A strategic framework for exploring alternative energy options in DND/CF

D. A. Neill
DRDC CORA

DRDC CORA TM 2009-010
March 2009

Defence R&D Canada
Centre for Operational Research & Analysis

ADM(S&T)

National Defence Défense nationale

Canada

A strategic framework for exploring alternative energy options in DND/CF

D.A. Neill
DRDC CORA

Defence R&D Canada – CORA

Technical Memorandum
DRDC CORA TM 2009-010
March 2009

Principal Author

Original signed by D.A. Neill, Ph.D.

D.A. Neill, Ph.D.

DRDC CORA Defence Scientist

Approved by

Original signed by Stephane Lefebvre

Stephane Lefebvre

DRDC CORA Section Head Strategic Analysis

Approved for release by

Original signed by Dale Reding

Dale Reding

DRDC CORA Chief Scientist

Sponsor: ADM(S&T)/DSTIC

Defence R&D Canada – Centre for Operational Research and Analysis (CORA)

Abstract

This study offers a strategic framework for the investigation of alternative energy sources by the Department of National Defence and the Canadian Forces. To this end, it consists of three chapters. An examination of the energy consumption patterns of DND/CF reveals that DND could derive the greatest benefits (in terms of reducing costs, reliance on fossil fuels, pollution and greenhouse gas emissions) by identifying and implementing non-fossil fuel, non-emitting alternative energy options to heat buildings, generate electricity, and provide motive power to naval vessels and aircraft. It assesses that the most promising technological options in these areas are geothermal heating and cooling for infrastructure; packaged nuclear reactors for electrical generation; and nuclear power for naval vessels. As there are no non-emitting, non-fossil-fuel alternatives to aviation fuel available at present, this would be a fruitful area for pure research. This study proposes a strategic framework for the investigation and assessment of alternative energy sources by DND/CF, consisting of a series of strategic principles, strategic priorities, strategic factors for consideration in developing any alternative energy program, and a number of caveats, and cautions that the cost and timelines involved in implementing significant technological changes across the entire Defence establishment require a robust, durable strategic rationale and careful, deliberate action by leaders and managers. The study concludes by providing some suggestions for further research and analysis, and recommends a governance structure for a way ahead based on an alternative energy research program championed by the Associate Deputy Minister, with Assistant Deputy Minister (Infrastructure and Environment) as the lead level one manager, and Assistant Deputy Minister (Science and Technology) as the key enabler.

Résumé

Ce document technique présente un cadre stratégique pour l'examen de sources d'énergie de remplacement par le ministère de la Défense nationale (MDN) et les Forces canadiennes (FC). Le document compte trois chapitres. Un examen des modes de consommation d'énergie au MDN/FC révèle que le MDN pourrait tirer profit (en terme de réduction des coûts, d'utilisation de combustibles fossiles, de réduction de la pollution et des émissions de gaz à effet de serre) en identifiant et en mettant en œuvre des moyens d'utiliser des combustibles autres que des combustibles fossiles, des options de consommation d'énergie renouvelable pour chauffer les bâtiments, produire de l'électricité et servir de force motrice pour les navires et les aéronefs. Il précise que les options technologiques les plus prometteuses sont le chauffage et la climatisation géothermiques pour les infrastructures; les réacteurs nucléaires pour la production d'électricité; et la propulsion nucléaire pour les navires militaires. Comme il n'existe, à l'heure actuelle, aucun carburant de remplacement qui serait sans émission ou exempt de combustible fossile pour les aéronefs, il s'agirait là d'un domaine dans lequel on pourrait orienter les recherches. Ce document technique propose un cadre stratégique pour l'examen et l'évaluation de sources d'énergie de remplacement par le MDN/FC, qui consiste à appliquer une série de principes, de priorités et de facteurs stratégiques, dont il faudra tenir compte dans l'élaboration de tout programme relatif aux énergies de remplacement. Il faudra également tenir compte d'un certain nombre de restrictions et prendre des précautions en ce qui a trait aux coûts et aux délais à prévoir pour la mise en œuvre de changements technologiques importants dans l'ensemble du ministère de la Défense, et cela nécessitera une justification stratégique solide et durable, ainsi que des actions prudentes et délibérées de la part des décideurs et des gestionnaires. Le présent document technique conclut en fournissant des suggestions relatives à la recherche et à l'analyse, et recommande une structure de gouvernance quant à la voie à suivre qui sera basée sur un programme de recherche sur les énergies de remplacement appuyé par le sous-ministre adjoint (Infrastructure et Environnement) à titre de gestionnaire de l'échelon 1, et le sous-ministre adjoint (Science et Technologie) à titre de facilitateur clé.

