity 17,155 MWh/A
Steam 43,800 MMBTU/A
Sludge 23,543 BDMT/A
DIP mill
Electricity 80,150 MWh/A
Steam 222,640 MMBTU/A
Sludge 11,116 BDMT/A
OTHERS
Electricity 70,000 MWh/A
Steam 500,000 MMBTU/A
Turbines
Steam 1,681,409 MMBTU/A
Generation 487,609 MWh/A
Boiler house
Electricity 7,812 MWh/A
Thermal efficiency 75%
MMBTU's in fuels 5,207,806 MMBTU/A
Natural gas 30,125,175 m3/A
Biomass 187,000 BDMT/A
Mixed Slugde 23,543 BDMT/A
DIP Sludge 11,116 BDMT/A
2,224,445
Energy:
Natural gas 1,079,385 MMBTU/A
Biomass 3,581,237 MMBTU/A
Mixed Sludge 420,822 MMBTU/A
DIP Sludge 126,362 MMBTU/A
Heating value @ 50% (BTU/Kg) | Heating value dry (BTU/Kg)
DIP 5,684 11,367
Mixed sludge 8,938 17,875
Wood waste 9,576 19,151
Natural gas (/Nm3) NN 35,830
% total energy
Electricity to run the mill: 828,872 MWh/A
Electricity cogenerated on site: 487,609 MWh/A 58.83%
Electricity from the grid: 336,963 MWh/A 40.65%
HYDRO GENERATION 4300 MWh/A 0.52%

DIP 3 – Cogen 2


Electricity 0 MWh/A
Steam - In 0 MMBTU/A
Steam - Out 0 MMBTU/A
Paper mill
Electricity 201,350 MWh/A
Steam total 1,700,000 MMBTU/A
Steam Boiler House 1,700,000 MMBTU/A
DIP mill
Electricity 160,301 MWh/A
Steam 445,280 MMBTU/A
Sludge 22,232 BDMT/A
Effluent treatment plant
Electricity 10,768 MWh/A
Steam 43,800 MMBTU/A
Sludge 25,003 BDMT/A
OTHERS
Electricity 70,000 MWh/A
Steam 500,000 MMBTU/A
Turbines
Steam 1,468,258 MMBTU/A
Generation 425,795 MWh/A
Electricity 8,315 MWh/A
Thermal efficiency 75%
Boiler house
MMBTU's in fuels 5,543,117 MMBTU/A
Natural gas 35,228,481 m3/A
Biomass 187,000 BDMT/A
Mixed Slugde 25,003 BDMT/A
DIP Sludge 22,232 BDMT/A
Energy:
Natural gas 1,262,236 MMBTU/A
Biomass 3,581,237 MMBTU/A
Mixed Slugde 446,920 MMBTU/A
DIP Sludge 252,724 MMBTU/A
Heating value @ 50% (BTU/Kg)
Heating value dry (BTU/Kg)
DIP 5,684 11,367
Mixed sludge 8,938 17,875
Wood waste 9,576 19,151
Natural gas (/Nm3) NN 35,830
Electricity to run the mill: 450,733 MWh/A
Electricity cogenerated on site: 425,795 MWh/A
Electricity from the grid: 24,938 MWh/A
% total energy
94.47%
5.53%

APPENDIX 5: LCA DOCUMENTATION

ISO REPORT – LCA STUDY (ISO ISO14040)

Study: *Using Life Cycle Assessment (LCA) as a tool to enhance Environmental Impact Assessment (EIA)*

Author: Fernando Cornejo
NSERC Environmental Design Chair in Process Integration

Date: 2005

** *This report is based on one of the recommendations from the Critical review performed to this study.*

Definition of the goal & scope

- *Goal of the study*: The goal of this study is to identify environmental performance of new process designs at an integrated newsprint mill.
- *The intended audience* of this study is the environmental scientific community and the NSERC Environmental Design Chair in Process Integration at the Ecole Polytechnique de Montreal.
- *The intended application:* LCA in this study is used as a comparative tool to assess design alternative's environmental performance.
- *Functional unit*: The production of 1 ADMT (i.e., 1 air dried metric ton, 10% moisture content) of newsprint. The reference flow is 1 ADMT of newsprint. The

reference flow and functional unit are considered same for all the design alternatives.

- *System boundaries*: Since this LCA is a comparative study, several differences between the boundaries in previous work and the current project exist (*Salazar 2004*). The following modifications were made:
  - ☐ Exclusion of the forest and sawmill from the system boundaries. At the same time, manufacturing, maintenance and disassembly of assets have been excluded from the system since these are used for several functional units during their life cycles and their impact for one functional unit is negligible.
  - ☐ Chips, recycled paper and biomass (hog fuel) are considered as elemental flows, only considering their transportation. For the elemental flows in this study, a marginal technology analysis has been carried out to demonstrate that the changes will not strongly affect the current market (*Weidema1999*). The modification of the system boundaries was performed in order to avoid system expansion
- *System description:* The current base case is an integrated newsprint mill located in Northern Ontario, it has an average production of 375,000 Finished Metric Tons (FMT) of newsprint per year based on 84% virgin fibre (TMP) and 16% recycled fibre (DIP). Several design alternatives have been proposed to increase the DIP pulp production and to implement co-generation, the boundaries considered for the base case and the design alternatives remains constant aiming a consistent

comparison. The LCA boundaries considered for the environmental analysis of the different design alternatives, which include the following unit processes:

- *Facility level:* TMP line, DIP line, Boiler house (Steam from hog fuel, steam from natural gas and steam from sludge), paper machines, sludge treatment plant, effluent treatment plant, landfill site and the transportation of biomass, wood chips and recycled paper (one way).
- *Product-chain level:* electricity production, fuels production, chemicals production and the transportation of the final product for final delivery to the costumer (one way).

- *The data quality requirements* are the following: (1) Time: For the base case, the year of inventory collection is 2001. For the new design alternatives the data at the facility level are not data from 2001 but based on energy and mass balances, while for the product chain 2001 data is still used. (2) Geography: The system under study is located in Northern Ontario and therefore North American data is desirable. (3) Technology: Data based on average technology is desirable.
- *Treatment of data gaps:* Data gaps for the different alternatives were mainly related to chemicals used at the newsprint mill. They were treated using general databases (e.g. ETH – Organic and Inorganic Chemicals). When data gaps were identified for specific substances for a process unit (e.g. PM2.5 in natural gas production), literature review (e.g. USEPA emission factors and/or particle size distribution factors) or general databases were used.

- *Impact Assessment method:* TRACI impact model proposed by the US Environmental Protection Agency is considered to assess the environmental performance of the proposed design alternatives since the base case was assessed using the same model in previous work. Same choices of output-related impact categories are considered and these are related to different global, regional and local impact categories *(Salazar 2004)*
- *Limitations:* The limits of the LCA study are mainly related to data aggregation in the interpretation phase for the general data bases used, mostly due to their comprehensiveness (i.e. for some materials the entire life cycle is taken into account whereas for others only a fraction of the life cycle is considered). However, when comparing the design alternatives, this limitation is marginal. The absolute importance of the investigated parameters has not been assessed plus for the normalization step, a case-specific normalization approach has been used (Hofstetter 1999).

Life Cycle Inventory (LCI):

The sequence followed to carry out the inventory of the design alternatives is expressed by the following: System understanding → flow charts for process design → data gathering for design alternatives → mass and energy validations → validation by experts.

- Primary and secondary data sources are used to model the system. Primary data is related to the inventory at the facility level for each design alternative. This was based on energy and mass balances that calculated the consumption of recycled paper, wood chips, biomass (including sludge), new fuel requirements, cogeneration output and finally electricity requirements. Technical requirements related to the new equipment considered in the design alternatives, such as electricity consumption and chemical recipes, was specified by the manufacturer.
- The secondary data was estimated using general databases. The external databases considered are the following: (1) Franklin database (America averages, 95-99) to obtain data for fuel production (natural gas, gasoline and propane), transportation (trailer and locomotive) and natural resources on electricity production. (2) IVAM and BUWAL (European averages, 90-94) for most of the chemical production. (3) KCL 3.0 (Finnish average, 92) for landfill models and H_2O_2 and $NaBH_4$ production.
- The following Figures (1, 2 and 3) show the elements considered in the data modeling of the DIP, co-generation and overall mill design alternatives:

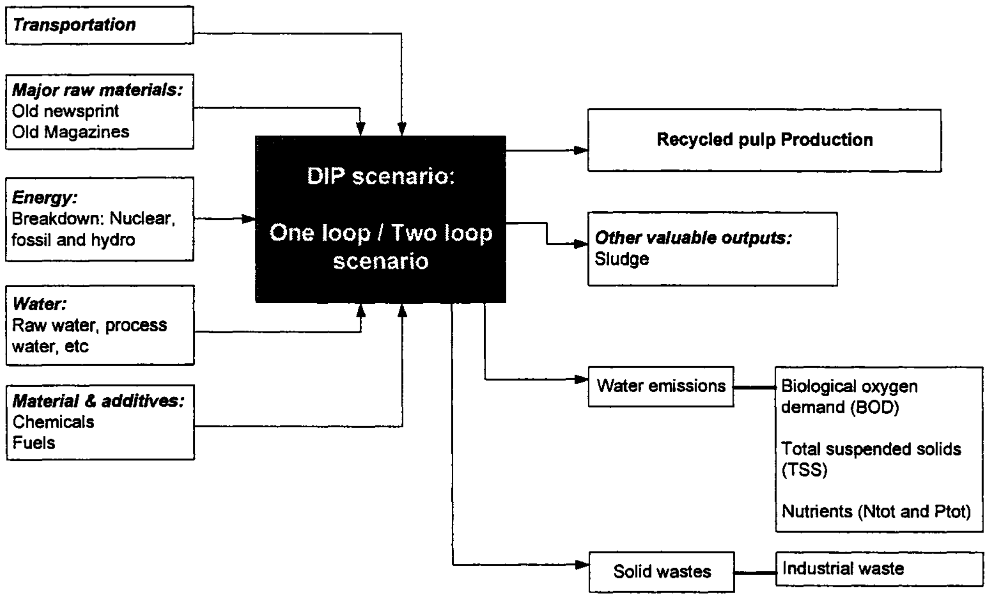


Fig. 1 DIP inventory considerations

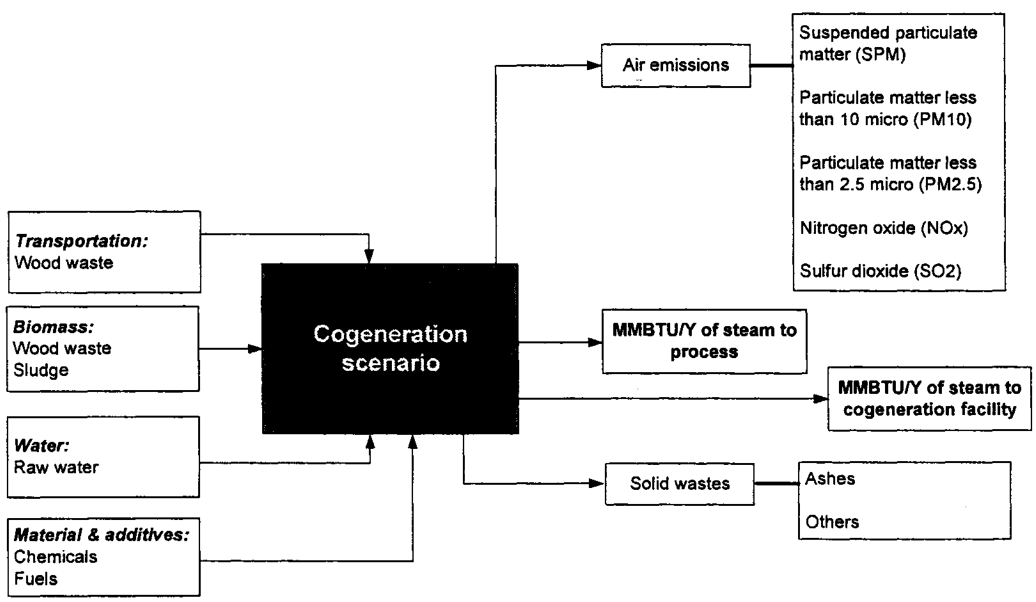


Fig. 2 Co-generation inventory considerations

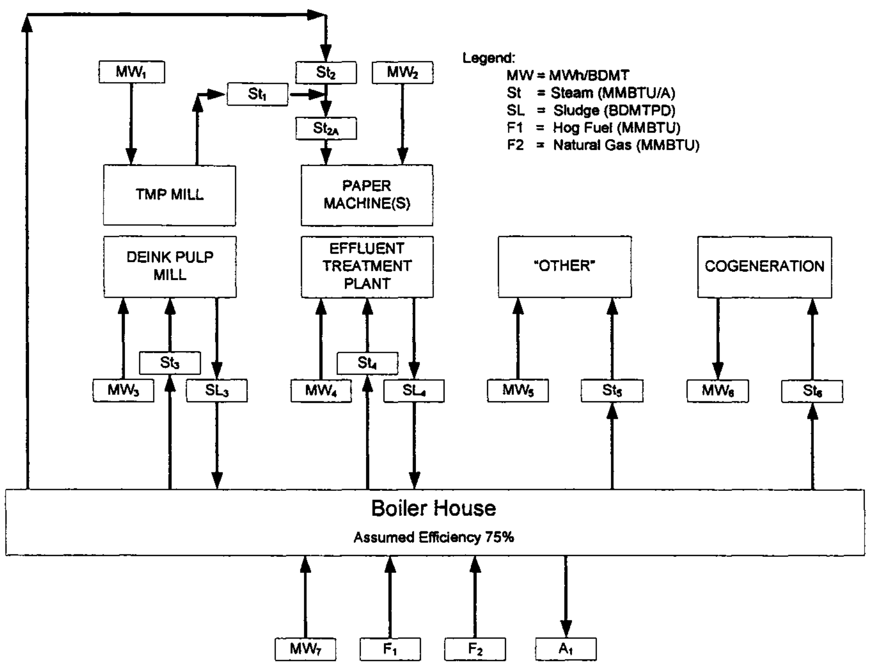


Fig. 3 Total mill & alternative's inventory considerations (Janssen et al. 2005)

- The main assumptions are the following: for chemicals, specific data were not available. More general databases, i.e. ETH chemicals inorganic / organic were used instead. Also, CO_2 emissions from biomass combustion are considered zero because they are part of the natural carbon cycle and the only waste from the mill that can generate GHG's in landfill contributing to global warming potential is the sludge and rejected paper.

Life Cycle Impact Assessment (LCIA):

- The system was modeled using SIMAPRO 5.1 and relevant impact categories were selected to model global, regional, and local potential impacts based on SETAC guidelines. The following Table 1 presents generic information about the model and the category indicators.

Impact Categories	Scale	Category Indicators	Characterization Models
Climate change	Global	g CO_{2eq}	IPCC
Ozone depletion		g $CFC11_{eq}$	WMO
Acidification	Regional	mol $H+_{eq}$	TRACI – Michigan
Eutrophication		g N_{eq}	TRACI – Michigan
Photo-oxidant formation		g NO_{xeq}/m	TRACI – Michigan
Eco-toxicity	Local	g $2,4D_{eq}$	TRACI – USA
Human health-cancer		g C_6H_{6eq}	TRACI – USA
Human health-non cancer		g C_7H_{7eq}	TRACI – USA
Human health criteria pollutants		DALY	TRACI – Michigan

Table 1 LCA impact categories

- Life Cycle Assessment (LCA) results are presented in the following Table 2:

Impact category	Unit	Base case	DIP 3 - Cogen 1	DIP 5 - Cogen 1	DIP 1- Cogen 1	DIP 3 - Cogen 2
Global Warming	g CO_2	1,110,000	406,000	584,000	625,000	404,000
Ozone Depletion	g CFC11	0.006	0.00808	0.00522	0.00648	0.00814
Acidification	mol H^+	297	191	228	242	219
Photo-Oxidant Formation	g NO_x/m	2.55	2.62	2.64	2.77	2.87
Eutrophication	g N	430	327	381	350	331
Ecotoxicity	g 2,4-D	3,130	566	1,240	1,230	340
Human Health Cancer	g C_6H_6	74.4	21.4	32.2	36.2	16.6
Human Health Particulates	DALY	0.000145	0.000129	0.000136	0.000141	0.000137
Human Health Non cancer	g C_7H_7	363,000	136,000	196,000	211,000	137,000

Table 2 LCA results

- All the substances assessed by TRACI and included on the LCI are part of the LCIA. There are some LCI substances that are not assessed by TRACI. From them, TSS is an important release of the system. However, TSS in newsprint mill wastewater are biological and its impact is accounted for BOD, COD and nutrients in the eutrophication impact category.
- The LCIA results are relative expressed and do not predict impacts on the category endpoints, threshold or risk.

Life Cycle Interpretation:

A contribution analysis has been performed for each single LCA impact category considered in this evaluation in order to have a better assessment of each option.

The results of the he contribution analysis for global warming potential for the four feasible alternatives are depicted in Figure 4.

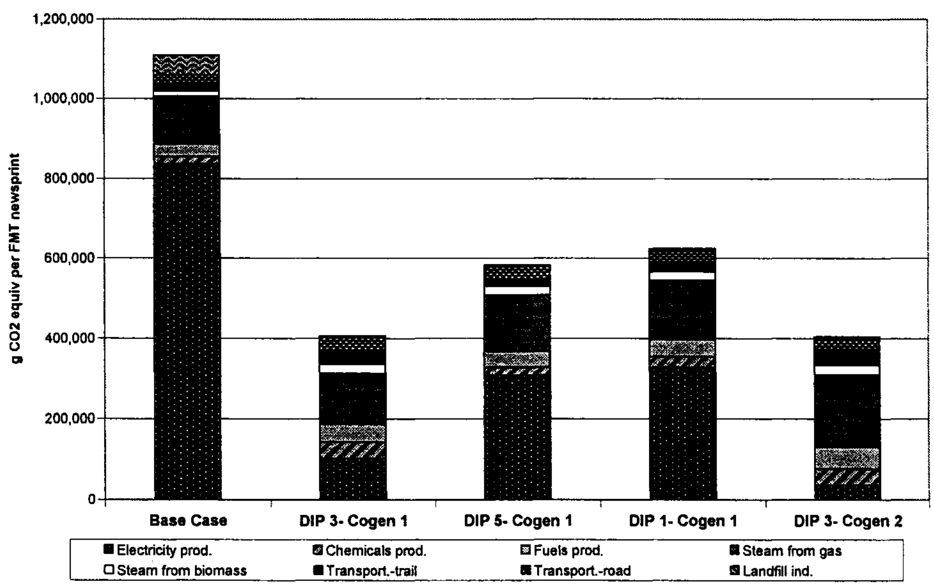


Fig. 4 Global warming results

The design alternatives all show a decrease in global warming emissions across the product system by 64% as maximal reduction reported for the design alternative DIP 3 – Cogen2, closely followed by scenario DIP 3 –Cogen 1.

Contribution analysis results related to the base case shows as the most important contributor of global warming to the "electricity production" unit process. Natural gas burned in the boilers is the second biggest contributor to global warming. However, alternatives with 100% DIP increase in combination with a co-generation facility show that "steam from gas" is the most important contributor to global warming since they reduce electricity consumption by 50% when compared to the base case. Emissions from industrial landfill affecting the Global Warming (GW) potential have been reduced to almost zero since the sludge produced by the process is burned in the boiler house to recover energy and to produce steam for the process. $CO_{2\ eq.}$ emissions produced by biomass burning have been considered as neutral from a global perspective point of view. However, $CO_{2\ eq}$ emissions due to biomass storage and transportation are considered in this analysis.

As illustrated at Figure 5, the production of chemicals is the major contributor to the ozone depletion impact category. The different technological configurations imply new chemical recipes to treat and produce the recycled fibre. By increasing to 100% DIP production represents an increase on the ozone depletion impact category since the new 100% line has a higher and different chemical recipe (see the chemical recipes in APPENDIX 4). The contribution of electricity production and fuels production is slightly varying across all the alternatives due to its limited contribution to this impact category.

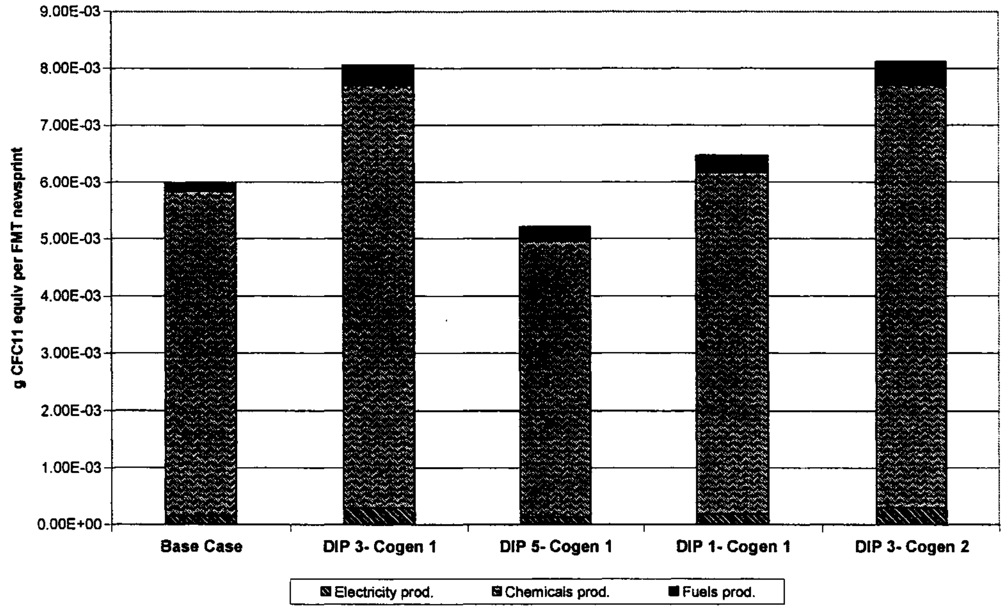


Fig.5 Ozone depletion results

The results of the contribution analysis for acidification are depicted in Figure 6. As can be seen, all the design alternatives reduced acidification levels when compared to the base case.

Electricity and Fuels production are identified as the first and second major contributors to the acidification levels in the base case. For the design alternatives, fuels production becomes the most important contributor since they have reduced their electricity consumption and at the same time, increased fossil fuels consumption due to co-generation, transportation, etc.

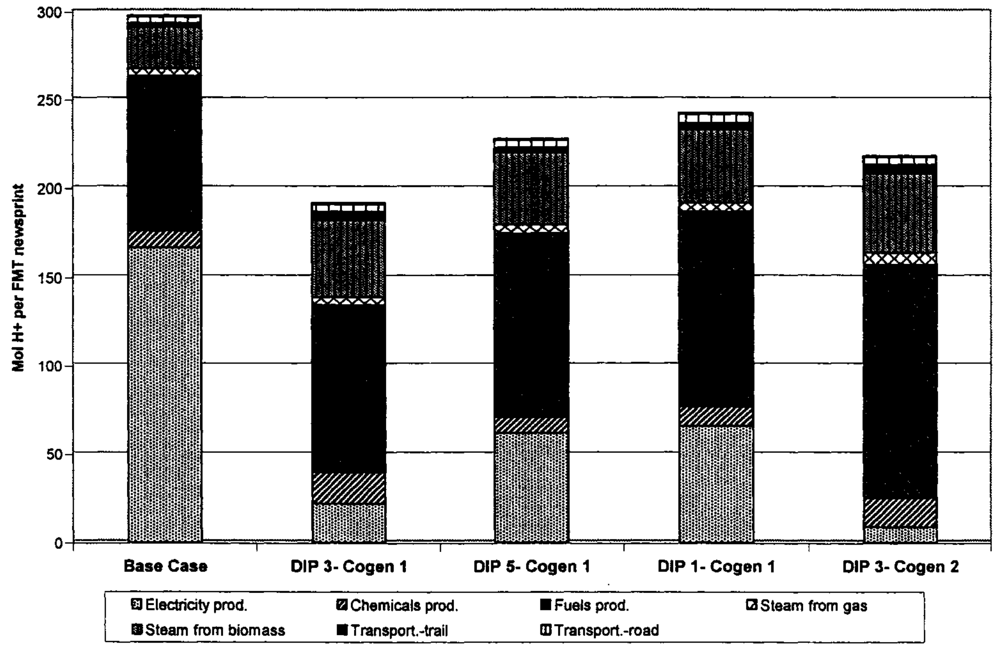


Fig. 6 Acidification results

Since DIP 3 – Cogen 2 has the highest consumption of natural gas; consequently, the results of fuels production are the highest across the design alternatives.

At the same time, depending on the alternative, steam from biomass could be the second or third major contributor to affect acidification levels. Alternatives where electricity consumption is highly reduced and biomass is increasingly consumed (100% DIP with co-generation, DIP 3 – Cogen1 and DIP 3 – Cogen 2); steam from biomass becomes the second major contributor. However, in scenarios where still exist TMP production (DIP 5 – Cogen 1 and DIP 1 – Cogen 1); electricity production is defined as the second major contributor.

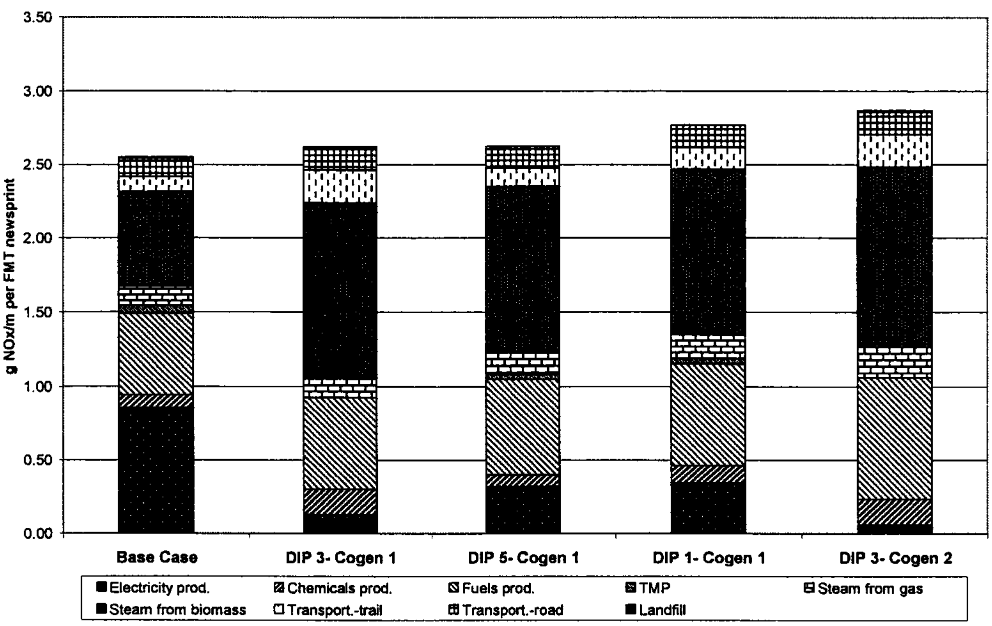


Fig. 7 Photo-oxidant formation results

The results of the contribution analysis for photo-oxidant formation are shown in Figure 7. All DIP alternatives generate more sludge and thus higher amounts of biomass to be burned in the boiler. These increased amounts of biomass generate higher emission levels of NO_X, CO and non-methane VOC at the facility-level, which increase the photo-oxidant formation levels e.g. for scenarios DIP 3 – Cogen 1 and DIP 3 – Cogen 2 (both considering 100% DIP) when compared to the base case. At the same time, DIP 3 – Cogen 2 shows the highest acidification levels due to its higher natural gas consumption and the consequently higher production of natural gas at the product-chain level.

Electricity consumption and steam from biomass are the first and second major contributors in the base case. However, with the new design alternatives, the first contributor to photo-oxidant formation becomes the steam from biomass due to the higher amounts of biomass consumed by the new design alternatives to produce steam. At the same time, since the consumption of electricity by the new design alternatives is way lower than the base case, this unit process becomes 3rd or 4th most important contributor to this impact category.

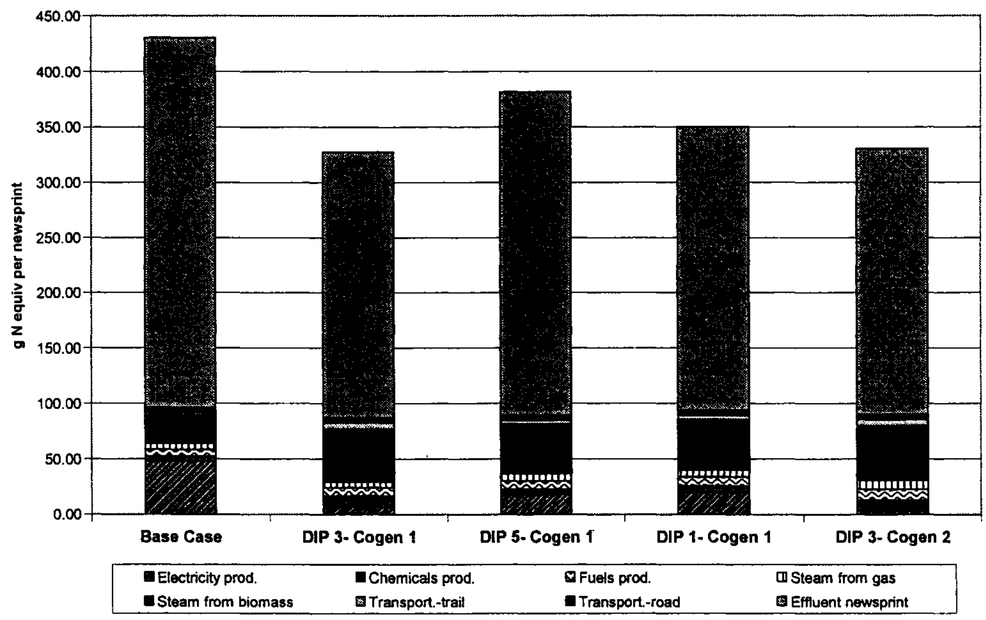


Fig. 8 Eutrophication results

As shown in Figure 8, the mill effluent is the major contributor to eutrophication. The most important substances affecting this impact category are Biological Oxygen Demand (BOD) and nutrients (total Phosphorus (P-tot) and total nitrogen (N-tot)). As can be seen, scenarios with 100% increased DIP production (*DIP 3 – Cogen 1 and DIP 3 - Cogen 2*) represent a reduction of 23- 24% eutrophication impact when compared to the base case since their final effluent contains lower concentration of BOD.

For human health particles (HHP), depending on the alternative, the most important contributors to this impact category are "steam from biomass" (biomass burning), fuels production and electricity production. Since electricity consumption is lower in alternatives where TMP production is completely shutdown (DIP 3- Cogen 1 and DIP 3– Cogen 2), the levels of HHP are the lowest reducing current levels by 11% maximum. However, in scenarios where there is still TMP production (i.e., increased 50% DIP), the HHP levels decrease at maximal of 6%.

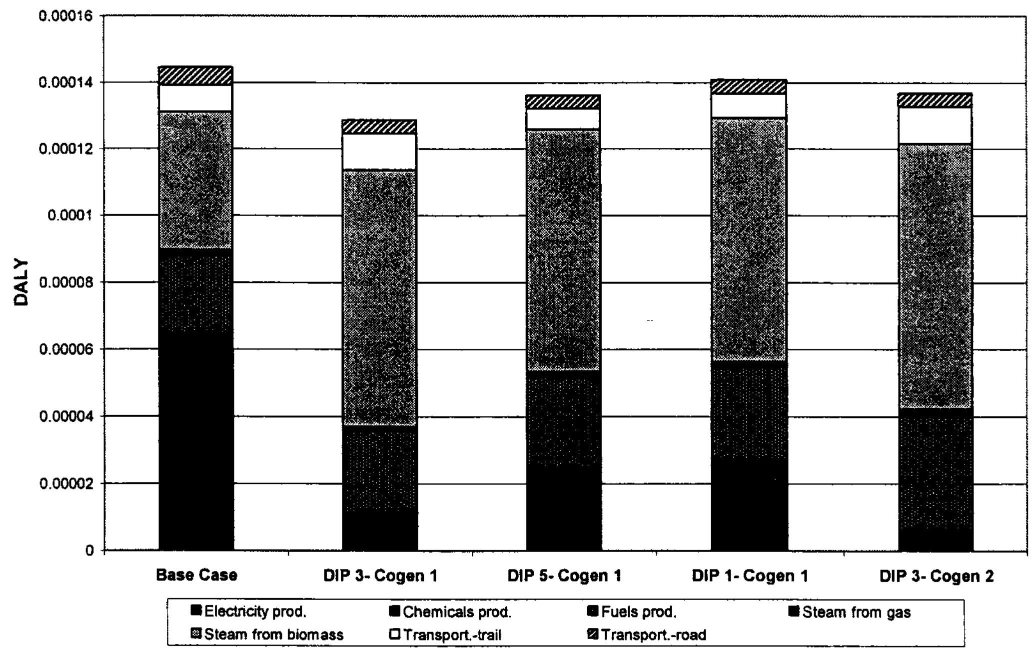


Fig. 9 Human Health Particles (HHP) results

For other human health related impact categories (human health cancer and human health non cancer) and eco-toxicity, the highest environmental benefits are perceived for scenarios where 100% increased DIP production and implementation of co-generation are considered. For these human related categories, the electricity production and chemical production are the most important contributors.

This section will present the contribution analysis of the human health related impact categories and eco-toxicity, which are depicted in the following Figures:

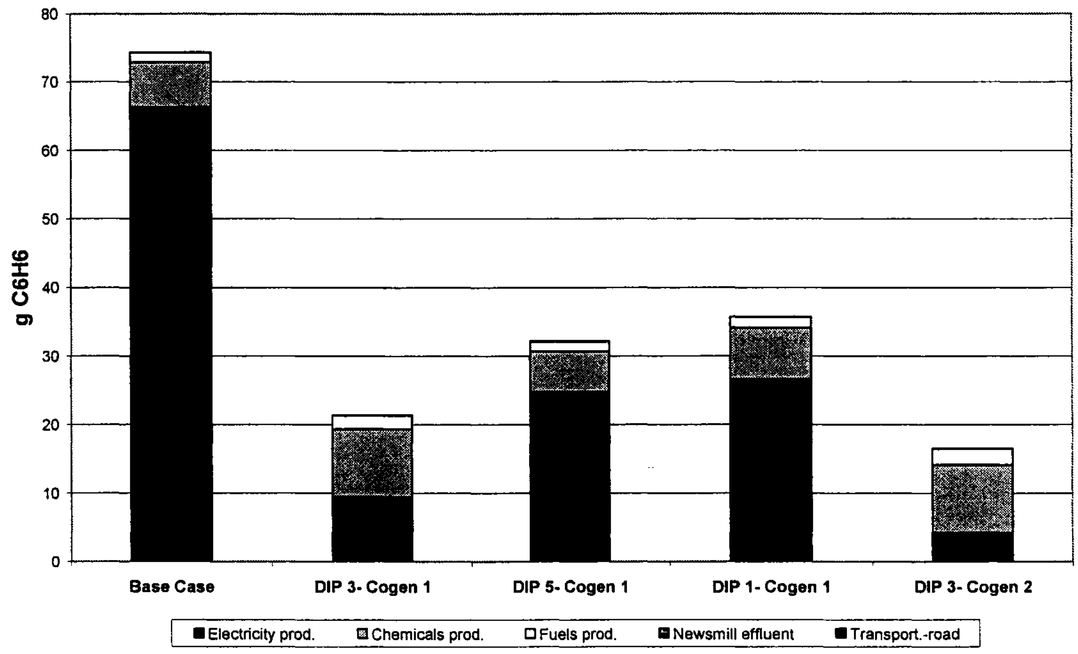


Fig. 10 Human Health Cancer (HHC) results – contribution analysis

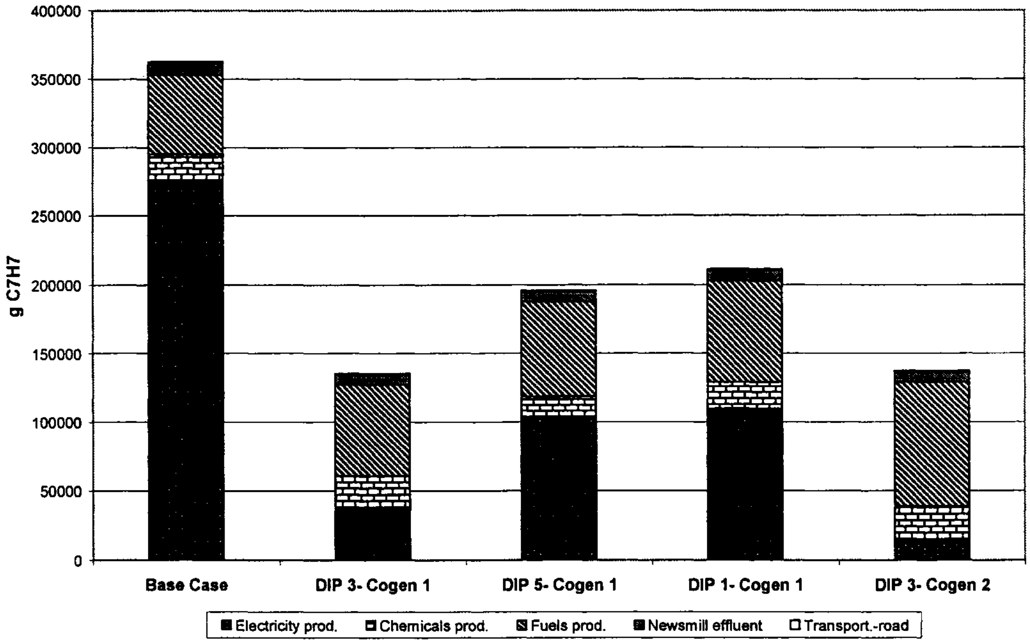


Fig. 11 Human Health Non Cancer (HHNC) results – contribution analysis

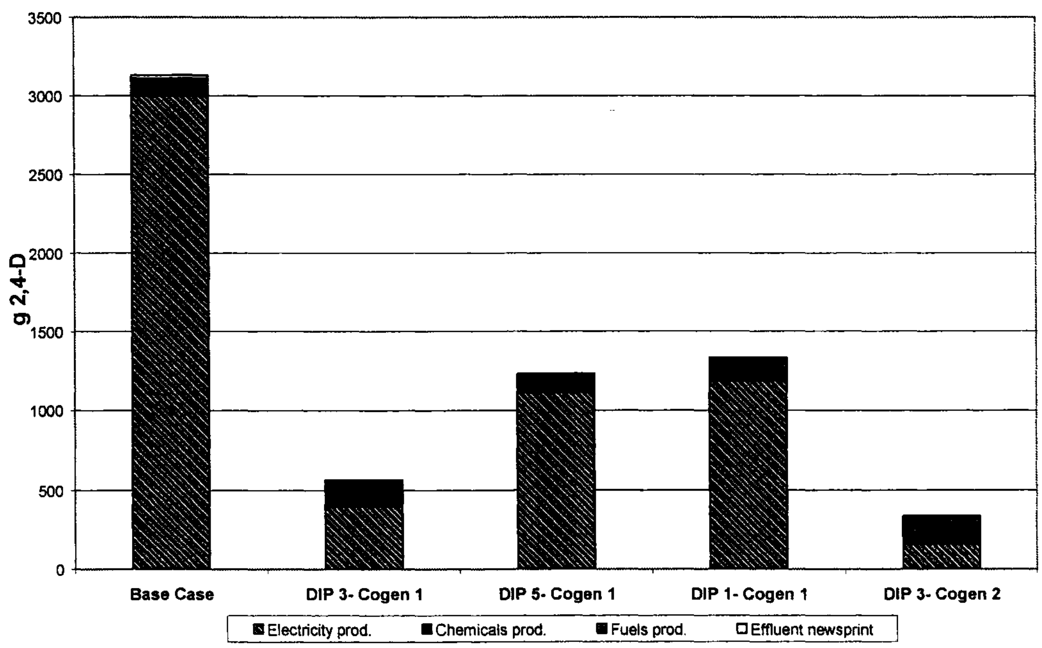


Fig. 12 Eco-toxicity results – contribution analysis

Since the most important contributing substances to each impact category are fairly constant across the different design alternatives, these are presented in the following Table 3:

Impact category	**Substance**
Global Warming potential	CO_2 and CH_4
Ozone Depletion	Halon 1301
Acidification	SO_2 and NOx
Photo-oxidant formation	NOx
Eutrophication	P-tot, N-tot and NOx
Human Health Particles	TSP, PM_{10}, $PM_{2.5}$ and SO_2
Human Health Cancer	As
Human Health Non-Cancer	Hg and Cd
Eco-toxicity	Hg

Table 3 Key substances contributing to LCA impact categories

Results of marginal technologies analysis

Marginal technologies are assessed in order to identify the potential effect of changes on materials consumption in market's availability. The changes are related to electricity, recycled paper, biomass and wood chips consumption.

Electricity market will be marginally affected by the changes on electricity consumption due to the new design alternatives. Since these alternatives represent a reduction (up to 50% depending on the alternative) of electricity consumption when compared to the base case, the electricity market will have an additional amount of electricity to be sold to other users. These reduction of electricity consumption represents as maximal as 0.54% of the total power generated by the grid which represents a marginal effect. The electricity produced from fossil fuels is the identified marginal technology because it is the most probable to be affected in order to meet the new demand if electricity consumption is reduced. Finally, with this reduction on electricity consumption due to the design alternatives, the grid's energy breakdown will not be affected (Grid produces 122,150 GWh/y, Source: Ontario Power Generation, 2001)

Recycled paper market will be slightly affected with the implementation of 100% DIP production alternatives since these will consume a higher amount of recycled paper, which represents 2.5% of Old Newsprint (ONP) and 1.3% of Old Magazines (OMG) of the total recycled fiber managed by the market. (Market manages 9.5 millions metric tons of ONP and 9.3 millions metric tons of OMG per year, Source: American Forest and Paper Association, 2003). The marginal technology is recollection and transportation of recycled paper.

Biomass market availability will not be affected because it is assumed that new amounts of biomass consumed by the design alternatives will be supplied by a new sawmill that will start to operate in parallel with our new design alternatives.

Since TMP production is reduced, the availability of wood chips on the market increases as maximal 340,000 BDMT per year. Market effects can not be calculated due to the lack of information related to wood chips availability on the market.

The following are the limitations associated to this study:

- The recommended data quality assessment by ISO 14043 has not been performed to the LCA inventory. At the background level; the data was the same as in a previous study which implies that the data's quality is equal to that work (*Salazar 2004*). Foreground inventory for the design alternatives was based on energy and mass balances, which were validated by experts. It would be beneficial to assess the quality of the foreground data by using quality indicators.
- Only LCA output related impact categories have been considered in this study, the input impact categories were not included since no models for these impacts are available.
- The consumption of wood chips, woodwaste and recycled wastepaper have been considered as elemental flows in the LCA modelling, future analysis of their importance should be evaluated by expanding LCA boundaries to include their markets in order to have a better assessment of the importance of these materials on the presented results.
- Since this project was oriented to use LCA as a comparative tool, the main objective, of the LCA analysis, was to select the best design alternative based on life cycle impact assessment results. Only contribution analysis was performed on the LCA results of the design alternatives. Consequently, it is recommended to analyse uncertainties and sensitivities of each single alternative as future work.

- The results obtained in this study and the consequent conclusions are only valid for the system studied and no generalization at can be made based on the analyses performed. This is mainly due to the influence of the electricity model, which varies among newsprint mills, on the impact assessment results.

Critical review:

The following document presents the critical review carried out by an expert from CIRAIG (Life Cycle Centre at Ecole Polytechnique de Montreal).

RAPPORT DE REVUE CRITIQUE

Titre de l'étude : *Using Life Cycle Assessment (LCA) as a tool to enhance Environmental Impact Assessment (EIA)*

Auteur(s) : Fernando Cornejo

Mandataire(s): NSERC Environmental Design Chair in Process Integration

Comité d'évaluation : Jean-François Ménard

Année de réalisation de l'étude : 2005

Ce rapport présente les commentaires du comité effectués lors de la revue critique.

RAPPORT DE REVUE CRITIQUE :

Remarques générales

1. Il est difficile, en vue du caractère incomplet de la documentation concernant l'étude ACV, de critiquer les aspects méthodologiques de l'étude. ***The documentation has been completed from the time of this critical review. Documentation related to contribution analysis (Process and substances), literature content, methodology and other results.***
2. Tous les éléments identifiés dans les normes de l'ISO comme devant apparaître dans le rapport de l'étude ACV, ne sont pas repris dans les diverses sections du mémoire traitant de l'ACV qui a été réalisée. Il aurait été intéressant de mettre en une seule annexe, tous ces éléments, quitte à faire référence, quand il y a lieu, aux sections du mémoire dans lesquelles chacun de ces éléments est traité. ***The first report included in this APPENDIX addresses this comment.***

Définition de l'objectif et du champ de l'étude

3. Il aurait fallu indiquer tous les éléments requis par ISO pour cette section, et non seulement les plus importants.
   a. Objectif de l'étude : raison de l'étude et public cible ;
   b. Cham de l'étude : fonctions du système de produits, fonction étudiée, unité fonctionnelle, flux de référence, frontières du système et description des processus élémentaires, critères d'inclusion, modes d'imputation, exigences quant à la qualité des données d'inventaire, méthodes d'évaluation des impacts, méthodes d'interprétation des résultats, hypothèses principales et limites de l'étude.

Answer : **The objective of this study is to analyze global, regional and local environmental performances of different design alternatives in comparison to a**

base case. The intended audience of this study is the environmental scientific community and the NSERC Environmental Design Chair in Process Integration at the Ecole Polytechnique de Montreal. The ISO elements required for this study are identified and included in the Report ISO 14040 in the Goal and Scope section (First report presented in this APPENDIX)

4. Le flux de référence n'est clairement identifié.

Answer: **1 ADMT of newsprint, same reference flow considered for all the design scenarios**

5. Les raisons pour la modification des frontières du système de produits, par rapport à celles utilisées pour l'étude sur laquelle est basée la présente étude, ne sont pas suffisamment détaillées.

Answer: **The reasons have been clearly stated in the ISO report and the thesis (i.e., LCA section), the main reason was to keep a simplify version of the LCA model to avoid expansion of system boundaries, same modifications have been performed on the base case's boundaries to be consistent in the final comparison. At the same time, the excluded unit processes are identified as non important by previous studies (Salazar, 2004)**

6. La liste et la description des processus élémentaires ne sont pas suffisamment détaillées.

Answer: **The elementary process included in the system boundaries are the following:**

Facility level: **TMP line, DIP line, Boiler house (Steam from hog fuel, steam from natural gas and steam from sludge), paper machines, sludge treatment plant, effluent treatment plant, landfill site and the transportation of biomass, wood chips and recycled paper (one way).**

Product-chain level: **electricity production, fuels production, chemicals production and the transportation of the final product for final delivery to the costumer (one way).**

7. Les processus élémentaires illustrés dans la figure représentant le système de produits ne correspondent pas exactement à ceux auxquels il est fait référence durant le reste de l'étude ACV. Il serait intéressant de reprendre cette figure afin d'y présenter individuellement tous les processus élémentaires considérés dans l'étude et pour lesquels des données ont été collectés, quitte à les regrouper en grandes étapes du cycle de vie. La terminologie utilisée dans cette figure devrait être la même tout le long de l'étude.

Answer: As part of the comment No.6, a description of the background and foreground unit processes, includes references to the names used in the study such as « steam from biomass » or « steam from gas » which represent the fraction of steam produced from biomass or natural gas.

8. Les technologies marginales et les conséquences de leur prise en compte ne sont pas clairement présentées. Les technologies marginales concernant les copeaux et les déchets de bois ne sont pas déterminées.

Answer: Marginal technologies are assessed in order to identify the potential effect of changes on materials consumption in market's availability. The changes are related to electricity, recycled paper, biomass and wood chips consumption. Results are presented in the ISO Report in the Interpretation section.

9. Les modifications apportées au système de produits correspondant au scénario de base ne sont pas présentées (nouveaux produits chimiques impliqués).

<u>Answer:</u> **The system boundaries have been modified; same conditions are considered for the modified base case and the design alternatives. However, new design alternatives have different chemical recipes; these recipes are presented as part of the technical specifications in APPENDIX 4.**

10. Les exigences quant à la qualité des données d'inventaire ne sont pas présentées.

<u>Answer:</u> **Data quality requirements are presented in the ISO report in the Goal & Scope section.**

11. Les raisons pour le choix de la méthode d'évaluation des impacts (TRACI du US EPA) ne sont pas clairement présentées. Il est fait allusion à une analyse de sa compatibilité avec les normes ISO et les recommandations du SETAC, mais les résultats de celle-ci ne sont pas présentés.

<u>Answer:</u> **TRACI impact model proposed by the US Environmental Protection Agency is considered to assess the environmental performance of the proposed design alternatives since the base case was environmentally assessed using the same model in previous work (*Salazar 2004*). The main reason is to be consistency in the final comparison.**

12. La méthode d'évaluation des impacts et ses catégories d'impact ne sont pas suffisamment décrites.

<u>Answer:</u> **A description of the chosen output impacts have been described in the literature review section.**

13. La revue critique est faite par une seule personne et non par un comité composé de trois membres.

<u>Answer:</u> **This has been changed in the LCA's peer review section of the thesis body.**

Analyse de l'inventaire

14. Les méthodes de calculs des paramètres d'inventaire ne sont pas présentées. Celles-ci pourraient être incluses dans l'annexe portant sur l'étude ACV. Les fichiers de calcul en format Excel ne sont pas suffisamment clairs, les choix sous-jacents à certains des calculs qui sont faits ne sont pas présentés et les résultats des ces calculs qui sont repris dans le logiciel ACV SimaPro ne sont pas clairement identifiés.

Answer: The Excel spreadsheets have been modified (format) in order to make them more understandable and practical. At the same time, the LCA model makes reference in the section "comments" to the source of the calculation.

15. Les hypothèses utilisées lors des calculs n'apparaissent pas clairement. Par exemple, lors des transports par camions, est-ce que les trajets de retour sont inclus.

Answer: This comment has been implemented in the new version of the thesis. Additionally, the transportation only includes one way.

16. Le type (primaires ou secondaires) ou la source (usine de production de papier, littérature, banque de données génériques) des données utilisées pour caractériser chacun des processus élémentaires n'est pas clairement spécifié.