Executive summary

A strategic framework for exploring alternative energy options in DND/CF

D.A. Neill; DRDC CORA TM 2009-010; Defence R&D Canada – CORA; March 2009.

Introduction or background: The following study was undertaken in response to the identification, by Assistant Deputy Minister (Science and Technology), of "energy and the environment" as key areas of interest for the Defence research community. It is designed to provide a strategic framework for the investigation and assessment of alternative energy sources by the Department of National Defence and the Canadian Forces. To this end, it consists of three chapters. The first chapter examines the energy consumption patterns of DND/CF across the defence establishment in the context of the principal criteria identified in the project tasking: the dollar cost of energy to DND/CF; the extent to which DND/CF is reliant on fossil fuels; and the characteristics of the greenhouse gas (GHG) emission patterns (or "carbon footprint") of DND/CF. The second chapter looks at the available, near-term and emerging alternative energy technologies that DND/CF might leverage to reduce its energy costs, its reliance on fossil fuels, and its "carbon footprint," identifying the key advantages, disadvantages, and structural costs of each. The third chapter is aimed at crafting a strategic framework to guide the examination of alternative energy sources, and examines the spectrum of strategic principles, priorities, and caveats that should be taken into consideration by the Defence establishment as it moves to conduct research on, evaluate and eventually adopt new energy technologies.

Results: This study determines that the most expensive areas of energy consumption for DND/CF are aviation fuel and grid electricity. The use of natural gas for building heat, ship's fuel, and fuel for land vehicles consume equal portions of the Defence "energy budget." Eighty five percent of the energy consumed by DND/CF comes directly or indirectly from fossil fuels; major consumption areas are natural gas for building heat and aviation fuel. Fuel for naval vessels and land vehicles constitutes a smaller proportion of the Department's fossil fuel demands. Finally, DND/CF produces most of its GHG emissions through consumption of grid electricity, aviation fuel, the use of natural gas for building heat, and to a lesser extent, naval fuel. The study concludes, therefore, that DND could derive the greatest benefit from identifying and implementing non-fossil fuel, non-emitting alternatives for the production of building heat and grid electricity, and for providing motive power to naval vessels and aircraft. It assesses that the most promising technological options in these areas are geothermal heating and cooling for infrastructure; packaged nuclear reactors for electrical generation (and for ancillary heat); and nuclear power (and, to a less effective extent, biofuels produced from waste biomass) for naval vessels. It further assesses that there are, at present, no non-emitting, non-fossil-fuel alternatives to aviation fuel available, and that this, therefore, would be a fruitful area for pure research.

The study offers a number of overarching cautions, including that DND/CF should avoid biofuel options deriving from the use of food grains; that DND/CF will probably not be able to take cost-effective economic advantage of alternative energy options that do not prove to be economically viable for mainstream consumption; and that the start-up costs associated with the adoption of alternative energy technologies, while perhaps recoverable over time, will almost always be more expensive over the short term than continuing to use conventional power and energy technologies. The downstream adoption by Defence of any proposed alternative energy technology must be predicated upon a robust business case incorporating all costs and benefits.

On the basis of these cautions and the foregoing analysis, the study proposes a strategic framework for the investigation and assessment of alternative energy sources by DND/CF, consisting of a series of strategic principles, strategic priorities, strategic factors for consideration in developing any alternative energy program, and a number of caveats. Research into and the eventual adoption of alternative energy options should follow four strategic principles.

> **Operational Principle:** an alternative energy option must maintain or enhance the Department's ability to carry out its fundamental operational missions.
>
> **Cost Principle:** subject to the Operational Principle, an alternative energy option must provide power at a proportional cost equivalent to or lower than existing energy sources (taking into consideration the recovery of installation costs through lower operating and maintenance costs over the life cycle of the equipment). Business case analysis must take into account the fully-burdened costs of any proposed new technology. DND should exercise extreme caution when considering any alternative energy technology that has not proven competitive in the broader civilian economy.
>
> **Environmental Principle:** subject to the Cost Principle, an alternative energy option must have a net environmental impact no greater than existing energy sources.
>
> **Political-legal principle**: an alternative energy option must conform to legal, regulatory and policy constraints. Where these would preclude exploitation of an alternative energy option that meets the operational, cost and green principles, DND should be willing to seek changes to legislation, regulations or policy, as appropriate.

The study notes that these principles pose some internal conflicts and that decision-makers will have to decide how they should be prioritized, and in what order (and for what reasons) they may, if necessary, be abrogated. In terms of strategic priorities, the paper proposes focusing research and development efforts on identifying alternative energy options in the areas of environmental conditioning for DND/CF facilities; electrical generation for DND/CF facilities; and non-emitting, non-fossil-fuel means of vehicular propulsion, focussing on naval vessels, aircraft and land vehicles.

Significance: In undertaking any such research and development program, the Department will have to remain cognizant of a series of crucial strategic considerations, including (but not limited to) political, legal and regulatory factors, including public perception; the importance of maintaining the primacy of, and the Department's ability to execute, the Defence mission; avoiding any increase in pollution emissions, and reducing them wherever possible; the importance of working in close cooperation with allies, especially the US; the need to identify secure, sustainable and if possible, diverse alternative energy supplies; the importance of minimizing the environmental impact of activities (like military training) or pollutants (like persistent toxic chemicals) that are relatively unique to Defence; the financial imperative of providing power to Defence assets at consistent or, if possible, lower cost; and the need to ensure that any alternative energy program has, as a key priority, the goal of maintaining (or, if possible, enhancing) the operational effectiveness of Defence forces. The study further cautions that the cost and timelines involved in implementing significant technological changes across the entire Defence establishment entails a need for timely, but careful and deliberate, action by leaders and managers at all levels.

The study offers some suggestions for further research, including a variety of cost-benefit analyses for the incorporation of existing alternative solutions into present and planned infrastructure; engineering analyses to determine the feasibility of making use of emerging alternative energy options; operational research aimed at identifying areas where innovative alternative energy applications might achieve disproportionate results; pure and applied research to identify new energy alternatives, and to resolve outstanding technical problems with existing alternatives; and strategic analysis aimed at assessing, inter alia, the longer-term strategic implications of the widespread adoption of new energy sources by Canada, its allies, and its potential adversaries.

Considerations for implementation: This study recommends that the Associate Deputy Minister be asked to serve as the Departmental champion for the adoption of alternative energy solutions. Assistant Deputy Minister (Infrastructure and Environment) would be the logical lead level one manager, and the Environmental Chiefs of Staff (as the managers of the bulk of DND/CF infrastructure, where most of the Department's energy is consumed, and most of its GHG generated) will be vital partners. Assistant Deputy Minister (Science and Technology) will be the key level one enabler, and the coordinator for all scientific research and coordination of inter-allied cooperation.

This page intentionally left blank.

Sommaire

A strategic framework for exploring alternative energy options in DND/CF

D.A. Neill; DRDC CORA TM 2009-010; R & D pour la défense Canada – CORA; Mars 2009.