Answer: The type of data (primary or secondary) and the source are defined in the section Goal & Scope and Inventory. This is included in the ISO Report.

17. Aucune analyse n'est faite sur les résultats du calcul de l'inventaire.

Answer: The Life Cycle Inventory (LCI) has been presented in APPENDIX 8; Facility inventory has been analyzed in previous stages of this project such as techno-economic analysis and EIA.

Évaluation des impacts du cycle de vie

18. Les analyses de contributions sont faites en considérant les processus élémentaires sous forme désagrégée, c'est-à-dire que les processus indiqués dans les fichiers de résultats en format Excel sont ceux qui découlent de la modélisation faite avec le logiciel SimaPro et de l'utilisation de banques de données génériques. Les liens entre les processus indiqués et les processus identifiés durant la description des systèmes de produits ne sont pas clairement spécifiés et il est ainsi impossible de connaître les impacts associés à ces derniers puisque, par exemple, dans le cas de la production de l'électricité, les impacts de la production des différents carburants utilisés à cette fin doivent être comptabilisés avec ceux des sites de génération électrique (centrales). Il aurait plus intéressant d'identifier d'abord les contributions des processus élémentaires tels que clairement présentés durant la description des systèmes de produits, quitte à ensuite faire référence aux contributions des sous-processus. À tout le moins, il aurait fallu expliquer les agrégations (en classe de processus) réalisées lors des analyses de contribution.

Answer: **The aggregation of data could be a limitation of this study if the aim of this project would have been the analysis of single alternatives. However, this study has a comparative nature, the same conditions have been considered to all the scenarios and the objective is to select the best alternative based on a comparison of their environmental performances.**

Contribution analysis spreadsheets have been reviewed and modified; finding that a small mistake on the Global warming sheet was done. Landfill emissions from the alternatives are reduced to almost "zero" since there is a small amount rejected paper from paper machines that is send to landfill (i.e., broken paper) and this contributes to generate GHG emissions from landfill sites, which is

marginal compare to other unit processes. The same amount of broken paper has been considered for all the design scenarios.

19. Il aurait été intéressant de procédé aux analyses de contributions de la même façon pour chacune des catégories d'impacts, en identifiant les processus élémentaires et les substances dominants.

Answer: Since the contribution of substances to each impact category remains fairly constant across the different design alternatives, a table is included in ISO Report in the Interpretation section. This table makes reference to the most important substances contributing to each impact category.

20. Les analyses de contribution pour les catégories d'impacts concernant la toxicité humaine et l'écotoxicité ne sont pas présentées.

Answer: The ISO Report presents all the contribution analysis for all the impact categories in the Interpretation section.

21. Les substances non identifiées par la méthode d'EICV devraient être rapportées dans le mémoire, ainsi que la masse totale (ou %) qu'elles représentent par rapport à l'ensemble des émissions du système de produits. De plus, l'effet potentiel de leur exclusion devrait être évalué, du moins qualitativement.

Answer: New chemicals consumed by the new design alternatives have been assessed by the LCA model. However, there are substances which are not assessed in this study; these are the same as the ones not assessed by the base case (Salazar 2004)

Interprétation du cycle de vie :

22. Les données manquantes à l'étude devraient être clairement rapportées (si applicable). Si applicable, l'effet de leur exclusion devrait être traité.

<u>Answer:</u> **The model does not have missing data and the exclusion of certain unit processes (i.e. sawmill) has been assessed in previous work (Salazar 2004), showing that their effect is marginal for all the impact categories based on contribution analysis. This LCA study only looks for a comparative assessment of design alternatives under same conditions.**

23. Il devrait être mentionné le fait que les données génériques sont tirées de plusieurs sources (banques de données) et que leur niveau d'agrégation n'est pas toujours le même (certaines sont complètement agrégées et d'autres le sont partiellement, faisant appel à d'autres données). Ceci peut faire en sorte que l'étude présente des inconsistantes.

<u>Answer:</u> **Same conditions have been considered to model and to compare the proposed design alternatives; the degree of aggregation has a marginal effect on the final outcome, which is the comparison itself. However, the completeness of all the data bases is not analyzed; some of them include the production of the material and some others include the whole life cycle. However, this is considered as a limitation of this study.**

24. Aucune limite d'interprétation ou critique à la méthodologie ne sont rapportées dans le cadre de la discussion (ex : qualité des données utilisées, choix des catégories d'impact).

<u>Answer:</u> **A section of limitations and recommendations is included in the ISO Report in the Interpretation section.**

NB : Cette revue critique s'applique uniquement aux aspects méthodologiques relatifs à la tenue d'étude ACV. Les aspects méthodologiques relatifs à la rédaction d'un mémoire de maîtrise ne sont pas l'objet de la présente revue. Ainsi plusieurs éléments sont laissés à la discrétion de l'auteur et des membres du jury. Les recommandations issues de ce rapport sont issues de la série de normes ISO 14 040 et de lignes directrices internes au CIRAIG pour la conduite d'ACV.

APPENDIX 6: ENVIRONMENTAL IMPACT ASSESSMENT (EIA) REPORT

Hypothetical Environmental Assessment Report (EA)

"Implementation of cogeneration and increased De-inked pulp (DIP) production at an integrated newsprint mill"

By

Fernando Cornejo

2005

Executive Summary

The current report evaluates changes in air emissions, water emissions and solid waste generation by implementing a cogeneration facility and increasing to 100% de-inked pulp (DIP) production at a hypothetical integrated newsprint mill.

The project modifications are oriented to implement a brand new DIP line to replace 100% the thermo-mechanical pulp production and the implementation of a cogeneration system to co-generate 78% of the overall electricity consumed by the mill or 40 MW (nominal).

Implementation of cogeneration implies increasing consumption of non-fossil fuels such as biomass and sludge. At the same time, the cogeneration design allows the process a slight reduction on natural gas consumption. Best Available Technologies (BATs) implemented in this project are Low NOx burners to control NOx emissions and electrostatic precipitators to control Total Suspended Particles (TSP)

General environmental results showed that new air emission levels are far below current provincial regulation. Besides, distance-to-regulation comparisons suggest that project modifications will not have an important air impact in the receiving environment.

Water emissions are slightly reduced as a consequence of the installation of a new DIP line replacing the TMP and suggesting a positive impact final effluent quality.

The solid waste generation (Sludge, industrial trash and ash) increase due to the new project modifications. However, a main modification in the boiler house allows to the design to burn 100% of the sludge generated at the mill site reducing the amount of landfilled sludge. At the same time, the increased amount of burned biomass will increased ash production from the boiler house.

Finally, the report presents conclusions related to the most important and regulated emissions, as well as the overall environmental benefits of implementing the aforementioned project modifications.

Introduction

An environmental assessment was conducted to assess the environmental performance of the proposed project aiming to implement a biomass-based cogeneration system and the increase of de-inked pulp (DIP) production at an integrated newsprint mill in order to obtain the necessary permits to proceed with this project.

The mill under study is located in a hypothetical area in Ontario, along the KAPI River. The nearest community is located 200 m from the facility area and the population is approximately 10,300 habitants (1991).

In 1922, the mill started to operate as a sulphite mill and in 1928 it began producing newsprint as well as hydroelectric power. Currently, the mill produces lumber from a sawmill dating 1995, which was expanded in 1997. Newsprint and specialty paper grades are currently being produced at the mill on four paper machines fed by two TMP pulping lines and a deinking operation. The two TMP lines were built respectively in 1993 and 1996, respectively and the de-inking facility was built in 1992 and expanded in 1995.

The average mill production is 387,000 finished metric tons (FMT) per year of newsprint using 20% recycled fiber and 80% virgin fiber.

This project aims at shutting down the TMP production and replaces it by the expansion of the DIP facility.

Scope and boundaries of the study

Several DIP and cogeneration scenarios have been economically assessed. The 1100 t/d DIP scenario presented here, in combination with a cogeneration facility which co-generates 78% of the electricity used at the mill, is the most economically feasible scenario retained. This environmental study has been oriented to these following areas:

- Thermo-mechanical pulping process;
- De-inked pulping process;
- Paper machines;
- Boiler house;
- Sawmill;
- Transportation of recycled paper and wood waste;

This report presents the results of the environmental assessment for future changes in emissions to air and water and for solid waste generation due to the retrofit process design modifications to the facility.

The assessment includes the following:

- Identification and description of the significant air and water emission sources as well as the solid waste generation,
- Estimation of emission rates for each identified contaminant of concern due to the project modifications and comparison with base case's emissions.
- Comparison of concentrations with relevant applicable environmental regulations at municipal, provincial and federal level.

Project justification

Currently, the mill has high manufacturing costs for the production of newsprint from a combination of TMP and DIP pulp produced on site; the highest costs are linked to virgin fiber and electricity. It was identified that a lower manufacturing cost can be obtained by reducing the use of virgin fiber and by increasing recycled fiber usage.
At the same time, the implementation of cogeneration based on biomass further reduces the electricity costs per generated megawatt-hour (MWh) of energy, because this energy generation is less expensive than electricity purchased from the grid. Unfortunately, the current economic stability of the fuel market is uncertain. In the last five years, significant instability in fuel prices has been reported and can significantly impact future electricity prices.

Project benefits

- **Environmental benefits:** The environmental benefits of this project result from the recycling of a waste product (recycled paper) and the use of renewable fuel source (biomass) for the production of steam and electricity in a clean and efficient manner.
  Recycling newsprint has two main environmental advantages: (1) providing newspaper publishers a viable alternative to virgin newsprint, thereby reducing the need of virgin fibre, and (2) decreasing the amount of newsprint to be landfilled or incinerated since there will be more demand of recycled fiber by mills. Furthermore, recycled newsprint manufacturing consumes less than 50 percent of the electricity required for virgin newsprint thus resulting in a reduction of greenhouse gas (GHG) emissions and other pollutants.
  The Kyoto agreement has become more important at the national level. The pulp and paper industry is one of the most important industries in Canada and any initiative towards the reduction of GHG can be an advantage for the industry with respect to its perception by the general public and Federal Government. Carbon dioxide (CO_2) emitted by non-fossil fuels such as or sludge is not taken into account in the overall calculation for GHG. However, CO_2 coming from fossil fuels are included in GHG calculations. In the new cogeneration design, consumption of natural gas is reduced by incrementing the biomass proportion in the fuel feed to the boiler which will cause a reduction of GHG currently emitted by the facility.

- **Social benefits:** This project will enhance the economic performance and quality of life in the surrounding communities. Since this will be a macro-project, the implementation of this project will employ long-term (permanent) workers and increase the amount of indirect employment during the installation and construction phase. Moreover, it should bring more profitability to the mill and guarantee long term jobs, stability and benefits for workers.

Project description

In this section, the base case, which is the actual mill situation, is described and compared to the project modifications oriented to increase de-inked pulp production and implementation of cogeneration for the production of the same tonnage of newsprint.

Base Case

General aspects

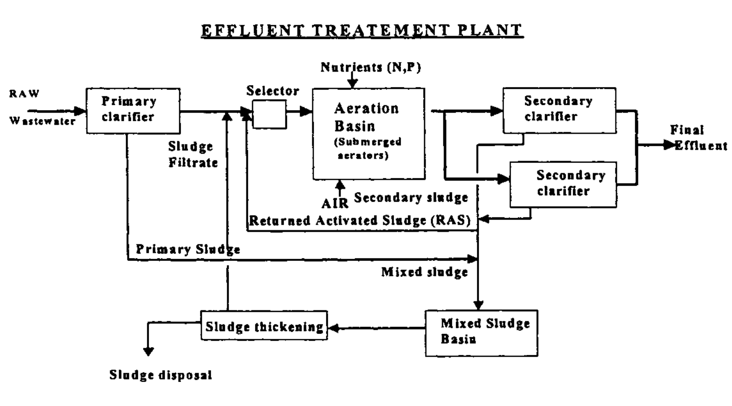
The base case is an actual integrated newsprint mill producing 1,100 Finished Metric tons (FMT) of newsprint per day, using 80% virgin fiber and 20% recycled fiber. Virgin fiber is produced and supplied to the paper machines by two thermo-mechanical pulping (TMP) line using a conventional TMP configuration. In parallel, a 1-loop DIP line feeds recycled fiber to the paper machines. Wood chips are mainly supplied by two sawmills at 32 km and 95 km from the facility. The waste paper is mainly collected in Ontario, but a percentage is imported from Chicago.

The boiler house is currently operated using natural gas as the primary fuel producing 6,700 MMBTU steam per day for the mill by using 6 boilers based mainly on natural gas and biomass. There are several air pollutants emitted by the boiler house due to the burning of natural gas and biomass. However, all the emissions are far below the current regulation and permit levels as it will be shown in section 3. The sludges produced in the wastewater treatment plant and in the DIP operation are burnt in the boilers as biomass (~50%).

The remaining sludge produced from DIP and Effluent Treatment Plant (ETP) is currently being landfilled together with industrial trash outside the mill premises in two landfill sites owned by the mill.

The existing cogeneration facility has two back-pressure turbines: the first turbine produces a small amount of electricity (2% of the mill's overall electricity consumption), and the second turbine has been shut-down for technical reasons.

The mill's total effluent is averaging 50,000 m^3 per day all of which is treated in the effluent treatment plant (ETP) where primary and secondary sludges are produced as shown in Figure 2.1. Figure 2.1: Effluent Treatment Plant operation (ETP)



Project modifications

This section describes both projected modifications oriented to increase to 100% the production of de-inked pulp and the implementation of cogeneration at the current integrated newsprint mill.

New cogeneration system configuration

The following modifications are projected to be implemented at the existing cogeneration system (Figure 2.2):

- Reactivation of turbine #6 (currently not operating);
- A New Air Cooled Condenser (ACC) has been considered for condensing the steam from the turbines when the water-cooled condenser capacity is exceeded;
- Boiler #3 is converted to be able to burn wood waste; the other boilers remain unchanged.

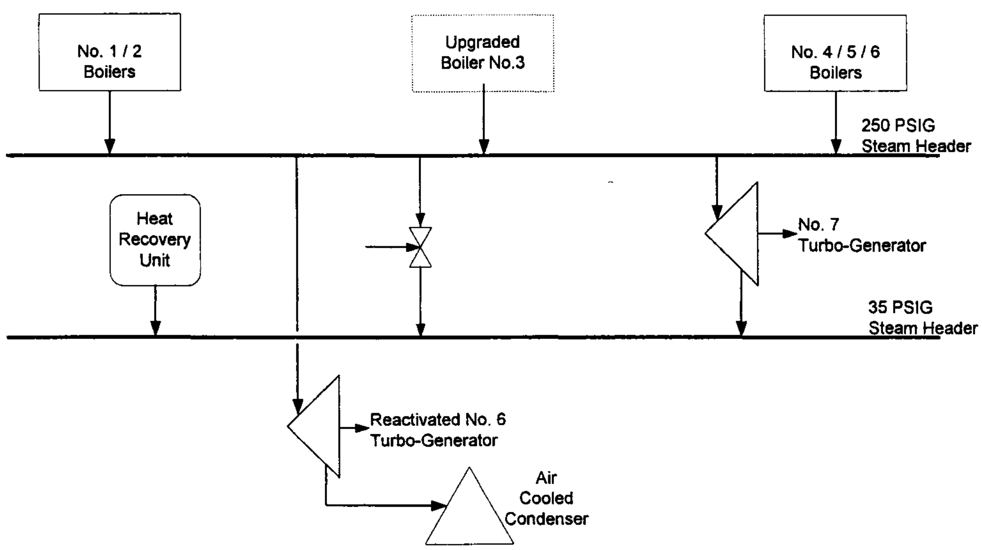


Figure 2.2: New cogeneration design configuration

With the new configuration, steam production capacity has been increased to balance the steam that would be supplied by TMP (Currently shut-down since it has been considered to increase to 100% DIP production). At the same time, the biomass burning capacity has increased and a slight reduction in natural gas consumption is forecasted.
The electricity production of the turbines has been estimated to be 350 000 MWh per year which will cover 78% of the mill's total electricity consumption.
The quantity of fuel required by the boilers has been determined by calculating/estimating the fuel heating values and the boiler efficiency shown in Table 2.1.

Table 2.1: Amounts of different fuels used

Natural gas	26,000,000 m3/y
Wood waste	187,000 BDMTY
DIP sludge	25,000 BDMTY
Mixed sludge (Primary & secondary)	21,500 BDMTY
** *Bone Dry Metric ton per year (BDMTY)*	

New De-inked system configuration

Since the project modification aims to replace 100% of the current thermo-mechanical pulp (TMP) production, this project is aiming to install a new de-inking system of a 1-loop system (Figure 2.3) and it should produced 1,100 Air Dry Metric tons per day (ADMTD) of DIP pulp based on recycled paper coming from Old Newsprint (ONP) and Old Magazines (OMG) to replace 100% of the current TMP production. The estimated yield for this new DIP line is 92%.

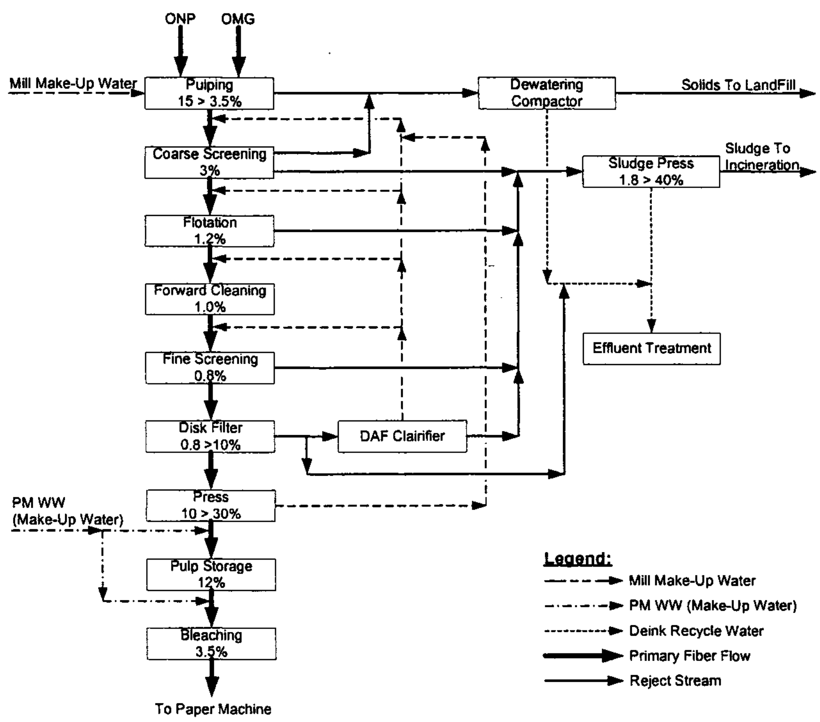


Figure 2.3: New DIP line design configuration

Waste paper enters the mill in either bales or loose form. The waste paper is weighed before feeding the drum pulper. Wastepaper, dilution water and pulping chemicals are fed into the inlet chute of the drum pulper.

After the pulping zone, pulp is transferred to the screening section where the impurities are removed from the reject end of the drum. From the pulp storage tank, the pulp is directed to a three stage coarse screening system.

Accepts from the coarse screens are fed to the flotation system. From the flotation system, pulp is diluted and pumped into a four stage, cascade connected to the cleaning system. Rejects from the final stage are fed to the sludge tank. Accepts from the forward cleaners are fed to a four stage fine screening system whereas the rejects from the final stage are fed to the sludge tank.

Clean pulp is thickened with a disc filter to approximately 12% consistency prior to pressing. This thickened pulp is then fed to the screw press to obtain a 30% consistency. The screw press is used in this thickening process. Filtrate from the screw press is circulated back to the flotation feed. The screw press removes much of the water contained in the pulp, thereby isolating the recycle plant water from the paper machine water.

All the sludge being produced by this new DIP 1-loop line will be sent to the sludge treatment plant, dried and then diverted to the boiler as biomass.

Air quality

This section discusses current contaminant levels in the receiving environment and future changes in air emissions resulting from the mill modification projects.

Base Case

The current system is designed to produce 400,000 FMT of newsprint per year (actual average production is 387 000 FMT per year). The facility is reporting the following air emissions levels produced from several sources around the mill (Table 3.1)

Table 3.1 Current levels of air emissions

Contaminant	Half-hours Max. emission rate (g/s)	POI concentration ($\mu g/m^3$)	MOE criteria ($\mu g/m^3$)	Contributor	% of the criteria
TSP	4.75	61.39	100	Sawmill, BH and others	61.4%
Sulphur Dioxide	13.17	227.43	830	Bleaching, DIP & H_2SO_4 prod.	27.4%
Hydrogen Sulphite	0.05	6.24	30	ETP	20.8%
Nitrogen Oxides	29.71	50.04	500	Boiler house	10%
<u>VOC's:</u>					
Toluene	0.11	1.9	2000	Others	0.09%
Xylenes	0.09	1.55	2300	Others	0.07%
Acetone	0.487	8.41	48000	Spray painting	0.02%
Butanol, n-	0.045	0.78	2278	Spray painting	0.03%
Ethyl benzene	0.015	0.26	4000	Others	0.006%
Formaldehyde	0.0056	0.10	65	TMP	0.1%
Methanol	1.56	26.94	9300	Others	0.3%
Naphthalene	0.000019	0.00	36	Boiler house	0.09%

*** Point-of-Impingement (POI) is a Provincial regulation for air emissions (see section 3.3 for an explanation) given by the Ontario Ministry of Environment (MOE)*

Total Suspended Particles (TSP) have the highest emissions when compared to existing regulation, followed by sulphur dioxide (SO_2), hydrogen sulphite (H_2S) and nitrogen oxides (NO_x). Due to their lower concentrations, Volatile Organic Compounds (VOCs) are not considered a critical potential environmental risk.

Summary of air contaminants

The following section describes the main contaminants emitted to the environment as a consequence of mill modifications:

Particulate matter (PM)

TSP may consist of solid particles or liquid droplets, and they may have different chemical compositions. PM with aerodynamic diameters of less than 50 micrometers (μm) are classified as total suspended particles (TSP). PM with aerodynamic diameters greater than 50 μm are not considered suspendable; they settle out of the atmosphere and are not considered a health risk for the general public.
The estimation of PM levels was performed using the nearest receptor;, a residential area located approximately 200 meters north of the mill. The maximum concentration for TSP is approximately 69 μm/m^3. The POI criterion for TSP has been established at 100 μg/m^3.
Fugitive dust emitted during transportation of waste paper and hog fuel has not been considered relevant since all the access roads are paved.

Nitrogen oxides

Due to lower combustion temperatures and lower nitrogen content in wood and sludge compared to natural gas, the new configuration in the boiler house allows a reduction of NO_x levels emitted to the environment. The NO_x concentration in the environment is 47 μm/m^3. The POI criterion for this pollutant has been established at 500 μg/m^3.

Sulfur Dioxide

Modifications in the boiler house resulted in an increase in biomass as the primary fuel which in turn reduces natural gas consumption and as a consequence SO_2 emissions from the boiler house have slightly increased. The level of SO_2 in the receiving environment is 270 μg/m^3. The POI criterion for this pollutant has been established at 830 μg/m^3.

Summary of applicable regulation

The following Table 3.2 shows the different requirements related to air emissions provided by each region in Canada. (Environmental Canada, 2002)

Table 3.2 Approach followed by each Region in Canada – Air

Approach /Province	AB	BC	MB	NB	NF	NS	ON	QC	SK
Ambient Air	X	X	X	X	X	X	X	X	X
End-of-stack	X	X		X		X		X	
Point of Impingement					X		X		

From Table 3.2 two main requirements for the province of Ontario are:

- Ambient air quality (AAQ)
- Point of impingement (POI)

Current guidelines in Ontario for air emissions are given by the Point of Impingement (POI – Regulation 308) which is defined as any point on the ground or on a receptor, such as nearby buildings or local area outside the company's property at which the highest concentration of a contaminant caused by the aggregate emission of that contaminant from a facility is expected to occur.
Table 3.3 gives POI criteria for several air contaminants established by the Ontario government.

Table 3.3 POI criteria- Ontario

Contaminant	POI Ontario ($\mu g/m^3$)
H_2S	30
TSP	100
SO_2	830
NO_x	500
CO	6000

The following Table 3.4 gives an overview of all air quality standards for the Province of Ontario.

Table 3.4 Ambient Air quality criteria -Ontario

Contaminant	Air quality Ontario ($\mu g/m^3$)
H_2S 1 hour	 6
NO_x 1 hour 24 hours Annually	 400 200 100
SO_2 1 hour 24 hours Annually	 690 275 55
TSP 24 hours Annually	 120 60
CO 1 Hour 8 Hours	 36200 15700

Best Available Technologies (BATs)

Best Available Technologies (BAT) have been considered in the design to control NO_x and Total Suspended Particles (TSP) emissions from the boiler house. The BAT analysis addresses technologies such as low NO_x burners and electrostatic precipitators. This BAT is based on a report from Environment Canada (2002)

NOx emission control

The emission control measures presented are for large, combined wood and oil/gas fired boilers. Emissions from these units are affected by wood/sludge fuel characteristics, in particular moisture content, boiler load, firing and combustion technique, furnace geometry, amount of refractory, over fire air design and the oil or gas burner capacity and usage. All are important factors in determining the aggregate emissions (Environmental Canada, 2002). Current measures considered for controlling NO_x emissions from power boilers are summarized in Table 3.6.