Introduction ou contexte: Le document technique suivant a été élaboré en réponse à l'identification, par le sous-ministre adjoint (Science et Technologie), de « l'énergie et de l'environnement » comme domaines d'intérêt clés pour le milieu de la recherche au ministère de la Défense. Il a pour but de fournir un cadre stratégique pour l'examen de sources d'énergie de remplacement par le ministère de la Défense nationale (MDN) et les Forces canadiennes (FC). Le document compte trois chapitres. Le premier chapitre examine les habitudes de consommation d'énergie du MDN/FC au ministère dans le contexte du principal critère identifié dans l'établissement des tâches du projet; le coût en dollars de l'énergie au MDN/FC; dans quelle mesure le MDN/FC se fie aux combustibles fossiles; et les caractéristiques des modes d'émission de gaz à effet de serre (GES) (ou « le bilan carbone ») du MDN/FC. Le deuxième chapitre porte sur les technologies d'énergie de remplacement disponibles, à moyen terme et émergentes, que le MDN/FC pourrait employer pour réduire ses coûts en énergie, sa dépendance aux combustibles fossiles et son « bilan carbone », et il précise les avantages, inconvénients et coûts pour chacun d'eux. Le troisième chapitre vise à élaborer un cadre stratégique visant à orienter l'examen des sources d'énergie de remplacement et à examiner l'éventail des principes, priorités et restrictions stratégiques qui devraient être pris en compte par la Défense dans la recherche, l'évaluation et éventuellement l'adoption de ces nouvelles technologies énergétiques.

Résultats: Le présent document technique détermine que les domaines de consommation d'énergie les plus coûteux pour le MDN/FC sont le carburant aviation et l'électricité de réseau. La consommation de gaz naturel pour le chauffage des bâtiments, du carburant des navires, et du carburant des véhicules terrestres compte des portions égales du budget d'énergie. 85% de l'énergie consommé par le Ministère est en forme des combustibles fossiles, surtout pour le chauffage des bâtiments, l'électricité de réseau et le carburant d'aviation; le carburant des navires et des véhicules terrestres constituent une portion plus petit de la demande pour les combustibles fossiles. La majeure partie des émissions de GES du Ministère provient de la consommation de l'électricité de réseau, le carburant d'aviation, et la consommation de gaz naturel pour le chauffage des bâtiments; l'utilisation de combustibles fossiles dans les systèmes de propulsion des navires militaires représente une moindre partie de la production de GES. Par conséquent, il conclut que le MDN pourrait tirer profit de l'identification et de la mise en œuvre de solutions utilisant des carburants de remplacement autres que les combustibles fossiles, des sources d'énergie sans émission pour chauffer les bâtiments et remplacer l'électricité de réseau et pour propulser les navires militaires et les aéronefs. Il précise que les options technologiques les plus prometteuses sont le chauffage et la climatisation géothermiques pour les infrastructures; les réacteurs nucléaires pour la production d'électricité (et pour chauffer les bâtiments auxiliaires); et la propulsion nucléaire pour les navires militaires (ainsi que, dans une moindre mesure, les biocarburants à partir de biomasse). Comme il n'existe, à l'heure actuelle, aucun carburant de remplacement qui serait sans émission ou exempt de combustible fossile pour les aéronefs, il s'agirait là d'un domaine dans lequel on pourrait orienter les recherches.

Le document technique mentionne un certain nombre de mises en garde très importantes, notamment que le MDN/FC devrait éviter des options de biocarburants dérivés de céréales vivrières, qu'il ne serait probablement pas capable de tirer profit sur le plan économique des options relatives aux énergies de remplacement qui ne s'avèrent pas économiquement viables pour la consommation grand public; et que les coûts de démarrage associés à l'adoption de technologies d'énergie de remplacement, bien qu'elles puissent être récupérables au fil du temps, seront toujours plus coûteuses à court terme que l'utilisation continue de sources d'électricité et de technologies classiques. L'adoption, par la Défense, de n'importe quelle technologie d'énergie de remplacement proposée doit être fondée sur une analyse de cas solide incluant tous les coûts et avantages.

À la lumière de ces mises en garde et de l'analyse des dispositions précédentes, le document propose un cadre stratégique pour l'examen et l'évaluation de sources d'énergie de remplacement par le MDN/FC, qui consiste à appliquer une série de principes, de priorités et de facteurs stratégiques, dont il faudra tenir compte dans l'élaboration de tout programme relatif aux énergies de remplacement. Il faudra également tenir compte d'un certain nombre de restrictions. La recherche relative à de nouvelles options d'énergie de remplacement et leur adoption éventuelle doit suivre les quatre grands principes suivants :