Table 3.6: Boiler NOx control technologies (Environment Canada report, 2002[1])

	Over fire Air System Upgrade	**Low NO_x Burners Selective**	**Non Catalytic Combustion**
Description	Installation of large over fire air ports, dampers & controls.	Replacement of older standard burners with newer staged combustion designs.	Injection of ammonia or urea into a high temperature section of the furnace
Applicability and prevalence	Wood only and combination of wood and fossil fuel, water wall boilers with small ports, and poor furnace mixing, in units often built before 1980.	Combination of wood and fossil fuel boilers and fossil fuel only fired boilers with older standard burners. Moderately common in new installations.	Mostly wood only and combination of wood and fossil fuel field erected boilers. Very rare. Applied in some US locations where AAQ does not meet federal or local standards.
Potential emission reduction assumed	**NO_x: 20-40 ng/J.**	**NO_x: 40-60 ng/J.**	**NO_x: 20-50 ng/J.**
Constraints and considerations	Uncertain prediction of emission reduction, unlikely suitable for some very old boilers.	Reduced proportion of fossil to wood fuel usage undermines justification.	Uncertain prediction of emission reduction. If NH3 used: transport of a hazardous material.

Note:
Reduced fossil fuel usage is often realized, and an important driver for such upgrades. The estimates presented here do not include the effect of reduced fossil fuel usage on emissions or economics which may be large.

The costs of these NOx control measures for existing power boilers are presented in Table 3.7.

Table 3.7: Cost related to NOx control technologies (Environment Canada report, 2002[1])

	Air System Upgrade Existing older boiler	Low NO_x Burners Selective Existing older boiler	Non Catalytic Reduction older Existing older boiler
Capital Costs, in M$	0.2-0.5	0.4-1.3	0.6-1.7
Annualized Capital Cost in k$/a	30-80	60-210	90-270
Operating Cost in k$/a	90-140	110-210	220-440
Annualized total cost of Control Measure in k$/a	120-220	170-420	310-710
Annualized total cost of Control Measure, $/GJ heat input	0.05-0.09	0.08-0.16	0.14-0.25
Pollutant Removal Costs, $ per tonne (NO_x as NO_2)	1100-3100	1100-2700	2800-12,000

Low NO_x burners (LNB)

Upgrading the air system of existing boilers has several constraints. The most important constraint is the uncertainty of emission reductions as current boilers are old and an upgrade is not enough to achieve the target levels (Environmental Canada, 2002). Due to fossil fuel reductions by replacing them with non-fossil fuels such as biomass, NO_x emission levels are not critical in the design. It has been decided to implement a medium cost-effective alternative from the analyzed options (Table 3.7). The most suitable option will be the low NO_x burners. (Environmental Canada, 2002)

LNBs reduce the formation of NO_x by performing the combustion process in fuel rich and fuel lean zones within the flame. The fuel rich zone is the primary combustion zone and prevents the formation of thermal NO_x (formation of NO_x caused by high flame temperatures) resulting from low oxygen concentration. The cooler, fuel lean zone prevents formation of thermal and fuel NO_x (formation of NO_x resulting from the oxidation of fuel bound nitrogen). LNBs can reduce NO_x emissions by as much as 60 percent. (Environmental Canada, 2002)

Particles emission control

For controlling particulate emissions, the electrostatic precipitator is the preferred control device in new facilities due to its high availability and efficiency (Tables 3.8 and 3.9). Another advantage is that water is not added to the flue gas as it is for wet scrubbing

which would increase plume opacity. Bag houses have not gained wide acceptance because of concerns regarding bag life and the risks of downtime due to catastrophic bag failure. (Environmental Canada, 2002)
Multiple cyclones and most types of wet scrubbers generally represent older technology, and are considerably less costly even allowing for treatment of the scrubbing medium in the case of wet scrubbers (Environmental Canada, 2002). However, they are unable to meet the current emission standards. (Environmental Canada, 2002)

Table 3.8: Manifestation of electrostatic precipitators (Environment Canada report, 2002[1])

Existing Older Boiler	New Greenfield Boiler
Description Installation of a modern, rigid electrode, three fields, two 50% chambers.	Increased removal efficiency by increasing collection area by 18%.
Applicability and Prevalence Power boilers built before the mid-1980s.	This expenditure would probably be made in areas where TSP is of concern in Canada.
Primary Justification and Benefits Reduction of STP emissions, reduced downtime and potential maintenance reduction.	Reduced TSP emissions.
Potential emission Reduction Assumed No limit to reduction of TSP and PM10 by adding collecting area. This example assumes reduction from 225 to 65 mg/SDm^3 at 7% ref. O_2, **about 77 ng/J.**	No limit to reduction of STP and PM10 by adding collecting area. This example assumes reduction from 100 to 65 mg/SDm$_3$ at 7% ref. O_2, **about 28 ng/J.**
Constraints and Considerations High costs due to space limitations in many cases. Mill specific studies required to reduce cost uncertainty.	Need to specify the emission level very early on in the design process. Cost.

Table 3.9: Cost figures for electrostatic precipitators (Environment Canada report, 2002[1])

	Existing Older Boiler	New Greenfield Boiler
Capital Costs, in M$	4-10	0.5-1.2
Annual Capital Cost in k$/a	640-1600	80-190
Operating Cost in k$/a	260-700	90-180
Annual total cost of Control Measure in k$/a	900-2300	170-370
Annual total cost of Control Measure, $/GJ	0.40-0.90	0.04-0.06
Pollutant Removal Costs, $ per tonne TSP	5100-12,000	1300-2100

Summary of air quality analysis

Based on air emission calculations and results showed in the preceding table, we have concluded the following summary in Table 3.10

Table 3.10 Summarize of results – Air emissions

Emission	Units	*Base case*	*New scenario*	*POI criteria*	*Air quality standards (Annual)*
TSP	*ug/m3*	61	69	**100**	**60**
NOx	*ug/m3*	50	47	**500**	**100**
SO2	*ug/m3*	227	270	**830**	**55**

- Electrostatic precipitators and Low NOx burners are considered in the design of the new cogeneration system as a result of the Best Available Technologies (BATs) analysis.
- TSP are the most important air contaminants identified for the proposed project modifications. TSP maximal concentration in the receiving environment is approximately 69 $\mu g/m^3$ which is below POI criteria (Table 3.10). However, if the estimated concentration is compared with air quality standards for TSP (annually) predicted, TSP levels are higher than the 60 $\mu g/m^3$ proposed by this air quality standard.
- SO_2 levels have increased due to the increase in non-fossil fuels consumption. The emitted levels are far below current POI standards (Table 3.10). However, SO_2 predicted levels exceed established standards for this contaminant when compared to air quality standards (annually).
- Nitrogen oxides are lower since natural gas consumption has been reduced. Biomass generates nitrogen oxides but a combination of lower temperatures in the combustion

by non-fossil fuels and best available control technologies represent an overall reduction of this contaminant.

- Volatic organic compounds (VOCs) do not represent an important environmental emission due to their low concentration in comparison with current standards and regulations for Ontario.

Water quality

This section discusses current and future changes in contaminant levels in the final effluent.

Base Case

The existing facility has a conventional wastewater treatment using activated sludge technology as secondary treatment. The Effluent Treatment Plant (ETP) also includes primary and secondary clarifiers. The base case has an average water consumption of 50 000 m^3/day. Paper machines are direct users of fresh water. After use in the paper machines, the water is used in the mill as white water. The water is currently taken from the nearest KAPI River located next to the mill. Following the project modifications, the volume of fresh water consumed will remain constant.

Current effluent quality

Based on data collected for the base case, the following average concentrations and loads per volume of final effluent have been determined by the mill, as shown in Table 4.1.

Table 4.1: Current concentration and loads of pollutants in the final treated effluent

	Emissions to river – Base case	
Pollutant	*g/m³*	*kg/d*
TSS	40	2,000
BOD	8.47	424
Zn	0.3	15
Methanol	0.05	2.5
Mn	0.25	12.5
Dioxins (TEQ) – (ug/m³)	2.445	0.0122
Polychlorinated furans (PCDF) – (ug/m³)	2.123	0.1062
N-tot	4.3	215
Phosphate	1.2	60
Phenol	0.02	1
Cd	0.4	20
Cu	2.6	130

Summary of water contaminants

Biochemical Oxygen Demand (BOD) and Total Suspended Solids (TSS) are the main contaminants affected by project modifications. However, the current design of the Effluent Treatment Plant (ETP) will not be affected by changes in the pulp furnish because the raw waste load from the mill to the treatment will decrease and the hydraulic load generated by the operation will remain constant.

BOD produced by a De-inked process is less (kg/t) and more biodegradable than the one produced by a TMP process. As TMP production has been replaced with DIP production, the BOD levels in the effluent can be treated with lower aeration.

The nutrient load is an ETP design parameter based on BOD. Since the raw waste load will be decreased, the nutrient load will also be decreased proportionally.

The calculation of the new concentrations (mg/L) for the final treated effluent to the river, for BOD and TSS, were defined by taking as basis, literature references and the assumed concentrations were validated by process experts (see Table 4.2). From the new BOD and TSS concentrations for the proposed scenario; the environmental loads (kg/day) for TSS and BOD to the receiving environment were calculated by using mass balance results and total production numbers as shown in Table 4.3 for flow, Biological Oxygen Demand (BOD) and Total Suspended Solids (TSS) for the base case and the changes by the project modification.

Table 4.2 Calculated/estimated water concentrations in final effluent

Emission	**Units**	***Base case***	***New scenario***
TSS	*mg/L*	40	35
BOD5	*mg/L*	8.47	4.0
Flow	*m3/d*	50,000	50,000

The efficiency removal of the Activated Sludge Treatment (AST) is between 98-99% and the overall efficiency of Effluent Treatment Plant (ETP) is higher than 99%.

Table 4.3 Calculated/estimated environmental load – water emissions to river

Emission	**Units**	***Base case***	***New scenario***
TSS	*kg/d*	2,000	1,750
BOD5	*kg/d*	424	200
Flow	*m3/d*	50,000	50,000

Summary of applicable regulation

This section presents the regulatory framework oriented to pulp and paper effluent contaminants at the Provincial and Federal level. This framework is being summarized in the following Acts:

- Fisheries Act (FA) – Federal Regulation
    - Environmental Effects Monitoring (EEM)
- Pulp & Paper Effluent Regulation (PPER) - Provincial Regulation

Currently, the mill has the following regulatory background as shown in Table 4.4:

Table 4.4: Existing regulatory framework for BOD and TSS

Biochemical Oxygen Demand (BOD)	Total Suspended Solids (TSS)
5,830 kg/d	9,180 kg/d

Summary of water quality analysis

Based on estimations, final effluent levels are lower than reported for the current facility. TSS levels show a 12.5 % reduction of current levels (from 2,000 to 1,750) by implementing a brand new DIP pulp production line. BOD levels are reduced by 53%, from 424 to 200 kg/day.
It has been considered that other contaminants such as metals and nutrients are slightly affected by project modifications.
Comparison of TSS and BOD levels with current regulation for pulp and paper effluents showed that current pollutant levels are far below target limit concentrations.

Solid wastes

This section discusses the types of solid waste generated by the current facility and the changes of this waste by project modifications. The solid waste assessed in this section is industrial waste, sludge from operation (Effluent Treatment Plant and DIP operation) and ash generated in boiler house.

Base case

The current operation generates different types of solid waste as shown in Table 5.1.

Table 5.1: Types of generated solid waste

Solid waste	Description
Industrial waste	Non fiber (glass, metal, sand, plastics, wires, etc) rejects removed in the early stages of the DIP pulp production by the drum pulper and coarse screen.
Sludge	Sludge material from DIP pulp production and effluent treatment plant. The main component of this waste is fiber.
Ash	By-product of the combustion of organic material in boiler house.
Others	Office waste material, domestic waste, etc.

Table 5.2 shows the quantities of the different solid wastes generated during current operations:

Table 5.2: Amounts of actual generated waste

Emission	Units	Base Case
Landfilled DIP Industrial trash	*tons/y*	1,060
Landfilled Ash	*tons/y*	6,361
landfilled Sludge	*tons/y*	8,300
Sludge diverted (primary, secondary and DIP sludge)	*tons/y*	23,300
Others landfilled	*tons/y*	8,180

Summary of solid waste generation levels

In this section, solid generation from DIP and boiler house is assessed to show the changes relative to the base case.

Deink Operation

DIP operation generates two types of waste: industrial trash (coming from pulping and cleaning stages) and sludge (recycled fiber rejects) coming from later stages in the process. The predicted efficiency for the new DIP line is 92%.
The design considers sludge produced in the Effluent Treatment Plant (ETP) and De-inked pulp production (DIP). This sludge will be burned in the boiler house to recover latent energy from this waste. This consideration implies an increased amount of ash produced in the boilers as a by-product of burning biomass.
The new amount of industrial trash was calculated by taking a factor of 1.6% for the generation of industrial waste per day, the same factor was considered for the calculation of industrial waste from the current DIP line with a yield of 92 %. 1,189 ADMT/d of pulp per day are thus necessary to feed to the DIP Line in order to produce 1,100 ADMT/d of final treated pulp send to paper machines. This is yielding 76.1 ADMT/d of

DIP sludge and 18.9 ADMT/d of industrial trash. For a yearly production of 352 days, the total amount of industrial trash produced will be 6,650 t/d (See Table 5.3 below) Sludge out-of-the-system is considered to be zero (Table 5.3), since the DIP sludge in combination with primary and secondary treatment sludges will be all diverted to the boilers as biomass to be burned. Currently, 8,300 BDMT of sludge per year are landfilled outside the mill (Table 5.3)

Boiler house and sludge disposal

Boiler house configuration modifications allow for an increase in the amount of biomass burnt (in this case biomass being a mix of sludge and wood waste). The combustion will be supported by natural gas as secondary fuel.
The boiler house thermal efficiency is 75%. Several references heating values and fuel compositions were obtained from literature references for wood waste and sludge composition and used in the overall calculation for solid waste generation.
The new demand of fuels by the boiler house to produce high pressure steam is as follows:

- Wood waste consumption: 187 000 BDMT/year
- DIP sludge consumption: 25 000 BDMT/year
- Mixed sludge (Primary and secondary): 21 500 BDMT/year

The following Table 5.3 shows the current generation of wastes (t/y) and the future situation by implementing the project modifications.

Table 5.3: Current and new amounts of generated waste

Emission	Units	Base Case	*New Scenario (Cogen + 100% DIP)*
Landfilled DIP Industrial trash	*Tons/y*	1,060	6,650
Landfilled Ash	*Tons/y*	6,360	15,890
landfilled Sludge	*Tons/y*	8,300	0
Sludge diverted (primary, secondary and DIP sludge)	*Tons/y*	23,300	47,230
Others landfilled	*Tons/y*	8,180	8,180
TOTAL	*Tons/y*	46,240	77,950
Total waste Landfilled	%	49.7%	39.4%
Total waste diverted	%	50.3%	60.6%

New project modifications will allow a reduction of landfilled material (from 49.7% to 39.4%). This is achieved by burning all sludge (DIP and primary and secondary) in the boiler house.

Summary of applicable regulation

There are no regulations defined for this type of wastes produced by pulp and paper mills. The applicable regulation is only for landfill sites.
Extra amounts of waste material will be landfilled in two landfill sites owned by the mill outside the mill premises.
Since the amount of landfilled waste has a slight increase, it has been assumed that this increased material will not have any effect on the current landfill operation.

Summary of solid waste analysis

Based on the results, it can be seen that project modifications are improving the general environmental situation of the mill since the ratio material landfilled/diverted is lower than the current ratio. However, ash quantities increase as larger quantities of material being burnt in the boiler house.

Conclusions

Best Available Technologies (BATs) aim to reduce emission levels of NO_x and TSP have been considered in the design of the new projects. Based on the results of this analysis, project modifications will bring the following advantages:

1. Implementation of cogeneration increases air emission levels. However changes are not significant compared to the permit and regulation levels represented by several provincial and federal regulations and standards.
2. Increasing transportation of hog fuel and waste paper has not been considered important, since all the routes and access roads are paved, the emission of fugitive dust is negligible.
3. Design considerations allow the process to reduce natural gas consumption and replace it with non-fossil fuels such as biomass and dried sludge coming from the operation.
4. By implementing a new DIP line and shutting down existing TMP, a BOD and TSS reductions can be achieved in the final effluent by 13 and 53 %, respectively.
5. Solid waste generation is affected by sludge being incinerated in the boiler house and by reducing the quantities of sludge required to be landfilled. The reduction of landfilling organic waste (Sludge) is an important environmental credit for the project.
6. Amounts of diverted material and landfilled material have changed by implementing project modifications. The percentage of diverted (reused sludge) material is increasing by almost 10% in comparison with current levels (50.3 %) and landfilled waste is decreased by the same percentage.

7. Increasing de-inking pulp production will lead to decreased use of virgin fiber and electricity consumption in the production of newsprint and establish a more economically competitive operation.

Literature references

1. Multi-Pollutant emission reduction analysis foundation (MERAF) for the pulp and paper sector, Environment Canada & AMEC consultants, 2002

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3. Guide to Environmental Assessment requirements for electricity projects, Ontario Ministry of Environment, March 2001.

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3. Proposed guidance for air dispersion modeling, Ontario Ministry of Environment, November 2003.

4. Procedure for preparing an emission summary and dispersion modeling report, Ontario Ministry of Environment, June, 1998.

5. Point-of-Impingement (POI) regulation permits, Ontario Ministry of Environment, 1998.

6. Pulp and paper effluent regulations, Department of Fisheries and Oceans, May 1992.

Nomenclature

- ADMT: Air Dry Metric ton. Normal reference is for pulp at 10 % moisture or 90% consistency
- AST: Activated Sludge Treatment plant
- AAQ : Ambient Air Quality
- BAT: Best Available Technologies
- BDMT : Bone Dry Metric ton. Totally dried material (100% Consistency).
- BOD: Biological Oxygen Demand
- CWS: Canadian Wide Standards
- DIP: De-inking Pulp, from waste paper (recycled paper)
- EEM: Environmental Effects Monitoring

- FMT: Finished Metric Ton. Normal reference for product at 8% moisture or 92% consistency
- GHG: Green House Gases
- GJ: Giga Joule
- mg/L: milligrams per litter
- MMBTU: Million BTUs
- MOE: Ministry of Environment, Ontario
- MWh: megawatt-hour
- ONP: Old Newsprint
- OMG: Old Magazines
- PM: Particulate Matter
- $PM_{2,5}$: Particulate Matter less than 2.5 microns
- PM_{10}: Particulate Matter less than 10 microns
- PPER: Pulp & Paper Effluent Regulation
- POI: Point-Of-Impingement, Air emissions regulation, Ontario
- TMP: Thermo-Mechanical Pulp, based on virgin fiber (wood chips)
- TSP: Total Suspended Particles
- TSS: Total Solids Suspended
- ug/m^3: micrograms per cubic meter
- VOCS: Volatile Organic Compounds

APPENDIX 7: DECISION MAKING DOCUMENTATION

Intégration des procédés dans l'industrie papetière
Process Integration in the Pulp & Paper Industry

ÉCOLE POLYTECHNIQUE MONTRÉAL

Expert panel

Guidelines & protocols

Winter 2004

Introduction:

The guidelines and protocols are created with the aim of standardizing the different choices and steps during the weighting process.

The main steps in the weighting process are the following:

- First contact with experts,
- Send information package,
- Answer questionnaire,
- Face to face panel.

This document explains elements such as the number of panelists, decision consensus or elicitation situation, choice of the most preferable tool for the weighting, and the references taken into account by the team who designed and developed the weighting process and its guidelines. At the same time, an overall explanation of each step in the face to face panel is given to explain its dynamics and the desired achievements during this process.

This document has been developed only for internal use and it is given to the panelists as a reference to make the process more transparent.

Weighting

Weighting is defined as the process to weight several criteria based on different standards and references to propose importance

- ***Objectives of the weighting process***

The main objective for the expert panel is to evaluate the relative importance of "site-specific" and "site-generic" environmental criteria related to process modifications at an integrated newsprint mill in order to make a decision oriented to choose the best scenario from an environmental point of view

- **Guidelines & protocols**

Several protocols have been established to carry out the weighting process.

Panel size and composition

The number of experts is a critical aspect for which limited literature exists. While there is no standard procedure for establishing the panel size, several guidelines emerge from recent practices, and those have been the main source of information to set the number of panelists.

Experimental evidence on the performance of small and large panels with different aggregation methodologies gives some empirical indicators. For behavioral aggregation techniques which include face-to-face interaction, such as Nominal Group Technique (NGT), experimental evidence shows that better results are obtained with panels made up of five to nine members. (Goicoechea et al.1982).

Turoff (1975) suggests that as few as 10 people are sufficient for an assessment panel. However, there are several publications where the number of people is lower than 10 such as Duarte, B.P.M. (2001); Keeney, R.L. and Von Winterfeldt, D. (1991), Moon, J.H. and Kang, C.S. (1999).

For the current panel, several people with different backgrounds have been considered and the main reason to consider a multi-disciplinary panel has been the fact that an elicitation with experts should be balanced by including several different points of view (see Table 1). This will result in an increased reliability of and lower biases in the elicitation process.

EIA experts	Dave Wilson, Daniel Lemire
LCA experts	Jean Francois Ménard, Albert Chan
Corporation experts	Dan Martineau
Regulation experts	Pascale Lagace

Table 1: Considered experts for the panel

Feedback and consensus

The elicitation of the experts' opinion will be used to obtain weights for several environmental criteria (site-specific and site-generic). For this purpose, the panelists should try to agree on the assigned weights for the different criteria.

A secretary will be taking notes of the concerns and comments of the experts about possible non-agreed issues and these notes will be documented and considered for further panel exercises and for the discussion of the results. (See Section 2 - Responsibilities)

Weighting tool

The main characteristics required of the weighting tool used in the panel process are:

- High transparency in the weighting process,
- Acceptable scientific practice (LCA; EIA, etc.),
- Simple mathematics to treat the experts' opinion and to confirm their consistency,
- Easy-to-handle method that can be applied to environmental and economic criteria,
- Reflecting uncertainty in decision maker's opinion with simple procedures.

A brainstorming session with other team members and a Multi-Criteria Decision Making (MCDM) expert was done and it was decided to choose the Analytic Hierarchical Process (AHP) due to its simpler mathematics and its wide application reported in the literature. At the same time, AHP answers to the required characteristics (as mentioned above) for this exercise (see Table 2).

AHP is based on pairwise comparisons and contains indicators that measure the consistency of these comparisons. This feature makes the AHP optimal to be used for the panel evaluation (Saaty, 1980). Based on Saaty (1980), the indicators to measure this consistency are calculated with the following formulas:

- Consistency Index (CI): where

$$CI = \frac{\lambda_{\max} - n}{(n-1)}$$

λ_{max} = eigenvalue of the comparison matrix

n = number of decision criteria

- Consistency Ratio (CR):

$$CR = \frac{CI}{RI} \quad \textit{RI: Random index}$$

If CR is higher than 10%, the elicitation should be performed again until a ratio lower than 10% is reached.

Issue	Benefit	Feature of AHP - Delphi	Limitations
Transparency	Justifiable and communicable results.	Clear elicitation and assignment of weights. Easy to understand mathematical treatment.	
Acceptable scientific practice	Well-known and accepted method.	Used for many purposes: engineering, environmental, etc.	
Simplicity and usability	Easy to use by non decision-making experts, flexibility to different problems.	Simple mathematics, pair-wise comparisons	
Uncertainty - Ability to perform sensitivity analysis	Confidence in the results, better informed decision	Matrix format easy to modify, uncertainty can be assessed using sensitivity analysis.	It is not easy to deal with uncertainty in a formal way.
Consistency check	Measure of the consistency of the elicitation process	Easy formal mathematic treatment of consistency	
Ability to handle a large amount of criteria			Consistency is harder to reach with more than 10 criteria.

Table 2: Benefits and limitations of AHP to achieve project requirements

Literature references reported that AHP is the most popular MCDM method. Salo and Hämäläinen (1997) demonstrated that elicitation procedures in AHP can be carried out such that the results are in accordance with Multi-Attribute Value Theory (MAVT).

The disadvantage of AHP is the problem of rank reversal (i.e. the ranking of alternatives can be changed by the addition (or deletion) of irrelevant alternatives), but based on the context of this panel, this problem will not be of importance.

The scale to be used by the experts to qualify the criteria during the elicitation has been defined as follows:

Importance	Score
X is equally important as Y	1
Y is equally important as X	1
X has moderate importance over Y	3
Y has moderate importance over X	1/3
X has strong importance over Y	5
Y has strong importance over X	1/5
X has very strong importance over Y	7
Y has very strong importance over X	1/7
X has extreme importance over Y	9
Y has extreme importance over X	1/9

Opinion quantification & software

The elicitation and evaluation by the panel is quantified in a spreadsheet in which the AHP has been modeled (including consistency check). After this elicitation, the consistency is verified and, if needed, the elicitation will be performed again to reduce the CR below 10%.

- **Methodology to perform the panel**

The methodology to carry out the panel has been defined by using 6 steps (Figure 1). The first 2 steps are related to the project results and their screening and the last 4 steps qualify the importance of the weighting criteria.