> **Principe opérationnel :** Les options relatives aux sources d'énergie de remplacement doivent maintenir ou améliorer la capacité du ministère à accomplir ses missions opérationnelles fondamentales.
>
> **Principe du coût d'origine :** pour ce qui est du principe opérationnel, les options relatives aux sources d'énergie de remplacement doivent fournir de l'électricité à un coût proportionnel équivalent ou inférieur aux sources d'énergie existantes (compte tenu de la récupération des coûts d'installation et en établissant des coûts d'exploitation et d'entretien moins élevés, pendant la durée de vie utile de l'équipement). L'analyse de cas doit tenir compte des coûts imputés de n'importe quelle nouvelle technologie proposée. Le MDN doit faire preuve d'une extrême prudence au moment d'envisager des technologies d'énergie de remplacement qui ne s'est pas avérée concurrentielle dans des économies civiles plus générales.
>
> **Principe écologique :** pour ce qui est du principe du coût d'origine, les options relatives aux sources d'énergie de remplacement doivent avoir une incidence nette sur l'environnement qui n'est pas supérieure à celle des autres sources d'énergie existantes.
>
> **Principe politico-juridique** : une option d'énergie de remplacement doit respecter les contraintes juridiques et réglementaires, ainsi que les contraintes relatives aux politiques. Lorsque celles-ci empêchent le recours à une option d'énergie de remplacement qui satisfait aux principes opérationnels, financiers et écologiques, le MDN devrait être prêt à apporter des changements aux dispositions législatives, à la réglementation ou aux politiques, s'il y a lieu.

Le présent document technique fait remarquer que ces principes entraînent certains conflits internes et que les décideurs auront à déterminer comment établir les priorités et à déterminer dans quel ordre (en fournissant les raisons) il devrait, si cela est nécessaire, être abrogés. Pour ce qui est des priorités stratégiques, le document technique propose de cibler les efforts de recherche et développement sur l'identification d'options d'énergie de remplacement dans les domaines du conditionnement environnemental des installations du MDN/FC; de la production d'électricité pour les installations du MDN/FC; de modes de propulsion des véhicules n'utilisant pas de combustibles fossiles et ne produisant pas d'émissions, principalement dans le cas des navires militaires, des aéronefs et des véhicules terrestres.

Importance: Dans le cadre de ces programmes de recherche et développement, le Ministère doit demeurer intéressé aux considérations stratégiques cruciales, y compris (sans toutefois s'y limiter) les facteurs politiques, juridiques et réglementaires, incluant la perception du public, l'importance de maintenir la prépondérance de la capacité du Ministère à exécuter la mission de la Défense; l'évitement de toute augmentation des émissions polluantes et leur réduction, lorsque cela est possible; l'importance de travailler en collaboration étroite avec les Alliés, particulièrement les États-Unis; la nécessité d'identifier différentes sources d'énergie sûres, durables et, si possible, diversifiées; l'importance de réduire au minimum les incidences environnementales des activités (comme la formation militaire) ou les polluants (comme les produits chimiques toxiques persistants) qui sont propres à la Défense; l'impératif financier de fournir de l'électricité aux installations de la Défense à un coût de revient intéressant ou, si possible, à un coût moindre; produits chimiques toxiques); et la nécessité de s'assurer que tout programme d'énergie de remplacement a pour but principal de maintenir (ou, si possible, d'améliorer) l'efficacité opérationnelle des forces de défense. Le document technique contient des mises en garde à l'effet que le coût et les échéanciers associés à la mise en œuvre de changements technologiques importants dans l'ensemble du Ministère comprennent des actions opportunes, mais prudentes et délibérées, prises par les dirigeants à tous les niveaux.

Le document technique conclut en fournissant quelques suggestions pour la recherche à venir, y compris diverses analyses coûts-avantages en vue d'intégrer les solutions de remplacement existantes dans l'infrastructure actuelle et à venir; des analyses techniques visant à déterminer la faisabilité du recours à des options d'énergie de remplacement émergentes; de la recherche opérationnelle visant à identifier les domaines où des applications innovatrices utilisant des sources d'énergie de remplacement pourraient permettre d'atteindre des résultats performants; de la recherche pure et appliquée ayant pour but d'identifier de nouvelles sources d'énergie de remplacement et de résoudre les problèmes techniques non réglés associés aux sources d'énergie de remplacement; et des analyses stratégiques visant à évaluer, entre autres choses, les implications stratégiques à long terme de l'adoption répandue de nouvelles sources d'énergie par le Canada, ses alliés et ses adversaires potentiels.