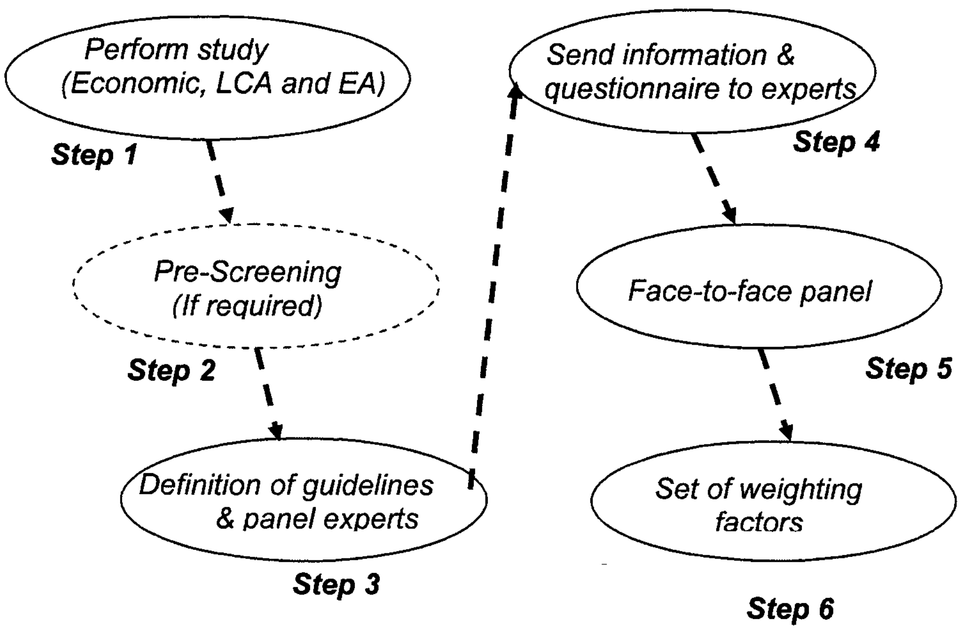

Figure 1: The 6-step methodology to perform the panel

Questionnaire

This step is used to obtain information and personal opinion from the panelists. This can be used as a source to measure consistency of the expert opinion before and after the face-to-face step (see Figure 1). A similar approach has been taken by Mohorjy et al. (1997) and this gave better results in the overall interpretation at the end of the process. The questionnaire will consist of several specific questions to get more information related to the point of view of the experts and their background.

Information and data in PowerPoint and Word format are sent to the experts to help them to become familiar with the overall problematic. The following documents will be sent to them:

1. Welcome letter
2. Questionnaire
3. Guidelines & protocols
4. PowerPoint presentation with an introduction of environmental aspects (LCA-EA) of the problem, overall project results and targets,
5. List with terminology and acronyms,
6. Literature references (Reports, LCA papers, etc).

The questionnaire and all this information should be sent to the experts four weeks before the face-to-face panel and the filled out questionnaire should be returned two weeks before the panel is held.

Face-to-face panel

Face-to-face interaction occurs when the experts meet and discuss their opinions and estimates weights until agreement is reached (see Figure 2)

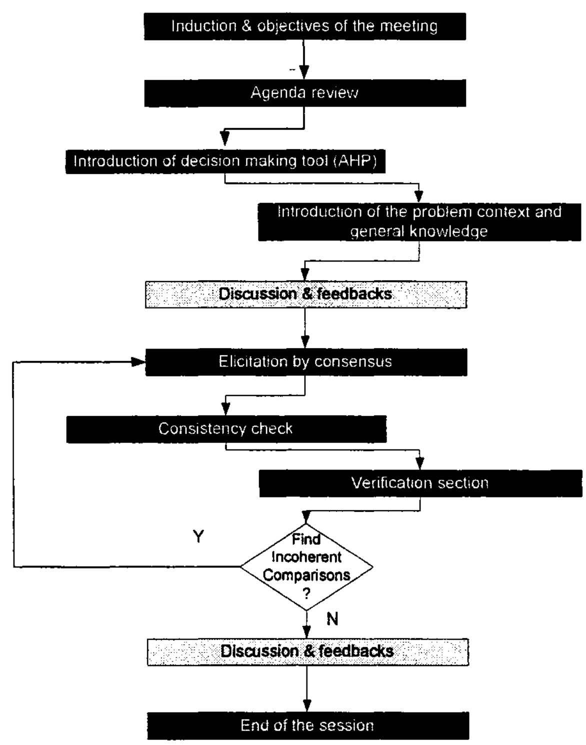

Figure 2: Methodology for the face-to-face panel

The following points describe each of the steps during the face-to-face panel:

Introduction

At the beginning of the panel, the facilitator will discuss the following:

- Introduction of experts (name, brief description of backgrounds and expertise).
- What is going to be done during the time they will spend here?
- Why the experts have been chosen to participate in the panel
- Description of the final outcome desired from the process

At the end of this section, the facilitator should achieve the following:

- Make people to know each other
- Experts understanding of why they have been chosen.
- A preliminary idea on how the final product should be at the end of the day.

Agenda review and introduction to AHP

In this section, the facilitator will explain the different sections during the execution of the weighting process, as well as an introduction to the weighting tool (Analytic Hierarchical Process). Also the following information will be given to the experts:

- Dynamics of the interactions,
- Valuation scale,
- Feedback treatment and consistency measure.

At the end of this section, the following should be achieved:

- Experts understanding of the agenda for the panel,

- Experts understanding of the weighting tool and the dynamics of the panel

Specific introduction to the project problem

The face-to-face panel will include a summary of the information given in the presentation which has been sent to the experts during the questionnaire phase (include in the documentation package). This summary has the goal to make sure experts understanding of the current problem context and to solve related questions before starting the elicitation process.

In this section, a member of the team will do a summary presentation containing the following sections:

- **Section I:** Brief discussion of LCA and EA,
- **Section II:** Brief introduction to the problem addressed by the M.Sc project: "Implementation of cogeneration and increased de-inked pulp production at an integrated newsprint mill",
- **Section III:** Presentation of environmental and economic results of the feasible scenarios,
- **Section IV:** Presentation of the reference targets and the calculations and information behind those.

At the end of this section, the following should be achieved:

- Experts' understanding of the problem context faced in this M.Sc project,
- Experts' understanding of the differences between LCA and EA,
- Experts' understanding of the targets and their relative meaning in LCA and EA.

Targets definition

Targets have been calculated for the environmental criteria based on different source of information. The methodology followed to define LCA targets is the following:

Contribution Analysis ↓	The emissions contributing to a total of 99% of each impact category have been identified.
Identification of Emission Targets ↓	A relative national reduction target was found for all the emissions identified. When no reduction target was available, it was set to 0% reduction. All the targets were relative to a reference year.
Calculation of Targets Relative to Year 2001 ↓	All relative targets were recalculated relative to year 2001 which corresponds to the base case.
Calculation of Targets for Impact Categories	If Canada has committed to reduce its emission by X% it, has been assumed that our system should also reduce its emission by X%. Using the data from the base case, emission targets have been transformed in impact category targets.

For EA or site-specific criteria, current regulation has been taken into account such as Point-of-impingement (POI – Ontario Ministry of Environment) for air emissions and pulp and paper effluent regulations (Current mill regulatory levels) for water emissions.

First discussion and feedbacks

In this section, the facilitator will ask the panelists the following questions:

- Are there any improvement opportunities for the presentation of the data, other formats, etc.?
- Are there any missing data or information?

During this period, the facilitator should be focused on the interaction between the experts and the secretary will take notes of all the feedback related to the first phase of the panel agenda.

Face-to-face discussion

The facilitator starts the pairwise comparison of the criteria in such a way that the panelists will concentrate on the criteria to be weighted by using pair wise comparisons. The facilitator introduces the criteria two-by-two in order to start the elicitation and discussion among the experts resulting in consensus and assign a value to the criteria weights. This procedure is repeated for each pair of criteria.

Consistency verification

One member of the team should verify all the incoherent results and communicate to the facilitator which comparisons, if necessary, should be carried out again in order to obtain a final set of weightings with a consistency ratio lower than 10%.
At the same time, the facilitator presents the overall results to the experts in order to ensure they are comfortable with them. If the experts are not comfortable, it may be necessary to perform again some of the comparisons.

Final discussion and feedbacks

The facilitator asks the panelists about the panel and which aspects should be taken into consideration to improve the panel efficiency. The results of the first (see 1.3.2.4) and second discussion should give direction to the construction of new and more efficient formats to present results and information.
A template has been created to document experts' feedbacks and remarks during the face-to-face panel.

Analysis of results

The analyses that will be performed on the final set of weighting factors will be the following:

- **Sensitivity analysis:** This analysis will serve to see how sensitive are the final set of weightings by applying sensitivity factors higher than 10% or perturbation factors lower than 10%.

Responsibilities

Facilitator responsibilities

- To have a neutral stance during the process and acting in a neutral way as well,
- To help the panelists to perceive and understand a situation in order to take action to improve it for themselves.
- To ensure that an appropriate venue is available and that it is appropriately equipped.
- To explain in a clear way each section in the process.
- To control the timetable and before moving on, check for concerns of group members or panelists.

Observer responsibilities

- To observe the whole panel process and give feedbacks about improvement aspects.
- To help the facilitator to check for concerns of the panelists.

Secretary responsibilities

- The secretary has the main responsibility to set all the logistic material surrounding the panel (computer, projector, photocopies, etc).
- To handle and calculate expert opinion consistency and to communicate the identified problems to the facilitator to start with a new elicitation.
- To take notes and to fill out the template related to expert feedbacks to document the whole process.

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Intégration des procédés dans l'industrie papetière
Process Integration in the Pulp & Paper Industry

ÉCOLE POLYTECHNIQUE MONTRÉAL

Expert panel

Questionnaire

Winter 2005

Introduction:

The following questionnaire is designed to receive initial information related to your perception of the treated problems.

At the same time, your background and expertise are being asked in the two first questions to have a better knowledge of their strengths. Ideally, this questionnaire should be completed before performing the face-to-face panel in order to receive more information and enhance the weighting process.

The following steps should be followed to achieve good results:

- Review the PowerPoint presentation and understand the problem context and the overall results.

Fill out the questionnaire by answering each question from your own point of view.

Send the questionnaire back to us by fax to 514-340-5150 or by email at

Fernando.cornejo@polymtl.ca

Questionnaire:

A. We are aware that your expertise is highly important for the overall success of this overall exercise. Based on your expertise and point of view, could you add context on how your expertise is related to this problem?

____
____
____
____
____
____
____
____

B. At the same time, we would like to ask you to categorize your expertise in the following fields: pulp and paper (P&P), cogeneration (Cogen) and De-inking process (DIP), Life Cycle Assessment (LCA), Environmental Impact Assessment (EIA) and Environmental Regulations.
Please mark with an "X" where you feel that your expertise matches the most by using the following criteria:

1) Highly qualified (HQ) 2) Qualified (Q)
3) Aware of the subject (AS) 4) No expertise (NE)

	HQ	Q	AS	NE
P&P				
Cogen				
DIP				
LCA				
EIA				
Environmental regulations				

C. Without taking into account information included in the documentation materials rank by importance these environmental criteria in the absence of distance to target. The first column should be ranked by separating LCA from EIA criteria or by separated. The second column is oriented to rank all the criteria together:

	Parameter	**Ranking #1** (By separating LCA criteria from EIA criteria)	**Ranking #2** (By combining all the criteria)
LCA Criteria	Global warming		
	Ozone depletion		
	Acidification		
	Eutrophication		
	Photochemical Smog		
	Human Health Cancer		
	Human Health non cancer		
	Human Health Particles		
	Eco-toxicity		
EA Criteria	Total Suspended Particles (STP)		
	Nitrogen Oxide (NOx)		
	Sulphur dioxide (SO2)		
	BOD		
	TSS		

D. Please identify information that you think would assist the panel executor: project information, modeling information, environmental dimensions, etc.

TARGETS

Impact category	% reduction of 2001 levels	Target expressed on LCA impact categories	Main substances	Rational behind the target
Global warming	-20.31%	916,434	CO2 and CH4	The goal of the convention is to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner. The Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities. policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost. To achieve this, such policies and measures should take into account different socio-economic contexts, be comprehensive, cover all relevant sources, sinks and reservoirs of greenhouse gases and adaptation, and comprise all economic sectors. The international target is 6% reduction.
Ozone depletion	-94.72%	0	Halon 1301, CFC 114, CCl4	In the 1970s, scientists realized that chlorofluorocarbons (CFCs) might deplete the ozone layer. The ozone layer is expected to eventually recover, if all nations maintain their efforts to reduce ozone-destroying chemicals. However, it will probably be more than a decade before we begin to see definite signs of a recovery, and at least the year 2050 before any substantial recovery occurs. The use of these substances is prohibited since 1987 according to the Montreal Protocol.
Acidification	-37.24%	186	SOx, NOx, HCL	The long-term goal of the strategy is to achieve amount of acidifying deposition which does not damage ecosystems in the long term.
Phot. Smog	-37.68%	2	Nox, non-methane VOC, VOC, CO	They represent a balance between achieving the best health and environmental protection possible and the feasibility and costs of reducing the pollutant emissions.
Eutrophication	-6.58%	402	Nox, BOD, PO4, Ntot	They represent a balance between achieving the best health and environmental protection possible and the feasibility and costs of reducing the pollutant emissions.
HHP	-18.99%	0	TSP, Sox, Nox,	They represent a balance between achieving the best health and environmental protection possible and the feasibility and costs of reducing the pollutant emissions.
HHC	-42.21%	43	As, Cr, Pb, CCl4, Ni	The vision is reduction of emissions to levels that are insufficient to cause harm
HHNC	-30.12%	253,672	Hg, Co, Pb, Cu, As, Al, Cd, Se	The vision is reduction of emissions to levels that are insufficient to cause harm.
Eco-toxicity	-33.81%	2,072	Hg, Zn, Cr, CuAs, V, Se	The vision is reduction of emissions to levels that are insufficient to cause harm.

APPENDIX 8: LCA INVENTORY DATA

Substance	Compartment	Unit	DIP 3 – Cogen 1	DIP 3 – Cogen 2
air	Raw	kg	26.1	26.1
baryte	Raw	g	9.21	9.22
bauxite	Raw	g	3.38	3.39
bentonite	Raw	g	2.35	2.36
chlorine	Raw	pg	0.000000293	0.000000293
chromium (Cr)	Raw	mg	9.64	9.64
chromium (in ore)	Raw	mg	111	112
clay	Raw	g	4.13	4.15
clay minerals	Raw	mg	498	498
coal	Raw	mg	448	448
coal (18 MJ/kg) ETH	Raw	g	706	706
coal (27.1 MJ/kg)	Raw	g	3.42	3.42
coal (29.3 MJ/kg)	Raw	mg	14.7	14.7
coal ETH	Raw	kg	2.9	2.91
coal FAL	Raw	kg	52.2	18.1
cobalt (Co)	Raw	ng	567	567
cobalt (in ore)	Raw	ng	129	130
copper (Cu)	Raw	mg	137	137
copper (in ore)	Raw	g	1.26	1.27
crude oil	Raw	g	48	48
crude oil (41.9 MJ/kg)	Raw	mg	4.16	4.16
crude oil (42,6 MJ/kg) ETH	Raw	g	237	237
crude oil (42,7 MJ/kg) IDEMAT	Raw	mg	83.4	83.4
crude oil ETH	Raw	kg	1.87	1.87
crude oil FAL	Raw	kg	21.4	21.7
crude oil IDEMAT	Raw	g	90.2	90.2
energy (undef.)	Raw	kJ	31.4	31.4
energy from coal	Raw	kJ	72.4	72.4
energy from hydro power	Raw	MJ	53	33.8
energy from natural gas	Raw	MJ	12.6	12.6
energy from oil	Raw	kJ	26.3	26.3
energy from uranium	Raw	kJ	176	176
gas (35MJ/m3); from oil prod.	Raw	cu.in	987	987
gravel	Raw	g	159	160
Hog Fuel	Raw	kg	481	499
iron (Fe)	Raw	g	7.59	7.59
iron (in ore)	Raw	g	30.5	30.7
iron (ore)	Raw	g	3.1	3.1
lead (in ore)	Raw	mg	107	107
lead (Pb)	Raw	mg	17.2	17.2

lignite (8.1 MJ/kg) ETH	Raw	g	32.7	32.7
lignite ETH	Raw	kg	2.77	2.78
limestone	Raw	g	611	625
lubricant	Raw	mg	1.82	1.82
lubricating oil	Raw	mg	182	182
manganese (in ore)	Raw	mg	25.2	25.5
manganese (Mn)	Raw	mg	4.67	4.67
marl	Raw	g	48.1	48.2
material known, no data	Raw	kg	36.8	36.8
material unknown	Raw	mg	2.45	2.45
methane (kg) ETH	Raw	g	8.75	8.76
mining gas (30,3 MJ/kg) ETH	Raw	g	1.73	1.73
molybdene (in ore)	Raw	µg	1.29	1.29
molybdenum (Mo)	Raw	ng	123	123
NaCl	Raw	mg	65.8	65.8
natural gas	Raw	g	5.4	5.4
natural gas (35,0 MJ/m3) ETH	Raw	l	545	545
natural gas (36,6 MJ/m3; vol)	Raw	l	177	177
natural gas (vol)	Raw	l	805	806
natural gas ETH	Raw	m3	2.64	2.65
natural gas FAL	Raw	kg	64.4	89.5
nickel (in ore)	Raw	mg	74.4	74.5
nickel (Ni)	Raw	mg	4.82	4.82
nickel (ore)	Raw	g	222	222
palladium (in ore)	Raw	µg	1.57	1.57
palladium (Pd)	Raw	ng	25.8	25.8
petroleum gas ETH	Raw	l	91.3	91.4
platinum (in ore)	Raw	µg	1.76	1.76
platinum (Pt)	Raw	ng	29.5	29.5
pot. energy hydropower	Raw	MJ	5.17	5.18
potential energy water ETH	Raw	MJ	7.2	7.22
process and cooling water	Raw	l	35.6	35.6
reservoir content ETH	Raw	m3y	0.157	0.157
rhenium (in ore)	Raw	µg	1.67	1.67
rhenium (Re)	Raw	ng	26.1	26.1
rhodium (in ore)	Raw	µg	1.66	1.66
rhodium (Rh)	Raw	ng	27.4	27.4
rock salt	Raw	kg	3.96	3.97
sand	Raw	kg	6.84	6.84
sand, clay	Raw	g	1.34	1.34
silver (Ag)	Raw	µg	747	747
silver (in ore)	Raw	mg	4.19	4.19

soda	Raw	kg	12	12
sulphur	Raw	kg	5.69	5.69
tin (in ore)	Raw	mg	2.33	2.33
tin (Sn)	Raw	µg	414	414
turbine water ETH	Raw	m3	37.9	38
uranium (in ore)	Raw	mg	93.5	93.6
uranium (in ore) ETH	Raw	mg	110	111
uranium (U)	Raw	mg	4.15	4.15
uranium FAL	Raw	mg	656	188
waste paper (feedstock)	Raw	kg	972	973
water	Raw	kg	329	329
water (cooling)	Raw	kg	626	626
water (process)	Raw	kg	28.5	28.5
water (sea)	Raw	g	412	412
water (sea, for processing)	Raw	g	10.3	10.3
water (surface)	Raw	tn.lg	43.5	43.8
water barrage (vol)	Raw	cm3	680	680
water turbine	Raw	l	164	164
wood	Raw	g	4.62	4.62
wood (dry matter) ETH	Raw	g	17.6	17.7
wood/wood wastes FAL	Raw	g	42.2	52.3
zeolite	Raw	µg	279	279
zinc (in ore)	Raw	mg	1.82	1.84
zinc (Zn)	Raw	µg	546	546
1,2-dichloroethane	Air	µg	42.6	42.6
acetaldehyde	Air	mg	4.43	4.43
acetic acid	Air	mg	20.7	20.8
acetone	Air	mg	4.41	4.42
acetylene	Air	µg	7.75	7.75
acrolein	Air	µg	198	207
aerosols	Air	µg	9.9	9.9
Al	Air	mg	109	110
aldehydes	Air	g	16	16.2
alkanes	Air	mg	49.8	49.8
alkenes	Air	mg	7.86	7.88
ammonia	Air	g	2.9	2.88
arsenic	Air	mg	1.96	509
As	Air	mg	1.7	1.79
B	Air	mg	123	123
Ba	Air	mg	1.39	1.39
Be	Air	µg	112	118
benzaldehyde	Air	ng	147	147
benzene	Air	mg	49.5	49.6
benzo(a)pyrene	Air	µg	5.76	5.78
benzo(k)fluoranthrene	Air	ng	225	58.6

Br	Air	mg	6.78	6.79
butane	Air	mg	129	129
butane (unspec.)	Air	mg	26.2	26.2
butene	Air	mg	3.35	3.35
Ca	Air	mg	188	189
Cd	Air	mg	1.83	1.95
CF4	Air	µg	3.84	3.84
CFC-11	Air	µg	35.6	35.7
CFC-114	Air	µg	944	946
CFC-116	Air	µg	35.9	36.1
CFC-12	Air	µg	7.66	7.68
CFC-13	Air	µg	4.8	4.81
CFC-14	Air	µg	318	319
CFC-21	Air	µg	44.6	44.6
CFC (hard)	Air	ng	16.9	16.9
Cl2	Air	mg	4.28	4.4
CN (complex)	Air	µg	1.58	1.58
CO	Air	kg	4.25	4.49
CO2	Air	kg	22	22
CO2 (fossil)	Air	kg	329	321
CO2 (non-fossil)	Air	kg	12.3	12.6
cobalt	Air	mg	3.44	2.75
Cr	Air	mg	2.42	2.53
Cr (VI)	Air	mg	2.36	615
Cu	Air	mg	9.49	5.54
CxHy	Air	g	12.9	12.9
CxHy (alkanes)	Air	µg	652	652
CxHy (alkenes)	Air	µg	137	137
CxHy (non methane)	Air	g	1.99	1.99
CxHy (sulph)	Air	ng	7.76	7.76
CxHy aromatic	Air	mg	54	54.1
CxHy chloro	Air	ng	164	164
CxHy halogenated	Air	µg	2.68	2.69
CxHy incineration_msw	Air	µg	19.8	19.8
cyanides	Air	µg	15.2	15.2
dichloroethane	Air	µg	129	129
dichloroethene	Air	ng	834	834
dichloromethane	Air	µg	872	911
Dinitrogen oxide	Air	g	1.12	1.12
dioxin (TEQ)	Air	ng	4.14	2.25
dust	Air	g	73.2	73.2
dust (coarse) process	Air	g	3.95	3.95
dust (PM10) mobile	Air	mg	64.6	64.9
dust (PM10) stationary	Air	g	2.77	2.77
dust (SPM)	Air	mg	118	118
dust rough (s>10)	Air	g	1.1	1.1

ethane	Air	mg	301	302
ethanol	Air	mg	8.84	8.85
ethene	Air	mg	24.8	24.8
ethylbenzene	Air	mg	10.8	10.8
ethyne	Air	µg	99.8	100
Fe	Air	mg	91	91.1
fluoranthene	Air	µg	6.76	1.76
formaldehyde	Air	mg	30.8	30.9
H2	Air	µg	335	335
H2S	Air	mg	23.5	23.6
H2SO4	Air	g	1.79	466
HALON-1301	Air	µg	658	659
HCFC-21	Air	µg	130	130
HCFC-22	Air	µg	8.44	8.46
HCl	Air	g	23.1	8.33
HCN	Air	ng	554	554
He	Air	mg	107	107
heat losses	Air	kJ	951	951
heptane	Air	mg	28.2	28.2
hexachlorobenzene	Air	ng	12	7.4
hexane	Air	mg	59.3	59.3
HF	Air	g	1.52	663
HFC-134a	Air	pg	-0.0000594	-0.0000594
Hg	Air	mg	2.1	1.17
hydrazine	Air	µg	294	76.4
I	Air	mg	3.03	3.03
K	Air	mg	17.6	17.6
kerosene	Air	mg	5	5.21
La	Air	µg	39.7	39.8
MBTE	Air	ng	864	864
metals	Air	mg	39.4	44.2
methane	Air	kg	5.27	5.56
methanol	Air	mg	11.4	11.4
Mg	Air	mg	32.6	32.6
Mn	Air	mg	7.62	5.91
Mo	Air	µg	681	682
MTBE	Air	µg	2.21	2.22
n-nitrodimethylamine	Air	µg	41.9	43.7
N2	Air	mg	336	337
N2O	Air	g	87.3	90.2
Na	Air	mg	36.9	36.9
naphthalene	Air	µg	61.7	75.8
Ni	Air	mg	47.8	47.4
nitrogen	Air	mg	132	132
NO	Air	µg	93.4	93.4
NO2	Air	µg	876	876

non methane VOC	Air	g	930	1.16
NOx	Air	kg	1.91	1.94
NOx (as NO2)	Air	g	224	294
Olefins (unspec.)	Air	mg	1.12	1.12
organic substances	Air	g	153	155
P-tot	Air	mg	1.21	1.21
PAH's	Air	µg	896	898
particulates (PM10)	Air	g	385	385
particulates (PM2.5)	Air	g	208	213
particulates (SPM)	Air	g	310	315
particulates (unspecified)	Air	g	20.7	22.4
Pb	Air	mg	7.34	6.26
pentachlorobenzene	Air	ng	15.3	15.4
pentachlorophenol	Air	ng	2.48	2.48
pentane	Air	mg	185	185
phenanthrene	Air	µg	13.5	3.51
phenol	Air	mg	1.36	1.61
Phosphorus	Air	µg	154	154
propane	Air	mg	193	193
propene	Air	mg	6.48	6.49
propionaldehyde	Air	ng	117	117
propionic acid	Air	µg	410	413
Pt	Air	ng	176	176
pyrene	Air	µg	4.5	1.17
Sb	Air	µg	348	388
Sc	Air	µg	13.6	13.6
Se	Air	mg	29.2	9.81
Si	Air	mg	15.4	15.4
silicates	Air	mg	315	316
Sn	Air	µg	30.7	30.8
SO2	Air	g	490	245
soot	Air	µg	1.18	1.18
SOx	Air	kg	2.31	3.18
SOx (as SO2)	Air	g	279	280
Sr	Air	mg	1.35	1.35
sulphur	Air	g	5.2	5.2
Te	Air	kg	0	0
tetrachloroethene	Air	µg	191	200
tetrachloromethane	Air	µg	458	507
Th	Air	µg	26.3	26.3
Ti	Air	mg	3.91	3.92
Tl	Air	µg	9.63	9.65
toluene	Air	mg	26	26
trichloroethene	Air	µg	187	195
trichloromethane	Air	µg	3.42	3.43
U	Air	µg	28.6	28.6