Perspectives: Le présent document technique recommande que l'on demande au sous-ministre associé d'être le responsable ministériel pour ce qui est de l'adoption de solutions d'énergie de remplacement. Le sous-ministre adjoint (Infrastructure et Environnement) serait le gestionnaire de l'échelon 1, et les chefs d'état-major d'armée (à titre de gestionnaires de l'infrastructure globale du MDN/FC, où est consommée la majeure partie des ressources énergétiques du Ministère et où sont générées la plupart des émissions de GES) seront des partenaires importants. Le sous-ministre adjoint (Science et Technologie) agira comme facilitateur clé de l'échelon 1 et comme coordonnateur de toutes les activités de recherche et de coordination des la collaboration multinationale.

This page intentionally left blank.

Table of contents

List of figures

List of tables

1 Introduction

The following study has been undertaken in response to the identification, by Assistant Deputy Minister (Science and Technology), of energy and the environment as important future challenges for the Defence Research community: "… a future challenge for modern military forces includes finding solutions for lower energy consumption by reducing reliance on fossil fuels through technology advances, and mitigating environmental impacts of CF operations." ADM(S&T) directed that scooping work be undertaken to "frame a long-term study regarding DND/CF environmental impacts and sustainability (such as carbon footprint and related environmental effects) by identifying key challenges and opportunities to 'going green'."

This study aims to meet this requirement by devising a strategic framework to guide the investigation and assessment by the Department of National Defence and the Canadian Forces (DND/CF) of alternative energy sources to meet the Defence establishment's power needs. To this end, it consists of three chapters. The first chapter ("Energy and Defence") examines the energy consumption patterns of DND/CF across the full spectrum of defence activities in the context of the principal criteria identified in the project tasking: the dollar cost of energy to DND/CF; the extent to which DND/CF is reliant on fossil fuels; and the characteristics of the GHG emission patterns (or "carbon footprint") of DND/CF. The second chapter ("Energy alternatives for Defence") looks at the available, near-term and emerging alternative energy technologies that DND/CF might leverage to reduce its energy costs, its reliance on fossil fuels, and its "carbon footprint," identifying the key advantages, disadvantages, and structural costs of each. The third chapter ("Exploring alternative energy options") is aimed at crafting a strategic framework to guide the examination and adoption of alternative energy sources, and examines the spectrum of strategic principles, priorities, and caveats that should be taken into consideration by the Defence establishment as it moves to conduct research on, evaluate and possibly adopt new energy technologies. On the basis of the judgements derived from these three chapters, the conclusion recommends a comprehensive strategic approach to alternative energy, and offers suggestions as to where further research into alternative energy options should be targeted, and how it might best be effected through existing governance structures.

Concerning carbon dioxide. Policies aimed at curtailing GHG emissions are founded on the anthropogenic global warming (AGW) thesis, the essence of which is the contention that human-produced carbon dioxide is the principal driver of climate change. There are serious and growing concerns about the scientific validity of this thesis. As one critic of the AGW thesis has said, "We must get the science right, or we shall get the policy wrong."

The "global warming debate" notwithstanding, there are many valid strategic reasons for investigating alternatives to fossil fuels, including, but not limited to, cost; availability; pollution (e.g., sulphur and nitrous compounds and heavy metals, and the environmental impact of refining operations); supply-line vulnerability; the ever-increasing importance of hydrocarbons as chemical feedstock; and the reliance on oil revenue of unstable or untrustworthy regimes that export Islamic extremism and support jihadist terrorism. The identification and exploitation of alternative energy sources could have a positive impact in all of these key strategic areas.