V	Air	mg	94	91.1
vinyl chloride	Air	µg	45.3	45.3
VOC	Air	g	79.2	82.9
xylene	Air	mg	46.7	46.8
Zn	Air	mg	17.1	9.24
Zr	Air	µg	1.68	1.68
1,1-dichloroethene	Water	ng	435	435
1,1,1-trichloroethane	Water	ng	36.7	36.8
acenafthylene	Water	µg	262	262
acenaphthylene	Water	µg	769	771
Acid as H+	Water	mg	50.4	50.4
acid organic (as C)	Water	mg	56.5	56.5
acids (unspecified)	Water	g	87.8	87.8
Ag	Water	µg	50.1	50.2
Al	Water	g	4.42	4.43
alkanes	Water	mg	8.86	8.87
alkenes	Water	µg	830	831
anorg. dissolved subst.	Water	g	3.75	3.75
AOCl	Water	µg	437	437
AOX	Water	µg	401	402
arsenic	Water	µg	114	29.7
As	Water	mg	8.86	8.87
asbestos	Water	ng	6.51	6.51
B	Water	mg	615	652
Ba	Water	mg	613	614
baryte	Water	g	1.84	1.85
Be	Water	µg	3.94	3.94
benzene	Water	mg	10.5	10.5
BOD	Water	g	146	146
Ca	Water	mg	525	525
calcium compounds	Water	mg	26.1	26.1
calcium ions	Water	g	4.84	4.85
Cd	Water	mg	170	231
Ce	Water	µg	11	11
Chemical oxigen demand (COD)	Water	g	24.9	24.9
chlorinated solvents (unspec.)	Water	µg	3.33	3.34
chlorobenzene	Water	pg	41.9	41.9
chlorobenzenes	Water	pg	120	120
chloroform	Water	mg	9.47	9.47
chromate	Water	µg	604	702
Cl-	Water	g	408	469
Co	Water	mg	4.38	4.25
COD	Water	g	25.2	33.3
Cr	Water	mg	199	261
Cr (III)	Water	µg	141	141

Cr (VI)	Water	mg	1.13	297
Cs	Water	µg	68	68
Cu	Water	mg	148	125
CxHy	Water	mg	27.9	27.9
CxHy aliphatic	Water	µg	120	120
CxHy aromatic	Water	mg	75.6	75.7
CxHy chloro	Water	µg	70.6	70.7
cyanide	Water	µg	929	1.02
detergent/oil	Water	mg	15.4	15.4
di(2-ethylhexyl)phthalate	Water	ng	6.16	6.18
dibutyl p-phthalate	Water	ng	77.7	77.9
dibutylphthalate	Water	ng	26.5	26.5
dichloroethane	Water	µg	87.4	87.6
dichloromethane	Water	µg	835	836
dimethyl p-phthalate	Water	ng	490	491
dimethylphtalate	Water	ng	167	167
dioxins (TEQ)	Water	ng	89	89
dissolved organics	Water	mg	8.78	8.78
dissolved solids	Water	kg	3.62	4.94
dissolved substances	Water	g	78.6	78.6
DOC	Water	mg	58.9	59
ethyl benzene	Water	mg	1.89	1.89
fats/oils	Water	g	1.93	1.93
fatty acids as C	Water	mg	342	342
Fe	Water	g	6.5	6.54
fluoride ions	Water	mg	40.6	41.4
formaldehyde	Water	ng	399	401
glutaraldehyde	Water	µg	228	228
H2	Water	mg	2.62	2.62
H2S	Water	µg	107	107
H2SO4	Water	mg	152	161
heat losses	Water	kJ	61.3	61.3
hexachloroethane	Water	ng	1.48	1.48
Hg	Water	µg	33.6	38.5
HOCL	Water	mg	18.7	18.7
hydrazine	Water	mg	1.75	456
hydroxy (ions)	Water	ng	3.38	3.38
I	Water	mg	7.86	7.87
K	Water	g	1.03	1.03
Kjeldahl-N	Water	mg	9.84	9.84
MBTE	Water	ng	71	71
metallic ions	Water	mg	989	998
methanol	Water	g	1.82	1.82
Mg	Water	g	1.92	1.92
Mn	Water	g	9.61	9.63
Mo	Water	mg	7.92	7.94

MTBE	Water	ng	186	186
N-tot	Water	g	146	146
N organically bound	Water	mg	12.9	12.9
Na	Water	g	55.7	55.8
NH3	Water	mg	70.2	57.6
NH3 (as N)	Water	mg	96.4	96.5
NH4+	Water	mg	77.1	77.1
Ni	Water	mg	22.2	22.2
nitrate	Water	mg	163	164
nitrite	Water	mg	4.44	4.45
nitrogen	Water	g	1.5	1.5
OCl-	Water	mg	18	18
oil	Water	g	63	86.6
oil (animal/vegetable)	Water	pg	26.7	26.7
olefines	Water	µg	135	135
ortho-xylene	Water	mg	1.15	1.15
other organics	Water	g	9.83	13.7
P-compounds	Water	µg	46.6	46.6
PAH's	Water	mg	1.39	1.39
Pb	Water	mg	26.1	26.1
phenol	Water	mg	4.12	4.15
phenols	Water	mg	13.1	13.1
phosphate	Water	g	37.3	36.9
Phosphorus	Water	mg	4.19	4.3
Polychlorinated furans (PCDF)	Water	ng	77.3	77.3
Ru	Water	µg	780	780
S	Water	µg	29.7	29.7
salt	Water	mg	111	111
salts	Water	g	5.75	5.76
Sb	Water	µg	40.7	40.8
Se	Water	mg	10.9	10.9
Si	Water	mg	1.52	1.53
Sn	Water	µg	21.8	21.9
SO3	Water	mg	1.98	1.98
Sr	Water	mg	504	504
sulphate	Water	kg	2.1	2.15
sulphide	Water	mg	3.62	3.63
suspended solids	Water	kg	1.36	1.31
suspended substances	Water	g	21.5	21.5
tetrachloroethene	Water	ng	175	176
tetrachloromethane	Water	ng	268	269
Ti	Water	mg	126	127
titanium(IV)oxide	Water	pg	90.8	90.8
TOC	Water	g	3.97	3.97
toluene	Water	mg	13	13
tributyltin	Water	µg	140	140

tributyltinoxide	Water	µg	34.3	34.3
trichloroethene	Water	µg	14.8	14.8
trichloromethane	Water	µg	40.8	40.9
triethylene glycol	Water	mg	18.8	18.9
triethyleneglycol	Water	mg	7.99	7.99
undissolved substances	Water	g	5.97	5.98
V	Water	mg	11.7	11.6
vinyl chloride	Water	ng	49.8	50
VOC as C	Water	mg	23.3	23.3
W	Water	µg	98	98.2
xylene	Water	mg	6.42	6.43
Zn	Water	g	11	11
Abfaelle-Inertst.dep	Waste	g	12.4	12.4
Abfaelle-Restst.dep	Waste	mg	276	276
asbestos (tw)	Waste	ng	599	599
Bauspgut-Inertst.dep	Waste	mg	532	532
Beton-Inertst.dep	Waste	mg	411	411
Bohrabfall-Landf	Waste	g	1.84	1.84
Bohrabfall-Rstst.dep	Waste	g	3.07	3.07
bottom ash (mswi)	Waste	mg	67.7	67.7
chemical waste (inert)	Waste	mg	4.39	4.39
Deckfarbe-Inrtst.dep	Waste	ng	120	120
Depnrte-Flugasche	Waste	mg	761	761
diesel oil sludge (tw)	Waste	ng	350	350
Erdgasl-Inertst.dep	Waste	mg	86.3	86.3
FGC residues (mswi)	Waste	mg	6.44	6.44
final waste (inert)	Waste	g	148	148
fly ash (mswi)	Waste	mg	6.7	6.7
HgOH (tw)	Waste	pg	4.13	4.13
high active nuclear waste	Waste	mm3	0.25	0.25
industrial waste	Waste	mg	11	11
inorganic general	Waste	mg	19.2	19.2
Kat-Sonderabfalldep	Waste	mg	12.8	12.8
Klkstrst-Inertst.dep	Waste	µg	83.8	83.8
Kupfer-Inertst.dep	Waste	µg	8	8
L/Mrad. waste (rw)	Waste	mm3	16.7	16.7
mineral waste	Waste	mg	900	900
mineral waste (mining)	Waste	g	369	369
Minwolle-Inertst.dep	Waste	µg	437	437
produc. waste (not inert)	Waste	g	1.24	1.24
Rafschlamm-Landf	Waste	mg	15.3	15.3
Rckst-Entkrb-Restst.dep	Waste	mg	520	520
Rckst-Kuehlturmtassen	Waste	mg	42.5	42.5

Schweissstaub-Sabf	Waste	ng	96.5	96.5
slag	Waste	mg	21.9	21.9
slags/ash	Waste	mg	132	132
solid waste	Waste	kg	9.07	11.6
solid waste (nw)	Waste	mg	530	530
Stahl-Inertst.dep	Waste	mg	141	141
Steinkohle-Asche-Dep	Waste	g	2.1	2.1
Steinkohleberge-Dep	Waste	g	81.1	81.1
tailings	Waste	g	14	14
tailings (nw)	Waste	µg	113	113
waste	Waste	mg	93.8	93.8
waste bioactive landfill	Waste	g	127	128
waste in incineration	Waste	g	2.01	2.01
waste in inert landfill	Waste	kg	65.4	67.1
waste limestone	Waste	g	20	20
Zeolithe-Inertst.dep	Waste	mg	7.66	7.66
Al (ind.)	Soil	mg	101	102
arsenic (ind.)	Soil	mg	59	15.4
As (ind.)	Soil	µg	40.5	40.6
benzo(a)anthracene (ind.)	Soil	µg	24.8	6.44
benzo(a)pyrene (ind.)	Soil	µg	13.5	3.51
benzo(b)fluoranthene (ind.)	Soil	µg	20.3	5.27
benzo(e)pyren (ind.)	Soil	µg	22.5	5.86
benzo[ghi]perylene (ind.)	Soil	µg	22.5	5.86
C (ind.)	Soil	mg	312	312
Ca (ind.)	Soil	mg	405	406
Cd (ind.)	Soil	µg	1.38	1.38
Co (ind.)	Soil	mg	86	22.4
Cr (ind.)	Soil	µg	507	507
Cr (VI) (ind.)	Soil	mg	289	75.2
Cu (ind.)	Soil	mg	241	62.8
dibenzo(a,h)anthracene (ind.)	Soil	µg	6.76	1.76
dibenzo(a,i)pyrene (ind.)	Soil	µg	2.25	586
dioxin (TEQ) (ind.)	Soil	pg	135	35.1
Fe (ind.)	Soil	mg	203	203
fluoranthene (ind.)	Soil	µg	18	4.69
Hg (ind.)	Soil	µg	539	140
indeno[1,2,3-cd]pyrene (ind.)	Soil	µg	4.5	1.17
Mn (ind.)	Soil	mg	389	104
N	Soil	µg	74.7	74.7
Ni (ind.)	Soil	mg	198	51.5
oil	Soil	mg	9.53	9.53

oil (ind.)	Soil	mg	58.2	58.2
oil biodegradable	Soil	µg	277	278
oil biological	Soil	µg	18.7	18.7
P-tot	Soil	mg	5.17	5.18
Pb (ind.)	Soil	mg	94.5	24.6
perylene	Soil	µg	2.25	586
phenanthrene (ind.)	Soil	µg	207	53.9
pyrene	Soil	µg	27	7.03
S (ind.)	Soil	mg	60.8	60.9
selenium (ind.)	Soil	mg	18.1	4.71
vanadium (ind.)	Soil	mg	439	114
Zn (ind.)	Soil	mg	204	54.2
Ag110m to air	Non mat.	µBq	45.5	45.6
Ag110m to water	Non mat.	mBq	312	312
agric, trad;5;6;15;12	Non mat.	cm2a	153	153
alpha radiation (unspecified) to water	Non mat.	µBq	37	37
Am241 to air	Non mat.	µBq	852	854
Am241 to water	Non mat.	mBq	112	112
Ar41 to air	Non mat.	Bq	99.3	99.5
Ba140 to air	Non mat.	µBq	178	179
Ba140 to water	Non mat.	µBq	559	560
beta radiation (unspecified) to air	Non mat.	µBq	5.72	5.73
C14 to air	Non mat.	Bq	68.3	68.4
C14 to water	Non mat.	Bq	5.67	5.68
Cd109 to water	Non mat.	µBq	3.23	3.24
Ce141 to air	Non mat.	µBq	4.26	4.27
Ce141 to water	Non mat.	µBq	83.7	83.8
Ce144 to air	Non mat.	mBq	9.06	9.08
Ce144 to water	Non mat.	Bq	2.57	2.57
Cm (alpha) to air	Non mat.	mBq	1.35	1.35
Cm (alpha) to water	Non mat.	mBq	149	149
Cm242 to air	Non mat.	nBq	4.51	4.52
Cm244 to air	Non mat.	nBq	40.8	40.8
Co57 to air	Non mat.	nBq	78.6	78.8
Co57 to water	Non mat.	µBq	572	573
Co58 to air	Non mat.	mBq	1.3	1.3
Co58 to water	Non mat.	mBq	485	486
Co60 to air	Non mat.	mBq	1.93	1.94
Co60 to water	Non mat.	Bq	24.8	24.8
Conv. to industrial area	Non mat.	mm2	1.8	1.8
Cr51 to air	Non mat.	µBq	161	161
Cr51 to water	Non mat.	mBq	12.3	12.3
Cs134 to air	Non mat.	mBq	32.3	32.4
Cs134 to water	Non mat.	Bq	5.73	5.75
Cs136 to water	Non mat.	µBq	3	3.01

Cs137 to air	Non mat.	mBq	62.5	62.6
Cs137 to water	Non mat.	Bq	52.7	52.8
drill gas, land;0;0;15;12	Non mat.	cm2a	69.1	69.1
drill gas,sea;15;12;15;12	Non mat.	m2a	0	0
drill oil, land;0;0;15;6	Non mat.	cm2a	15.3	15.3
drill oil, sea;15;6;15;6	Non mat.	m2a	0	0
dump hrw;0;0;15;12	Non mat.	m2s	135	135
dump lmrw;0;0;15;12	Non mat.	m2s	53	53
dump rw;0;0;15;12	Non mat.	cm2a	71	71
Fe59 to air	Non mat.	µBq	1.78	1.78
Fe59 to water	Non mat.	µBq	9.9	9.92
Fission and activation products (RA) to water	Non mat.	mBq	336	336
H3 to air	Non mat.	Bq	707	709
H3 to water	Non mat.	kBq	168	168
heat losses to air	Non mat.	MJ	12.3	12.3
heat losses to soil	Non mat.	kJ	1.99	1.99
heat losses to water	Non mat.	kJ	223	223
hydro;0;0;10;7	Non mat.	mm2a	246	246
I129 to air	Non mat.	mBq	243	243
I129 to water	Non mat.	Bq	16.2	16.3
I131 to air	Non mat.	mBq	26.9	27
I131 to water	Non mat.	mBq	10.7	10.7
I133 to air	Non mat.	mBq	15.1	15.1
I133 to water	Non mat.	mBq	2.56	2.56
I135 to air	Non mat.	mBq	22.6	22.7
indus;5;1;15;12	Non mat.	cm2a	35.4	35.4
K40 to air	Non mat.	mBq	128	128
K40 to water	Non mat.	mBq	407	408
Kr85 to air	Non mat.	kBq	4180	4190
Kr85m to air	Non mat.	Bq	4.93	4.94
Kr87 to air	Non mat.	Bq	2.21	2.22
Kr88 to air	Non mat.	Bq	198	198
Kr89 to air	Non mat.	Bq	1.55	1.55
La140 to air	Non mat.	µBq	113	113
La140 to water	Non mat.	µBq	116	116
land use (sea floor) II-III	Non mat.	m2a	0.125	0.125
land use (sea floor) II-IV	Non mat.	cm2a	129	129
land use II-III	Non mat.	m2a	0.432	0.433
land use II-III bento	Non mat.	cm2a	218	218
land use II-IV	Non mat.	cm2a	130	130
land use II-IV bento	Non mat.	cm2a	22.5	22.5
land use III-IV	Non mat.	cm2a	143	144
land use IV-IV	Non mat.	mm2a	870	870
minin Ni; 0;0;10;8	Non mat.	mm2a	730	730

minin rocks.;0;0;15;12	Non mat.	m2s	0.205	0.205
minin U;0;0;17;8	Non mat.	mm2a	32.5	32.5
mining coal;0;0;25;9	Non mat.	cm2a	30.5	30.5
Mn54 to air	Non mat.	µBq	46.4	46.5
Mn54 to water	Non mat.	Bq	3.8	3.81
Mo99 to water	Non mat.	µBq	39.1	39.1
Na24 to water	Non mat.	mBq	17.2	17.3
Nb95 to air	Non mat.	µBq	8.19	8.21
Nb95 to water	Non mat.	µBq	317	318
Np237 to air	Non mat.	nBq	44.7	44.8
Np237 to water	Non mat.	mBq	7.16	7.17
Occup. as industrial area	Non mat.	mm2a	487	487
Pa234m to air	Non mat.	mBq	27	27.1
Pa234m to water	Non mat.	mBq	501	502
Pb210 to air	Non mat.	mBq	748	750
Pb210 to water	Non mat.	mBq	324	325
pipel;5;0;15;12	Non mat.	cm2a	596	596
Pm147 to air	Non mat.	mBq	23	23
Po210 to air	Non mat.	Bq	1.12	1.12
Po210 to water	Non mat.	mBq	324	325
Pu alpha to air	Non mat.	mBq	2.7	2.71
Pu alpha to water	Non mat.	mBq	447	448
Pu238 to air	Non mat.	nBq	101	102
Pu241 beta	Non mat.	Bq	11.1	11.1
Pu241 Beta to air	Non mat.	mBq	74.1	74.3
Ra224 to water	Non mat.	Bq	3.34	3.34
Ra226 to air	Non mat.	mBq	964	966
Ra226 to water	Non mat.	kBq	2.07	2.07
Ra228 to air	Non mat.	mBq	62.5	62.7
Ra228 to water	Non mat.	Bq	6.67	6.68
Rad.air-Ag110m	Non mat.	µBq	2.36	2.36
Rad.air-Am241	Non mat.	µBq	18.2	18.2
Rad.air-Andere-Beta	Non mat.	nBq	57.7	57.7
Rad.air-Ar41	Non mat.	Bq	5.16	5.16
Rad.air-Ba140	Non mat.	µBq	3.91	3.91
Rad.air-C14	Non mat.	Bq	1.39	1.39
Rad.air-Ce141	Non mat.	nBq	70.8	70.8
Rad.air-Ce144	Non mat.	µBq	193	193
Rad.air-Cm-alpha	Non mat.	µBq	28.8	28.8
Rad.air-Cm242	Non mat.	nBq	0.109	0.109
Rad.air-Cm244	Non mat.	nBq	0.993	0.993
Rad.air-Co57	Non mat.	nBq	4.1	4.1
Rad.air-Co58	Non mat.	µBq	21.8	21.8
Rad.air-Co60	Non mat.	µBq	33.9	33.9
Rad.air-Cr51	Non mat.	µBq	3.09	3.09
Rad.air-Cs134	Non mat.	µBq	687	687

Rad.air-Cs137	Non mat.	mBq	1.33	1.33
Rad.air-Edelgase	Non mat.	mBq	27.2	27.2
Rad.air-Fe59	Non mat.	nBq	51.2	51.2
Rad.air-H3	Non mat.	Bq	14.1	14.1
Rad.air-I129	Non mat.	mBq	5.2	5.2
Rad.air-I131	Non mat.	µBq	775	775
Rad.air-I133	Non mat.	µBq	250	250
Rad.air-I135	Non mat.	µBq	375	375
Rad.air-K40	Non mat.	mBq	7.75	7.75
Rad.air-Kr85	Non mat.	kBq	89.3	89.3
Rad.air-Kr85m	Non mat.	mBq	120	120
Rad.air-Kr87	Non mat.	mBq	81.6	81.6
Rad.air-Kr88	Non mat.	Bq	3.31	3.31
Rad.air-Kr89	Non mat.	mBq	58.6	58.6
Rad.air-La140	Non mat.	µBq	1.95	1.95
Rad.air-LT-Rd-Rn222	Non mat.	kBq	130	130
Rad.air-Mn54	Non mat.	nBq	815	815
Rad.air-Nb95	Non mat.	nBq	361	361
Rad.air-Np237	Non mat.	nBq	0.95	0.95
Rad.air-Pa234m	Non mat.	µBq	583	583
Rad.air-Pb210	Non mat.	mBq	33.3	33.3
Rad.air-Pm147	Non mat.	µBq	491	491
Rad.air-Po-210	Non mat.	mBq	49.7	49.7
Rad.air-Po210	Non mat.	mBq	6.46	6.46
Rad.air-Pu-alpha	Non mat.	µBq	57.8	57.8
Rad.air-Pu238	Non mat.	nBq	2.79	2.79
Rad.air-Pu241-Beta	Non mat.	mBq	1.59	1.59
Rad.air-Ra226	Non mat.	mBq	25.2	25.2
Rad.air-Ra228	Non mat.	mBq	3.83	3.83
Rad.air-Rn220	Non mat.	mBq	976	976
Rad.air-Rn222	Non mat.	kBq	1.41	1.41
Rad.air-Ru103	Non mat.	nBq	24.7	24.7
Rad.air-Ru106	Non mat.	mBq	5.78	5.78
Rad.air-Sb124	Non mat.	nBq	599	599
Rad.air-Sb125	Non mat.	nBq	85.9	85.9
Rad.air-Sr89	Non mat.	µBq	1.31	1.31
Rad.air-Sr90	Non mat.	µBq	950	950
Rad.air-Tc99	Non mat.	nBq	40.4	40.4
Rad.air-Te123m	Non mat.	µBq	10.6	10.6
Rad.air-Th228	Non mat.	mBq	3.27	3.27
Rad.air-Th230	Non mat.	mBq	6.46	6.46
Rad.air-Th232	Non mat.	mBq	2.07	2.07
Rad.air-Th234	Non mat.	µBq	583	583
Rad.air-U-alpha	Non mat.	mBq	20.9	20.9
Rad.air-U234	Non mat.	mBq	6.98	6.98
Rad.air-U235	Non mat.	µBq	338	338

Rad.air-U238	Non mat.	mBq	12.8	12.8
Rad.air-Xe131m	Non mat.	mBq	543	543
Rad.air-Xe133	Non mat.	Bq	53.3	53.3
Rad.air-Xe133m	Non mat.	mBq	70.2	70.2
Rad.air-Xe135	Non mat.	Bq	9.7	9.7
Rad.air-Xe135m	Non mat.	Bq	1.82	1.82
Rad.air-Xe137	Non mat.	mBq	67.7	67.7
Rad.air-Xe138	Non mat.	mBq	495	495
Rad.air-Zn65	Non mat.	µBq	3.64	3.64
Rad.air-Zr95	Non mat.	nBq	138	138
Rad.wat-Ag110m	Non mat.	mBq	1.39	1.39
Rad.wat-Alpha-Strahler	Non mat.	nBq	682	682
Rad.wat-Am241	Non mat.	mBq	2.4	2.4
Rad.wat-Ba140	Non mat.	µBq	2.57	2.57
Rad.wat-C14	Non mat.	mBq	121	121
Rad.wat-Cd109	Non mat.	nBq	14.8	14.8
Rad.wat-Ce141	Non mat.	nBq	383	383
Rad.wat-Ce144	Non mat.	mBq	54.8	54.8
Rad.wat-Cm-alpha	Non mat.	mBq	3.18	3.18
Rad.wat-Co57	Non mat.	µBq	2.62	2.62
Rad.wat-Co58	Non mat.	mBq	2.19	2.19
Rad.wat-Co60	Non mat.	mBq	522	522
Rad.wat-Cr51	Non mat.	µBq	56.5	56.5
Rad.wat-Cs134	Non mat.	mBq	122	122
Rad.wat-Cs136	Non mat.	nBq	13.8	13.8
Rad.wat-Cs137	Non mat.	Bq	1.13	1.13
Rad.wat-Fe59	Non mat.	nBq	45.5	45.5
Rad.wat-H3	Non mat.	kBq	3.59	3.59
Rad.wat-I129	Non mat.	mBq	346	346
Rad.wat-I131	Non mat.	µBq	48.2	48.2
Rad.wat-I133	Non mat.	µBq	11.8	11.8
Rad.wat-K-40	Non mat.	mBq	126	126
Rad.wat-La140	Non mat.	nBq	531	531
Rad.wat-Mn54	Non mat.	mBq	80.8	80.8
Rad.wat-Mo99	Non mat.	nBq	179	179
Rad.wat-Na24	Non mat.	µBq	79	79
Rad.wat-Nb95	Non mat.	µBq	1.46	1.46
Rad.wat-Np237	Non mat.	µBq	153	153
Rad.wat-Nuklidmix	Non mat.	µBq	4.76	4.76
Rad.wat-Pa234m	Non mat.	mBq	10.8	10.8
Rad.wat-Pb-210	Non mat.	mBq	100	100
Rad.wat-Po-210	Non mat.	mBq	100	100
Rad.wat-Pu-alpha	Non mat.	mBq	9.5	9.5
Rad.wat-Pu241-beta	Non mat.	mBq	237	237
Rad.wat-Ra-224	Non mat.	mBq	550	550
Rad.wat-Ra-226	Non mat.	Bq	45.5	45.5

Rad.wat-Ra-228	Non mat.	Bq	1.1	1.1
Rad.wat-Ru103	Non mat.	nBq	860	860
Rad.wat-Ru106	Non mat.	mBq	578	578
Rad.wat-Sb122	Non mat.	µBq	2.57	2.57
Rad.wat-Sb124	Non mat.	µBq	358	358
Rad.wat-Sb125	Non mat.	µBq	20.9	20.9
Rad.wat-Sp-u-Activ-pr	Non mat.	mBq	27.1	27.1
Rad.wat-Sr89	Non mat.	µBq	5.81	5.81
Rad.wat-Sr90	Non mat.	mBq	116	116
Rad.wat-Tc99	Non mat.	mBq	60.7	60.7
Rad.wat-Tc99m	Non mat.	µBq	1.21	1.21
Rad.wat-Te123m	Non mat.	nBq	108	108
Rad.wat-Te132	Non mat.	nBq	44.5	44.5
Rad.wat-Th-228	Non mat.	Bq	2.2	2.2
Rad.wat-Th-232	Non mat.	mBq	23.4	23.4
Rad.wat-Th230	Non mat.	Bq	1.69	1.69
Rad.wat-Th234	Non mat.	mBq	10.9	10.9
Rad.wat-U-238	Non mat.	mBq	81.9	81.9
Rad.wat-U-alpha	Non mat.	mBq	705	705
Rad.wat-U234	Non mat.	mBq	14.4	14.4
Rad.wat-U235	Non mat.	mBq	21.5	21.5
Rad.wat-Y90	Non mat.	nBq	297	297
Rad.wat-Zn65	Non mat.	µBq	167	167
Rad.wat-Zr95	Non mat.	mBq	4.91	4.91
radio active noble gases to air	Non mat.	Bq	5.92	5.93
radioactive substance to air	Non mat.	kBq	8360	8380
radioactive substance to water	Non mat.	kBq	73.7	73.8
radionuclides (mixed) to water	Non mat.	µBq	243	243
Rn220 to air	Non mat.	Bq	5.92	5.93
Rn222 (long term) to air	Non mat.	kBq	6000	6010
Rn222 to air	Non mat.	kBq	65.4	65.5
Ru103 to air	Non mat.	nBq	464	465
Ru103 to water	Non mat.	µBq	187	188
Ru106 to air	Non mat.	mBq	270	271
Ru106 to water	Non mat.	Bq	27	27.1
Sb122 to water	Non mat.	µBq	559	560
Sb124 to air	Non mat.	µBq	12.5	12.6
Sb124 to water	Non mat.	mBq	80.3	80.4
Sb125 to air	Non mat.	µBq	1.59	1.6
Sb125 to water	Non mat.	mBq	4.56	4.57
Sr89 to air	Non mat.	µBq	81.1	81.3
Sr89 to water	Non mat.	mBq	1.26	1.27
Sr90 to air	Non mat.	mBq	44.7	44.8

Sr90 to water	Non mat.	Bq	5.42	5.43
Tc99 to air	Non mat.	µBq	1.89	1.9
Tc99 to water	Non mat.	Bq	2.83	2.84
Tc99m to water	Non mat.	µBq	263	264
Te123m to air	Non mat.	µBq	204	204
Te123m to water	Non mat.	µBq	23.6	23.6
Te132 to water	Non mat.	µBq	9.65	9.67
Th228 to air	Non mat.	mBq	53	53.1
Th228 to water	Non mat.	Bq	13.3	13.4
Th230 to air	Non mat.	mBq	301	301
Th230 to water	Non mat.	Bq	78.2	78.4
Th232 to air	Non mat.	mBq	33.6	33.6
Th232 to water	Non mat.	mBq	75.7	75.9
Th234 to air	Non mat.	mBq	27	27.1
Th234 to water	Non mat.	mBq	505	506
trans, canal;5;5;15;12	Non mat.	m2s	221	221
trans, roadNL;5;2;15;12	Non mat.	mm2a	219	219
trans,rail NL;5;2;15;12	Non mat.	cm2a	18.5	18.5
U alpha to air	Non mat.	mBq	968	970
U alpha to water	Non mat.	Bq	32.7	32.8
U234 to air	Non mat.	mBq	324	325
U234 to water	Non mat.	mBq	670	672
U235 to air	Non mat.	mBq	15.7	15.7
U235 to water	Non mat.	mBq	997	999
U238 to air	Non mat.	mBq	416	416
U238 to water	Non mat.	Bq	1.69	1.7
waste heat to air	Non mat.	MJ	161	162
waste heat to soil	Non mat.	kJ	325	325
waste heat to water	Non mat.	MJ	9.59	9.59
Xe131m to air	Non mat.	Bq	10.2	10.2
Xe133 to air	Non mat.	kBq	3.01	3.01
Xe133m to air	Non mat.	Bq	1.51	1.52
Xe135 to air	Non mat.	Bq	513	514
Xe135m to air	Non mat.	Bq	50.5	50.6
Xe137 to air	Non mat.	Bq	1.25	1.26
Xe138 to air	Non mat.	Bq	13.7	13.7
Y90 to water	Non mat.	µBq	64.6	64.7
Zn65 to air	Non mat.	µBq	199	199
Zn65 to water	Non mat.	mBq	36.4	36.4
Zr95 to air	Non mat.	µBq	2.97	2.98
Zr95 to water	Non mat.	mBq	230	230

Substance	Compartment	Unit	DIP 5 – Cogen 1	DIP 1- Cogen1
air	Raw	kg	8.86	13.5
baryte	Raw	g	7.67	8.9
bauxite	Raw	g	1.94	2.46
bentonite	Raw	g	1.56	1.91
Chips	Raw	kg	482	481
chlorine	Raw	pg	0.000000093	0.000000146
chromium (Cr)	Raw	mg	3.06	4.82
chromium (in ore)	Raw	mg	68.8	85.4
clay	Raw	g	3.12	3.67
clay minerals	Raw	mg	158	249
coal	Raw	mg	448	448
coal (18 MJ/kg) ETH	Raw	g	225	353
coal (27.1 MJ/kg)	Raw	g	1.09	1.71
coal (29.3 MJ/kg)	Raw	mg	4.66	7.34
coal ETH	Raw	kg	1.62	2.12
coal FAL	Raw	kg	159	168
cobalt (Co)	Raw	ng	180	283
cobalt (in ore)	Raw	ng	103	120
copper (Cu)	Raw	mg	43.7	68.7
copper (in ore)	Raw	mg	769	963
crude oil	Raw	g	16.3	24.8
crude oil (41.9 MJ/kg)	Raw	mg	1.32	2.08
crude oil (42,6 MJ/kg) ETH	Raw	g	75.5	119
crude oil (42,7 MJ/kg) IDEMAT	Raw	mg	28.4	43.1
crude oil ETH	Raw	kg	1.22	1.52
crude oil FAL	Raw	kg	15.9	17.3
crude oil IDEMAT	Raw	g	90.2	90.2
energy (undef.)	Raw	kJ	9.97	15.7
energy from coal	Raw	kJ	24.6	37.5
energy from hydro power	Raw	MJ	46.6	49.2
energy from natural gas	Raw	MJ	4.28	6.51
energy from oil	Raw	kJ	8.96	13.6
energy from uranium	Raw	kJ	59.7	90.8
gas (35MJ/m3); from oil prod.	Raw	cu.in	314	493
gravel	Raw	g	113	134
H3BO3	Raw	kg	2.77	2.77
Hog Fuel	Raw	kg	346	359
iron (Fe)	Raw	g	2.41	3.79
iron (in ore)	Raw	g	28.2	31.8
iron (ore)	Raw	g	1.74	2.3
lead (in ore)	Raw	mg	71.4	87.2

lead (Pb)	Raw	mg	5.47	8.61
lignite (8.1 MJ/kg) ETH	Raw	g	10.4	16.3
lignite ETH	Raw	kg	1.53	2
limestone	Raw	g	416	489
lubricant	Raw	mg	1.86	1.91
lubricating oil	Raw	mg	186	192
manganese (in ore)	Raw	mg	17.8	20.8
manganese (Mn)	Raw	mg	1.48	2.34
marl	Raw	g	30	37.2
material known, no data	Raw	kg	11.7	18.4
material unknown	Raw	µg	777	1.22
methane (kg) ETH	Raw	g	4.98	6.37
mining gas (30,3 MJ/kg) ETH	Raw	mg	549	864
molybdene (in ore)	Raw	ng	669	887
molybdenum (Mo)	Raw	ng	39	61.3
Na	Raw	kg	4.02	4.02
NaCl	Raw	mg	22.4	34.1
natural gas	Raw	g	5.4	5.4
natural gas (35,0 MJ/m3) ETH	Raw	l	173	272
natural gas (36,6 MJ/m3; vol)	Raw	l	56.4	88.7
natural gas (vol)	Raw	l	451	596
natural gas ETH	Raw	m3	2.5	2.81
natural gas FAL	Raw	kg	53	56.6
nickel (in ore)	Raw	mg	44.7	56.2
nickel (Ni)	Raw	mg	1.53	2.41
nickel (ore)	Raw	g	70.5	111
palladium (in ore)	Raw	ng	806	1.07
palladium (Pd)	Raw	ng	8.19	12.9
petroleum gas ETH	Raw	l	63	76.8
platinum (in ore)	Raw	ng	906	1.21
platinum (Pt)	Raw	ng	9.37	14.7
pot. energy hydropower	Raw	MJ	2.8	3.73
potential energy water ETH	Raw	MJ	4.03	5.18
process and cooling water	Raw	l	19.9	26.3
reservoir content ETH	Raw	m3y	0.0878	0.113
rhenium (in ore)	Raw	ng	858	1.14
rhenium (Re)	Raw	ng	8.29	13
rhodium (in ore)	Raw	ng	855	1.14
rhodium (Rh)	Raw	ng	8.72	13.7
rock salt	Raw	kg	2.22	2.93
sand	Raw	kg	2.22	3.46
sand, clay	Raw	mg	752	994

silver (Ag)	Raw	µg	237	373
silver (in ore)	Raw	mg	2.89	3.52
soda	Raw	kg	3.82	6.01
sulphur	Raw	kg	3.07	4.11
tin (in ore)	Raw	mg	1.61	1.96
tin (Sn)	Raw	µg	132	207
turbine water ETH	Raw	m3	21.2	27.3
uranium (in ore)	Raw	mg	50.9	67.8
uranium (in ore) ETH	Raw	mg	61.8	79.4
uranium (U)	Raw	mg	1.32	2.08
uranium FAL	Raw	g	2.13	2.25
waste paper (feedstock)	Raw	kg	309	486
water	Raw	kg	164	218
water (cooling)	Raw	kg	199	313
water (process)	Raw	kg	9.07	14.3
water (sea)	Raw	g	140	213
water (sea, for processing)	Raw	g	3.51	5.34
water (surface)	Raw	tn.lg	45.4	46.2
water barrage (vol)	Raw	cm3	216	340
water turbine	Raw	l	52	81.8
wood	Raw	g	1.47	2.32
wood (dry matter) ETH	Raw	g	10.7	13.3
wood/wood wastes FAL	Raw	g	32.1	35
zeolite	Raw	µg	88.7	139
zinc (in ore)	Raw	mg	1.55	1.73
zinc (Zn)	Raw	µg	174	273
1,2-dichloroethane	Air	µg	13.5	21.3
acetaldehyde	Air	mg	3.47	4.08
acetic acid	Air	mg	16.3	19.1
acetone	Air	mg	3.45	4.07
acetylene	Air	µg	2.46	3.88
acrolein	Air	µg	101	132
aerosols	Air	µg	3.15	4.95
Al	Air	mg	54.6	72.7
aldehydes	Air	g	11.7	12.8
alkanes	Air	mg	35.4	42.7
alkenes	Air	mg	4.62	5.85
ammonia	Air	g	3	3.11
arsenic	Air	mg	6.57	6.93
As	Air	mg	1.06	1.29
B	Air	mg	54.2	75.2
Ba	Air	µg	764	986
Be	Air	µg	61.8	78
benzaldehyde	Air	ng	58.9	84.4
benzene	Air	mg	26.2	34.3
benzo(a)pyrene	Air	µg	4.37	5.16

benzo(k)fluoranthrene	Air	ng	755	797
Br	Air	mg	3.69	4.78
butane	Air	mg	104	122
butane (unspec.)	Air	mg	8.32	13.1
butene	Air	mg	2.21	2.72
Ca	Air	mg	84.7	117
Cd	Air	mg	1.35	1.57
CF4	Air	µg	1.22	1.92
CFC-11	Air	µg	19.8	25.5
CFC-114	Air	µg	523	674
CFC-116	Air	µg	20.6	26.1
CFC-12	Air	µg	4.25	5.48
CFC-13	Air	µg	2.67	3.43
CFC-14	Air	µg	184	232
CFC-21	Air	µg	14.2	22.3
CFC (hard)	Air	ng	5.37	8.45
Cl2	Air	mg	3.16	3.44
CN (complex)	Air	ng	503	791
CO	Air	kg	3.1	3.19
CO2	Air	kg	13.9	17.1
CO2 (fossil)	Air	kg	478	512
CO2 (non-fossil)	Air	kg	7.74	8.34
cobalt	Air	mg	5.24	5.75
Cr	Air	mg	1.46	1.81
Cr (VI)	Air	mg	7.93	8.37
Cu	Air	mg	20.9	22.5
CxHy	Air	g	4.28	6.59
CxHy (alkanes)	Air	µg	207	326
CxHy (alkenes)	Air	µg	43.6	68.5
CxHy (non methane)	Air	mg	634	997
CxHy (sulph)	Air	ng	2.64	4.01
CxHy aromatic	Air	mg	28.6	38.2
CxHy chloro	Air	ng	53.3	82.9
CxHy halogenated	Air	µg	1.5	1.99
CxHy incineration_msw	Air	µg	6.28	9.88
cyanides	Air	µg	11.9	13.9
dichloroethane	Air	µg	94.7	113
dichloroethene	Air	ng	265	417
dichloromethane	Air	µg	444	581
Dinitrogen oxide	Air	mg	356	561
dioxin (TEQ)	Air	ng	9.59	10.3
dust	Air	g	29.4	42.5
dust (coarse) process	Air	g	2.95	3.39
dust (PM10) mobile	Air	mg	47.6	56.4
dust (PM10) stationary	Air	g	1.9	2.31
dust (SPM)	Air	mg	59.6	75.1

dust rough (s>10)	Air	mg	349	548
ethane	Air	mg	415	438
ethanol	Air	mg	6.92	8.15
ethene	Air	mg	18.4	22
ethylbenzene	Air	mg	6	7.74
ethyne	Air	µg	60.1	75.4
Fe	Air	mg	45.6	60.6
fluoranthene	Air	µg	22.7	23.9
formaldehyde	Air	mg	19.2	23.9
H2	Air	µg	333	334
H2S	Air	mg	35.1	36.6
H2SO4	Air	g	6	6.34
HALON-1301	Air	µg	431	534
HCFC-21	Air	µg	114	131
HCFC-22	Air	µg	4.7	6.04
HCl	Air	g	68.9	73.1
HCN	Air	ng	176	277
He	Air	mg	68.3	84.8
heat losses	Air	kJ	302	475
heptane	Air	mg	17.9	22.3
hexachlorobenzene	Air	ng	24.6	26.6
hexane	Air	mg	37.6	46.8
HF	Air	g	4.11	4.38
HFC-134a	Air	pg	-0.000116	-0.000118
Hg	Air	mg	4.83	5.19
hydrazine	Air	µg	986	1.04
I	Air	mg	1.66	2.14
K	Air	mg	11.3	14
kerosene	Air	mg	2.53	3.32
La	Air	µg	22	28.3
MBTE	Air	ng	275	432
metals	Air	mg	23.1	27.9
methane	Air	kg	3.28	3.59
methanol	Air	mg	9.8	11.3
Mg	Air	mg	17.4	22.7
Mn	Air	mg	11.7	12.9
Mo	Air	µg	475	577
MTBE	Air	µg	2.05	2.33
n-nitrodimethylamine	Air	µg	21.3	27.9
N2	Air	mg	537	555
N2O	Air	g	59.2	61.4
Na	Air	mg	24.9	30.5
naphthalene	Air	µg	45.6	50.3
Ni	Air	mg	38.7	45.5
nitrogen	Air	mg	41.9	65.8
NO	Air	µg	29.7	46.7

NO2	Air	µg	876	876
non methane VOC	Air	g	709	772
NOx	Air	kg	1.58	1.67
NOx (as NO2)	Air	g	168	188
Olefins (unspec.)	Air	µg	357	560
organic substances	Air	g	139	143
P-tot	Air	µg	684	876
PAH's	Air	µg	448	595
particulates (PM10)	Air	g	290	307
particulates (PM2.5)	Air	g	166	169
particulates (SPM)	Air	g	240	244
particulates (unspecified)	Air	g	12.1	14.8
Pb	Air	mg	9.39	10.5
pentachlorobenzene	Air	ng	9.27	11.6
pentachlorophenol	Air	ng	1.5	1.88
pentane	Air	mg	120	148
phenanthrene	Air	µg	45.3	47.8
phenol	Air	µg	925	1.06
Phosphorus	Air	µg	48.9	77
propane	Air	mg	182	205
propene	Air	mg	4.06	5.07
propionaldehyde	Air	ng	37.1	58.3
propionic acid	Air	µg	324	376
Pt	Air	ng	132	157
pyrene	Air	µg	15.1	15.9
Sb	Air	µg	229	266
Sc	Air	µg	7.44	9.61
Se	Air	mg	89.8	95.1
Si	Air	mg	4.91	7.72
silicates	Air	mg	173	223
Sn	Air	µg	16.6	21.6
SO2	Air	kg	1.24	1.3
soot	Air	µg	1.18	1.18
SOx	Air	kg	1.84	1.98
SOx (as SO2)	Air	g	162	208
Sr	Air	µg	748	964
sulphur	Air	g	1.72	2.65
Te	Air	kg	0	0
tetrachloroethene	Air	µg	97.8	128
tetrachloromethane	Air	µg	273	333
Th	Air	µg	14.3	18.6
Ti	Air	mg	2.14	2.76
Tl	Air	µg	5.33	6.87
toluene	Air	mg	16.9	20.8
trichloroethene	Air	µg	95.1	125
trichloromethane	Air	µg	2.51	2.99

U	Air	μg	15.8	20.3
V	Air	mg	79.4	93.3
vinyl chloride	Air	μg	23.2	30.5
VOC	Air	g	112	115
xylene	Air	mg	26.1	33.6
Zn	Air	mg	39.8	42.7
Zr	Air	μg	1.05	1.31
1,1-dichloroethene	Water	ng	138	218
1,1,1-trichloroethane	Water	ng	28.7	33.7
acenafthylene	Water	μg	83.2	131
acenaphthylene	Water	μg	800	885
Acid as H+	Water	mg	16.4	25.5
acid organic (as C)	Water	mg	18	28.2
acids (unspecified)	Water	g	89.6	92.3
Ag	Water	μg	32.2	39.9
Al	Water	g	2.46	3.22
alkanes	Water	mg	6.32	7.63
alkenes	Water	μg	587	710
anorg. dissolved subst.	Water	g	1.73	2.4
AOCl	Water	μg	139	219
AOX	Water	μg	244	309
arsenic	Water	μg	383	404
As	Water	mg	4.94	6.44
asbestos	Water	ng	2.07	3.26
B	Water	mg	333	423
Ba	Water	mg	357	459
baryte	Water	g	1.54	1.79
Be	Water	μg	2.18	2.81
benzene	Water	mg	6.86	8.47
BOD	Water	g	315	230
Ca	Water	mg	167	262
calcium compounds	Water	mg	8.28	13
calcium ions	Water	g	3.16	3.9
Cd	Water	mg	140	150
Ce	Water	μg	3.49	5.49
Chemical oxigen demand (COD)	Water	g	7.91	12.4
chlorinated solvents (unspec.)	Water	μg	3.06	3.45
chlorobenzene	Water	pg	13.3	21
chlorobenzenes	Water	pg	122	136
chloroform	Water	mg	9.67	9.96
chromate	Water	μg	433	482
Cl-	Water	g	270	323
Co	Water	mg	2.97	3.67
COD	Water	g	21.2	22.8
Cr	Water	mg	150	166

Cr (III)	Water	µg	44.9	70.6
Cr (VI)	Water	mg	3.78	3.99
Cs	Water	µg	46.6	56.8
Cu	Water	mg	213	225
CxHy	Water	mg	10.3	15
CxHy aliphatic	Water	µg	38.2	60
CxHy aromatic	Water	mg	46.9	59.1
CxHy chloro	Water	µg	31.1	43.8
cyanide	Water	µg	638	759
detergent/oil	Water	mg	5.22	7.95
di(2-ethylhexyl)phthalate	Water	ng	4.53	5.4
dibutyl p-phthalate	Water	ng	81	89.6
dibutylphthalate	Water	ng	8.42	13.2
dichloroethane	Water	µg	55.5	68.6
dichloromethane	Water	µg	691	803
dimethyl p-phthalate	Water	ng	511	565
dimethylphtalate	Water	ng	53	83.4
dioxins (TEQ)	Water	ng	90.9	93.6
dissolved organics	Water	mg	2.99	4.54
dissolved solids	Water	kg	2.87	3.11
dissolved substances	Water	g	25.2	39.5
DOC	Water	mg	46.1	54.4
ethyl benzene	Water	mg	1.2	1.49
fats/oils	Water	g	1.28	1.59
fatty acids as C	Water	mg	240	291
Fe	Water	g	3.56	4.65
fluoride ions	Water	mg	26.3	32.3
formaldehyde	Water	ng	242	299
glutaraldehyde	Water	µg	190	221
H2	Water	mg	2.62	2.62
H2S	Water	µg	71.3	87
H2SO4	Water	mg	82.2	104
heat losses	Water	kJ	19.5	30.7
hexachloroethane	Water	ng	1.09	1.29
Hg	Water	µg	25	28.9
HOCL	Water	mg	10.3	13.3
hydrazine	Water	mg	5.89	6.21
hydroxy (ions)	Water	ng	1.08	1.69
I	Water	mg	4.99	6.21
K	Water	mg	611	772
Kjeldahl-N	Water	mg	4.58	6.36
MBTE	Water	ng	22.6	35.5
metallic ions	Water	mg	637	758
methanol	Water	g	1.86	1.91
Mg	Water	g	1.09	1.39
Mn	Water	g	9.55	9.92