2 Energy and Defence

In executing the Defence mission during Fiscal Year (FY) 2007/2008—driving vehicles, flying aircraft, sailing ships, cooking food, heating and powering buildings, engaging and destroying enemy targets, etc.—DND/CF, according to statistics gathered by Assistant Deputy Minister (Infrastructure and Environment)(ADM(IE)), consumed a little over 22 Petajoules (PJ) of energy. This is roughly the amount of energy contained in five hundred thousand tonnes—half a billion litres—of oil. Put in those terms, it sounds like a great deal. Looked at from a national perspective, however, this is not an enormous amount of energy; that much could be transported by two super tankers. DND/CF consumed a little more than one-tenth of one percent of all the energy consumed by Canada in the form of primary fuels in a single year.[1] According to government figures, in 2006 Canada produced 16,796 Petajoules of energy—more than 750 times as much energy as the entire Department consumed.[2] The Defence establishment consumes a lot of energy, but in reality it is very much a bit player in Canada's broader energy production and consumption picture.

Aggregate energy consumption figures like "a little over 22 Petajoules," however, do not tell us much about where and how DND/CF consumes this energy, what we get out of it, and what it costs us, both in financial expenditures and in terms of environmental impact. The aim of this chapter, therefore, is to put the Department's energy consumption statistics into a useful context, in order to enable us to address the rest of the questions posed in this study. To gain a better understanding of how alternative energy sources might be leveraged to reduce the cost of energy to DND/CF, it is necessary to understand how much is spent on energy, and where the largest expenditures tend to accumulate. To address the political imperative to reduce reliance on fossil fuels, it is necessary to examine what proportion of Defence's energy consumption derives from fossil fuels, and where the largest concentrations of fossil fuel dependence may be found. And finally, in order to seek means of reducing the Department's "carbon footprint," one must first examine which energy sources produce carbon emissions;[3] how much they produce; and where those emissions tend to cluster in terms of Defence activities. The following sections will examine these questions, suggesting areas where the integration of alternative energy sources might produce the greatest benefits in terms of reducing costs, reducing reliance on fossil fuels, and reducing carbon emissions.

---

[1] Canada consumed approximately 321.7M barrels of oil equivalent in 2007. This equates to about 13.5 Exajoules of primary energy. See *Statistical Review of World Energy 2008* (London: British Petroleum, 2008), p. 40.

[2] Data derived from the Statistics Canada website at http://www.sc.gc.ca. Where DND plays a relevant role in energy terms, however, is as a proportion of the total energy consumed by "public administration" in Canada—127 PJ. Defence, it would appear, consumes approximately 1/6th of all energy consumed by Government.

[3] "Carbon emissions" is not a scientific term. Combustion of hydrocarbons produces a variety of molecules containing carbon atoms, including but not limited to carbon monoxide, carbon dioxide, and unburned fuel, as well as nitrous oxides, heavy metals and metal oxides, and so forth. For the purposes of this paper, "carbon emissions" will refer to carbon dioxide. Where quantified, the most commonly used measure is "tons of carbon dioxide equivalent", abbreviated as "t CO_2 eq."

2.1 Defence energy (I): the big picture

2.1.1 Question 1: The cost of energy to DND/CF

According to Treasury Board figures, the planned Departmental spending figures for Defence in FY 2007/08 was $17.845B, with an additional $3.908B in capital spending, for a total budget of $21.753B.[4] This helps put DND/CF expenditures on energy into proper context. According to data derived by ADM(IE) from the Financial Management and Accounting System (FMAS), the Department spent slightly more than $321M on energy from all sources in FY 2007/08. Energy expenditures therefore represented approximately 1.5% of the Defence budget in FY 2007/08 (figure 1).[5]