Mo	Water	mg	4.45	5.71
MTBE	Water	ng	171	194
N-tot	Water	g	150	153
N organically bound	Water	mg	7.87	9.93
Na	Water	g	33.2	42.6
NH3	Water	mg	103	111
NH3 (as N)	Water	mg	60.3	75.4
NH4+	Water	mg	38.2	52.2
Ni	Water	mg	12.4	16.2
nitrate	Water	mg	92.6	120
nitrite	Water	mg	2.46	3.17
nitrogen	Water	mg	478	751
OCl-	Water	mg	10	12.9
oil	Water	g	49.8	53.6
oil (animal/vegetable)	Water	pg	8.48	13.3
olefines	Water	μg	43	67.6
ortho-xylene	Water	μg	364	573
other organics	Water	g	7.92	8.48
P-compounds	Water	μg	41	47
PAH's	Water	μg	849	1.07
Pb	Water	mg	14.8	19.2
phenol	Water	mg	2.5	2.95
phenols	Water	mg	8.69	10.7
phosphate	Water	g	55.1	40.4
Phosphorus	Water	mg	2.6	2.82
Polychlorinated furans (PCDF)	Water	ng	78.9	81.3
Ru	Water	μg	497	618
S	Water	μg	9.44	14.8
salt	Water	mg	35.4	55.7
salts	Water	g	3.22	4.13
Sb	Water	μg	21.6	28.2
Se	Water	mg	6.16	7.89
Si	Water	mg	1.12	1.33
Sn	Water	μg	12.1	15.6
SO3	Water	mg	1.19	1.49
Sr	Water	mg	317	395
sulphate	Water	kg	2.1	2.17
sulphide	Water	mg	2.16	2.75
suspended solids	Water	kg	1.34	1.61
suspended substances	Water	g	8.81	12.7
tetrachloroethene	Water	ng	129	153
tetrachloromethane	Water	ng	196	234
Ti	Water	mg	71.4	91.4
titanium(IV)oxide	Water	pg	28.9	45.4
TOC	Water	g	2.32	2.96
toluene	Water	mg	8.35	10.3

tributyltin	Water	µg	77.7	100
tributyltinoxide	Water	µg	10.9	17.1
trichloroethene	Water	µg	9.3	11.5
trichloromethane	Water	µg	29.9	35.6
triethylene glycol	Water	mg	30.3	31.3
triethyleneglycol	Water	mg	2.54	4
undissolved substances	Water	g	5.54	6.21
V	Water	mg	7.22	9.09
vinyl chloride	Water	ng	36.5	43.6
VOC as C	Water	mg	16.1	19.6
W	Water	µg	54.8	70.4
xylene	Water	mg	4.58	5.53
Zn	Water	g	11.3	11.6
Abfaelle-Inertst.dep	Waste	g	3.94	6.19
Abfaelle-Restst.dep	Waste	mg	87.7	138
asbestos (tw)	Waste	ng	191	300
Bauspgut-Inertst.dep	Waste	mg	169	266
Beton-Inertst.dep	Waste	mg	131	205
Bohrabfall-Landf	Waste	mg	584	919
Bohrabfall-Rstst.dep	Waste	mg	977	1.54
bottom ash (mswi)	Waste	mg	21.5	33.9
chemical waste (inert)	Waste	mg	1.49	2.27
Deckfarbe-Inrtst.dep	Waste	ng	38.3	60.2
Depnrte-Flugasche	Waste	mg	242	381
diesel oil sludge (tw)	Waste	ng	111	175
Erdgasl-Inertst.dep	Waste	mg	27.4	43.1
FGC residues (mswi)	Waste	mg	2.05	3.22
final waste (inert)	Waste	g	47	73.9
fly ash (mswi)	Waste	mg	2.13	3.35
HgOH (tw)	Waste	pg	1.31	2.07
high active nuclear waste	Waste	mm3	0.0796	0.125
industrial waste	Waste	mg	3.73	5.68
inorganic general	Waste	mg	19.2	19.2
Kat-Sonderabfalldep	Waste	mg	4.07	6.41
Klkstrst-Inertst.dep	Waste	µg	26.6	41.9
Kupfer-Inertst.dep	Waste	µg	2.54	4
L/Mrad. waste (rw)	Waste	mm3	5.29	8.33
mineral waste	Waste	mg	306	466
mineral waste (mining)	Waste	g	207	273
Minwolle-Inertst.dep	Waste	µg	139	218
produc. waste (not inert)	Waste	mg	394	620
Rafschlamm-Landf	Waste	mg	4.88	7.67
Rckst-Entkrb-Restst.dep	Waste	mg	165	260
Rckst-Kuehlturmtassen	Waste	mg	13.5	21.2

Schweissstaub-Sabf	Waste	ng	30.7	48.2
slag	Waste	mg	21.9	21.9
slags/ash	Waste	mg	44.8	68.1
solid waste	Waste	kg	6.42	7.22
solid waste (nw)	Waste	mg	168	265
Stahl-Inertst.dep	Waste	mg	44.7	70.3
Steinkohle-Asche-Dep	Waste	mg	669	1.05
Steinkohleberge-Dep	Waste	g	25.8	40.6
tailings	Waste	g	4.44	6.99
tailings (nw)	Waste	µg	35.9	56.4
waste	Waste	mg	31.9	48.5
waste bioactive landfill	Waste	g	71.4	94.4
waste in incineration	Waste	g	1.13	1.49
waste in inert landfill	Waste	kg	41.1	44.2
waste limestone	Waste	g	20.4	21.1
Zeolithe-Inertst.dep	Waste	mg	2.43	3.83
Al (ind.)	Soil	mg	93.5	106
arsenic (ind.)	Soil	mg	198	209
As (ind.)	Soil	µg	37.3	42.4
benzo(a)anthracene (ind.)	Soil	µg	83.1	87.7
benzo(a)pyrene (ind.)	Soil	µg	45.3	47.8
benzo(b)fluoranthene (ind.)	Soil	µg	68	71.7
benzo(e)pyren (ind.)	Soil	µg	75.5	79.7
benzo[ghi]perylene (ind.)	Soil	µg	75.5	79.7
C (ind.)	Soil	mg	286	325
Ca (ind.)	Soil	mg	373	424
Cd (ind.)	Soil	ng	968	1.17
Co (ind.)	Soil	mg	288	304
Cr (ind.)	Soil	µg	467	530
Cr (VI) (ind.)	Soil	mg	970	1.02
Cu (ind.)	Soil	mg	810	854
dibenzo(a,h)anthracene (ind.)	Soil	µg	22.7	23.9
dibenzo(a,i)pyrene (ind.)	Soil	µg	7.55	7.97
dioxin (TEQ) (ind.)	Soil	pg	453	478
Fe (ind.)	Soil	mg	187	212
fluoranthene (ind.)	Soil	µg	60.4	63.8
Hg (ind.)	Soil	mg	1.81	1.91
indeno[1,2,3-cd]pyrene (ind.)	Soil	µg	15.1	15.9
Mn (ind.)	Soil	g	1.3	1.37
N	Soil	µg	51.4	62.6
Ni (ind.)	Soil	mg	664	701
oil	Soil	mg	3.03	4.77

oil (ind.)	Soil	mg	40.1	48.9
oil biodegradable	Soil	µg	168	209
oil biological	Soil	µg	5.95	9.36
P-tot	Soil	mg	4.74	5.39
Pb (ind.)	Soil	mg	317	334
perylene	Soil	µg	7.55	7.97
phenanthrene (ind.)	Soil	µg	695	733
pyrene	Soil	µg	90.6	95.6
S (ind.)	Soil	mg	56	63.7
selenium (ind.)	Soil	mg	60.8	64.1
vanadium (ind.)	Soil	g	1.47	1.55
Zn (ind.)	Soil	mg	679	717
Ag110m to air	Non mat.	µBq	25.5	32.7
Ag110m to water	Non mat.	mBq	174	224
agric, trad;5;6;15;12	Non mat.	cm2a	48.6	76.5
alpha radiation (unspecified) to water	Non mat.	µBq	20.7	26.6
Am241 to air	Non mat.	µBq	476	612
Am241 to water	Non mat.	mBq	62.7	80.6
Ar41 to air	Non mat.	Bq	55.5	71.4
Ba140 to air	Non mat.	µBq	99.8	128
Ba140 to water	Non mat.	µBq	313	402
beta radiation (unspecified) to air	Non mat.	µBq	3.2	4.11
C14 to air	Non mat.	Bq	38.2	49.1
C14 to water	Non mat.	Bq	3.17	4.07
Cd109 to water	Non mat.	µBq	1.81	2.32
Ce141 to air	Non mat.	µBq	2.38	3.06
Ce141 to water	Non mat.	µBq	46.8	60.1
Ce144 to air	Non mat.	mBq	5.07	6.51
Ce144 to water	Non mat.	Bq	1.43	1.84
Cm (alpha) to air	Non mat.	µBq	755	970
Cm (alpha) to water	Non mat.	mBq	83.1	107
Cm242 to air	Non mat.	nBq	2.52	3.24
Cm244 to air	Non mat.	nBq	22.8	29.3
Co57 to air	Non mat.	nBq	43.9	56.5
Co57 to water	Non mat.	µBq	320	411
Co58 to air	Non mat.	µBq	727	934
Co58 to water	Non mat.	mBq	271	348
Co60 to air	Non mat.	mBq	1.08	1.39
Co60 to water	Non mat.	Bq	13.9	17.8
Conv. to industrial area	Non mat.	mm2	1.8	1.8
Cr51 to air	Non mat.	µBq	89.8	115
Cr51 to water	Non mat.	mBq	6.88	8.84
Cs134 to air	Non mat.	mBq	18.1	23.2
Cs134 to water	Non mat.	Bq	3.21	4.12
Cs136 to water	Non mat.	µBq	1.68	2.16

Cs137 to air	Non mat.	mBq	34.9	44.9
Cs137 to water	Non mat.	Bq	29.5	37.9
drill gas, land;0;0;15;12	Non mat.	cm2a	22	34.6
drill gas,sea;15;12;15;12	Non mat.	m2a	0	0
drill oil, land;0;0;15;6	Non mat.	mm2a	486	765
drill oil, sea;15;6;15;6	Non mat.	m2a	0	0
dump hrw;0;0;15;12	Non mat.	m2s	42.9	67.4
dump lmrw;0;0;15;12	Non mat.	m2s	16.9	26.5
dump rw;0;0;15;12	Non mat.	cm2a	22.6	35.5
Fe59 to air	Non mat.	nBq	993	1.28
Fe59 to water	Non mat.	µBq	5.54	7.12
Fission and activation products (RA) to water	Non mat.	mBq	188	241
H3 to air	Non mat.	Bq	396	508
H3 to water	Non mat.	kBq	94	121
heat losses to air	Non mat.	MJ	3.91	6.14
heat losses to soil	Non mat.	J	633	996
heat losses to water	Non mat.	kJ	71.1	112
hydro;0;0;10;7	Non mat.	mm2a	78.2	123
I129 to air	Non mat.	mBq	136	175
I129 to water	Non mat.	Bq	9.07	11.7
I131 to air	Non mat.	mBq	15.1	19.4
I131 to water	Non mat.	mBq	6	7.71
I133 to air	Non mat.	mBq	8.45	10.9
I133 to water	Non mat.	mBq	1.43	1.84
I135 to air	Non mat.	mBq	12.7	16.3
indus;5;1;15;12	Non mat.	cm2a	11.2	17.7
K40 to air	Non mat.	mBq	71.4	91.7
K40 to water	Non mat.	mBq	228	292
Kr85 to air	Non mat.	kBq	2340	3000
Kr85m to air	Non mat.	Bq	2.76	3.54
Kr87 to air	Non mat.	Bq	1.24	1.59
Kr88 to air	Non mat.	Bq	111	142
Kr89 to air	Non mat.	mBq	867	1.11
La140 to air	Non mat.	µBq	63.2	81.2
La140 to water	Non mat.	µBq	64.9	83.4
land use (sea floor) II-III	Non mat.	m2a	0.116	0.132
land use (sea floor) II-IV	Non mat.	cm2a	120	136
land use II-III	Non mat.	m2a	0.242	0.311
land use II-III bento	Non mat.	cm2a	69.2	109
land use II-IV	Non mat.	cm2a	83.7	103
land use II-IV bento	Non mat.	mm2a	715	11.3
land use III-IV	Non mat.	cm2a	131	147
land use IV-IV	Non mat.	mm2a	971	10.6
minin Ni; 0;0;10;8	Non mat.	mm2a	232	365
minin rocks.;0;0;15;12	Non mat.	m2s	0.0652	0.103

minin U;0;0;17;8	Non mat.	m2s	326	513
mining coal;0;0;25;9	Non mat.	mm2a	971	15.3
Mn54 to air	Non mat.	µBq	25.9	33.3
Mn54 to water	Non mat.	Bq	2.13	2.73
Mo99 to water	Non mat.	µBq	21.9	28.1
Na24 to water	Non mat.	mBq	9.65	12.4
Nb95 to air	Non mat.	µBq	4.58	5.89
Nb95 to water	Non mat.	µBq	178	228
Np237 to air	Non mat.	nBq	25	32.1
Np237 to water	Non mat.	mBq	4	5.14
Occup. as industrial area	Non mat.	mm2a	487	487
Pa234m to air	Non mat.	mBq	15.1	19.4
Pa234m to water	Non mat.	mBq	280	360
Pb210 to air	Non mat.	mBq	419	538
Pb210 to water	Non mat.	mBq	181	233
pipel;5;0;15;12	Non mat.	cm2a	190	298
Pm147 to air	Non mat.	mBq	12.8	16.5
Po210 to air	Non mat.	mBq	627	806
Po210 to water	Non mat.	mBq	181	233
Pu alpha to air	Non mat.	mBq	1.51	1.94
Pu alpha to water	Non mat.	mBq	250	321
Pu238 to air	Non mat.	nBq	56.7	72.8
Pu241 beta	Non mat.	Bq	6.2	7.97
Pu241 Beta to air	Non mat.	mBq	41.4	53.3
Ra224 to water	Non mat.	Bq	2.3	2.81
Ra226 to air	Non mat.	mBq	539	693
Ra226 to water	Non mat.	kBq	1.16	1.49
Ra228 to air	Non mat.	mBq	35	45
Ra228 to water	Non mat.	Bq	4.61	5.61
Rad.air-Ag110m	Non mat.	nBq	752	1.18
Rad.air-Am241	Non mat.	µBq	5.79	9.1
Rad.air-Andere-Beta	Non mat.	nBq	18.4	28.9
Rad.air-Ar41	Non mat.	Bq	1.64	2.58
Rad.air-Ba140	Non mat.	µBq	1.24	1.96
Rad.air-C14	Non mat.	mBq	443	697
Rad.air-Ce141	Non mat.	nBq	22.5	35.4
Rad.air-Ce144	Non mat.	µBq	61.5	96.7
Rad.air-Cm-alpha	Non mat.	µBq	9.17	14.4
Rad.air-Cm242	Non mat.	nBq	0.0348	0.0547
Rad.air-Cm244	Non mat.	nBq	0.316	0.497
Rad.air-Co57	Non mat.	nBq	1.3	2.05
Rad.air-Co58	Non mat.	µBq	6.92	10.9
Rad.air-Co60	Non mat.	µBq	10.8	17
Rad.air-Cr51	Non mat.	nBq	984	1.55
Rad.air-Cs134	Non mat.	µBq	218	344
Rad.air-Cs137	Non mat.	µBq	422	664

Rad.air-Edelgase	Non mat.	mBq	8.66	13.6
Rad.air-Fe59	Non mat.	nBq	16.3	25.6
Rad.air-H3	Non mat.	Bq	4.49	7.06
Rad.air-I129	Non mat.	mBq	1.65	2.6
Rad.air-I131	Non mat.	µBq	246	387
Rad.air-I133	Non mat.	µBq	79.4	125
Rad.air-I135	Non mat.	µBq	119	188
Rad.air-K40	Non mat.	mBq	2.46	3.87
Rad.air-Kr85	Non mat.	kBq	28.4	44.7
Rad.air-Kr85m	Non mat.	mBq	38.2	60.1
Rad.air-Kr87	Non mat.	mBq	25.9	40.8
Rad.air-Kr88	Non mat.	Bq	1.05	1.65
Rad.air-Kr89	Non mat.	mBq	18.6	29.3
Rad.air-La140	Non mat.	nBq	621	976
Rad.air-LT-Rd-Rn222	Non mat.	kBq	41.3	64.9
Rad.air-Mn54	Non mat.	nBq	259	408
Rad.air-Nb95	Non mat.	nBq	115	180
Rad.air-Np237	Non mat.	nBq	0.302	0.475
Rad.air-Pa234m	Non mat.	µBq	185	292
Rad.air-Pb210	Non mat.	mBq	10.6	16.7
Rad.air-Pm147	Non mat.	µBq	156	246
Rad.air-Po-210	Non mat.	mBq	15.8	24.9
Rad.air-Po210	Non mat.	mBq	2.06	3.23
Rad.air-Pu-alpha	Non mat.	µBq	18.4	28.9
Rad.air-Pu238	Non mat.	nBq	0.886	1.39
Rad.air-Pu241-Beta	Non mat.	µBq	506	796
Rad.air-Ra226	Non mat.	mBq	8.01	12.6
Rad.air-Ra228	Non mat.	mBq	1.22	1.92
Rad.air-Rn220	Non mat.	mBq	310	488
Rad.air-Rn222	Non mat.	Bq	449	706
Rad.air-Ru103	Non mat.	nBq	7.87	12.4
Rad.air-Ru106	Non mat.	mBq	1.84	2.89
Rad.air-Sb124	Non mat.	nBq	190	299
Rad.air-Sb125	Non mat.	nBq	27.3	43
Rad.air-Sr89	Non mat.	nBq	415	653
Rad.air-Sr90	Non mat.	µBq	302	475
Rad.air-Tc99	Non mat.	nBq	12.8	20.2
Rad.air-Te123m	Non mat.	µBq	3.38	5.32
Rad.air-Th228	Non mat.	mBq	1.04	1.64
Rad.air-Th230	Non mat.	mBq	2.06	3.23
Rad.air-Th232	Non mat.	µBq	657	1.03
Rad.air-Th234	Non mat.	µBq	185	292
Rad.air-U-alpha	Non mat.	mBq	6.63	10.4
Rad.air-U234	Non mat.	mBq	2.22	3.49
Rad.air-U235	Non mat.	µBq	107	169
Rad.air-U238	Non mat.	mBq	4.06	6.38

Rad.air-Xe131m	Non mat.	mBq	172	271
Rad.air-Xe133	Non mat.	Bq	17	26.7
Rad.air-Xe133m	Non mat.	mBq	22.3	35.1
Rad.air-Xe135	Non mat.	Bq	3.08	4.85
Rad.air-Xe135m	Non mat.	mBq	577	908
Rad.air-Xe137	Non mat.	mBq	21.5	33.8
Rad.air-Xe138	Non mat.	mBq	157	248
Rad.air-Zn65	Non mat.	µBq	1.16	1.82
Rad.air-Zr95	Non mat.	nBq	43.9	69.1
Rad.wat-Ag110m	Non mat.	µBq	441	693
Rad.wat-Alpha-Strahler	Non mat.	nBq	217	341
Rad.wat-Am241	Non mat.	µBq	762	1.2
Rad.wat-Ba140	Non mat.	nBq	816	1.28
Rad.wat-C14	Non mat.	mBq	38.6	60.6
Rad.wat-Cd109	Non mat.	nBq	4.72	7.42
Rad.wat-Ce141	Non mat.	nBq	122	192
Rad.wat-Ce144	Non mat.	mBq	17.4	27.4
Rad.wat-Cm-alpha	Non mat.	mBq	1.01	1.59
Rad.wat-Co57	Non mat.	nBq	832	1.31
Rad.wat-Co58	Non mat.	µBq	697	1.1
Rad.wat-Co60	Non mat.	mBq	166	261
Rad.wat-Cr51	Non mat.	µBq	18	28.2
Rad.wat-Cs134	Non mat.	mBq	38.7	60.8
Rad.wat-Cs136	Non mat.	nBq	4.38	6.9
Rad.wat-Cs137	Non mat.	mBq	358	564
Rad.wat-Fe59	Non mat.	nBq	14.5	22.7
Rad.wat-H3	Non mat.	kBq	1.14	1.79
Rad.wat-I129	Non mat.	mBq	110	173
Rad.wat-I131	Non mat.	µBq	15.3	24.1
Rad.wat-I133	Non mat.	µBq	3.74	5.88
Rad.wat-K-40	Non mat.	mBq	39.9	62.8
Rad.wat-La140	Non mat.	nBq	169	266
Rad.wat-Mn54	Non mat.	mBq	25.7	40.4
Rad.wat-Mo99	Non mat.	nBq	56.8	89.3
Rad.wat-Na24	Non mat.	µBq	25.1	39.5
Rad.wat-Nb95	Non mat.	nBq	464	730
Rad.wat-Np237	Non mat.	µBq	48.6	76.4
Rad.wat-Nuklidmix	Non mat.	µBq	1.51	2.38
Rad.wat-Pa234m	Non mat.	mBq	3.44	5.4
Rad.wat-Pb-210	Non mat.	mBq	31.8	50.1
Rad.wat-Po-210	Non mat.	mBq	31.8	50.1
Rad.wat-Pu-alpha	Non mat.	mBq	3.02	4.75
Rad.wat-Pu241-beta	Non mat.	mBq	75.3	118
Rad.wat-Ra-224	Non mat.	mBq	175	275
Rad.wat-Ra-226	Non mat.	Bq	14.5	22.8
Rad.wat-Ra-228	Non mat.	mBq	349	549

Rad.wat-Ru103	Non mat.	nBq	273	430
Rad.wat-Ru106	Non mat.	mBq	184	289
Rad.wat-Sb122	Non mat.	nBq	816	1.28
Rad.wat-Sb124	Non mat.	µBq	114	179
Rad.wat-Sb125	Non mat.	µBq	6.66	10.5
Rad.wat-Sp-u-Activ-pr	Non mat.	mBq	8.61	13.5
Rad.wat-Sr89	Non mat.	µBq	1.85	2.91
Rad.wat-Sr90	Non mat.	mBq	36.7	57.8
Rad.wat-Tc99	Non mat.	mBq	19.3	30.3
Rad.wat-Tc99m	Non mat.	nBq	385	605
Rad.wat-Te123m	Non mat.	nBq	34.5	54.2
Rad.wat-Te132	Non mat.	nBq	14.1	22.2
Rad.wat-Th-228	Non mat.	mBq	699	1.1
Rad.wat-Th-232	Non mat.	mBq	7.44	11.7
Rad.wat-Th230	Non mat.	mBq	536	843
Rad.wat-Th234	Non mat.	mBq	3.46	5.43
Rad.wat-U-238	Non mat.	mBq	26	41
Rad.wat-U-alpha	Non mat.	mBq	224	353
Rad.wat-U234	Non mat.	mBq	4.56	7.18
Rad.wat-U235	Non mat.	mBq	6.84	10.8
Rad.wat-Y90	Non mat.	nBq	94.4	148
Rad.wat-Zn65	Non mat.	µBq	53.1	83.4
Rad.wat-Zr95	Non mat.	mBq	1.56	2.46
radio active noble gases to air	Non mat.	Bq	3.31	4.26
radioactive substance to air	Non mat.	kBq	4510	6010
radioactive substance to water	Non mat.	kBq	39.7	53
radionuclides (mixed) to water	Non mat.	µBq	136	174
Rn220 to air	Non mat.	Bq	3.31	4.26
Rn222 (long term) to air	Non mat.	kBq	3360	4310
Rn222 to air	Non mat.	kBq	36.6	47
Ru103 to air	Non mat.	nBq	259	333
Ru103 to water	Non mat.	µBq	105	135
Ru106 to air	Non mat.	mBq	151	194
Ru106 to water	Non mat.	Bq	15.1	19.4
Sb122 to water	Non mat.	µBq	313	402
Sb124 to air	Non mat.	µBq	7.01	9.01
Sb124 to water	Non mat.	mBq	44.9	57.7
Sb125 to air	Non mat.	nBq	892	1.15
Sb125 to water	Non mat.	mBq	2.55	3.28
Sr89 to air	Non mat.	µBq	45.4	58.3
Sr89 to water	Non mat.	µBq	707	908
Sr90 to air	Non mat.	mBq	25	32.1
Sr90 to water	Non mat.	Bq	3.03	3.89

Tc99 to air	Non mat.	µBq	1.06	1.36
Tc99 to water	Non mat.	Bq	1.59	2.04
Tc99m to water	Non mat.	µBq	147	189
Te123m to air	Non mat.	µBq	114	147
Te123m to water	Non mat.	µBq	13.2	16.9
Te132 to water	Non mat.	µBq	5.4	6.94
Th228 to air	Non mat.	mBq	29.7	38.1
Th228 to water	Non mat.	Bq	9.22	11.2
Th230 to air	Non mat.	mBq	168	216
Th230 to water	Non mat.	Bq	43.7	56.2
Th232 to air	Non mat.	mBq	18.8	24.1
Th232 to water	Non mat.	mBq	42.4	54.5
Th234 to air	Non mat.	mBq	15.1	19.4
Th234 to water	Non mat.	mBq	282	363
trans, canal;5;5;15;12	Non mat.	m2s	70.4	111
trans, roadNL;5;2;15;12	Non mat.	mm2a	69.5	109
trans,rail NL;5;2;15;12	Non mat.	mm2a	589	926
U alpha to air	Non mat.	mBq	542	696
U alpha to water	Non mat.	Bq	18.3	23.5
U234 to air	Non mat.	mBq	181	233
U234 to water	Non mat.	mBq	375	482
U235 to air	Non mat.	mBq	8.77	11.3
U235 to water	Non mat.	mBq	558	717
U238 to air	Non mat.	mBq	232	299
U238 to water	Non mat.	mBq	947	1.22
waste heat to air	Non mat.	MJ	110	134
waste heat to soil	Non mat.	kJ	202	252
waste heat to water	Non mat.	MJ	4.95	6.57
Xe131m to air	Non mat.	Bq	5.72	7.35
Xe133 to air	Non mat.	kBq	1.68	2.16
Xe133m to air	Non mat.	mBq	847	1.09
Xe135 to air	Non mat.	Bq	287	369
Xe135m to air	Non mat.	Bq	28.3	36.3
Xe137 to air	Non mat.	mBq	702	902
Xe138 to air	Non mat.	Bq	7.67	9.85
Y90 to water	Non mat.	µBq	36.2	46.5
Zn65 to air	Non mat.	µBq	111	143
Zn65 to water	Non mat.	mBq	20.4	26.1
Zr95 to air	Non mat.	µBq	1.66	2.13
Zr95 to water	Non mat.	mBq	128	165