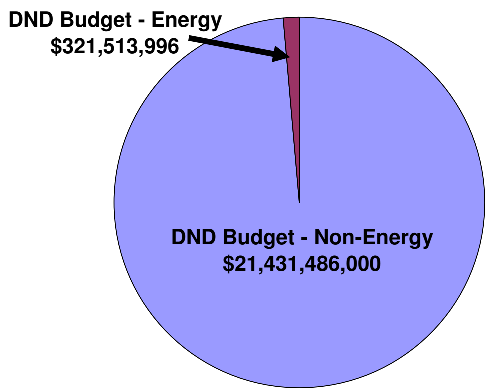

Figure 1- Energy as a proportion of the Defence budget FY 2007/08

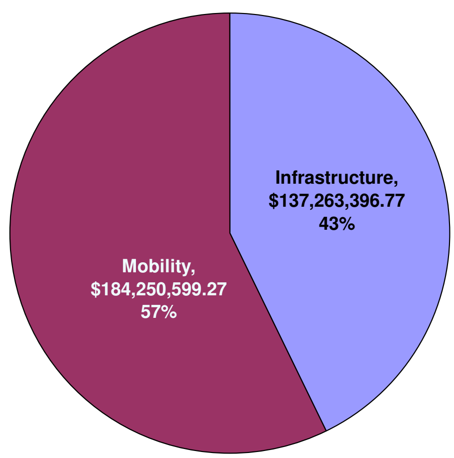

Figure 2 - Defence energy dollars FY 2007/08

[4] Department of National Defence, *2007-08 Report on Plans and Priorities*, accessed at http://www.tbs-sct.gc.ca/rpp/0708/nd-dn/nd-dn01-eng.asp#_Toc160251299.

[5] The figures derived from the FMAS are not validated to accounting standards; ADM(IE) notes that they are dependent on information reported by units, and are thus subject to errors, e.g., purchases recorded erroneously. However, they are sufficiently accurate for orders-of-magnitude comparisons.

This total breaks down further into two major areas of activity: energy consumed for mobility purposes, and energy consumed by infrastructure. In FY 2007/08, energy consumed by infrastructure accounted for approximately $137M in expenditures (roughly 43% of all energy costs), while energy consumed for mobility purposes (air, ground and sea movement) accounted for approximately $184M (57% of all energy costs). Figure 2 shows this breakdown.

Where infrastructure is concerned, the principal energy costs accrue from the use of electricity purchased from local grids, natural gas, liquid fuel for heating/cooking/power generation purposes, and heavy fuel oil.[6] For mobility tasks, the principal sources of energy are aviation fuel, diesel fuel, gasoline and ship's fuel. While infrastructure and mobility requirements are heavily dependent on fossil fuels, there is virtually no intersection between the fuel types required for operations and maintenance of infrastructure, and mobility operations. Mobility tasks require liquid distillate fuels, whereas infrastructure is supported mostly through natural gas (for building heat) and grid electricity.

Figures 3 and 4 provide a comparison of the dollar cost of purchasing energy to support, respectively, infrastructure and mobility operations in FY 2007/08. Within the realm of infrastructure maintenance and operations, grid electricity accounts for nearly half of all energy costs, while natural gas accounts for nearly one-third. Liquid fuels for heating, cooking and the provision of power, including heavy fuel oil (consumed by central heating plants) account for one-fifth of costs.

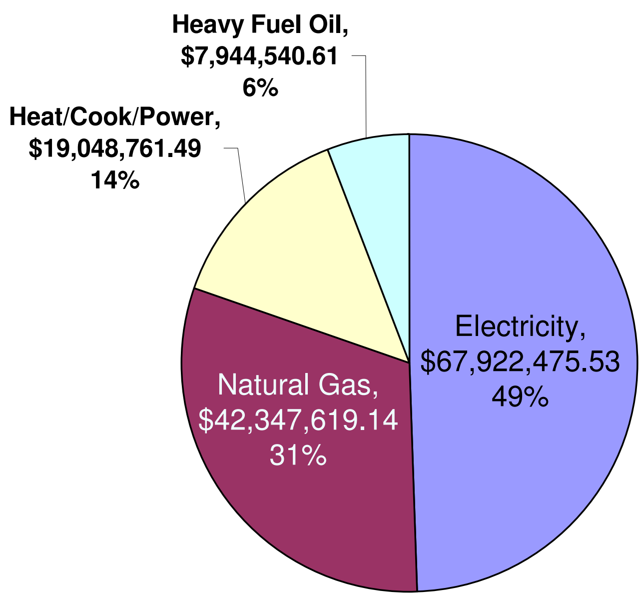

Figure 3 - Energy cost by source (Infrastructure - $137.3M) FY 2007/08

[6] ADM(IE) notes that while these figures provide a generally accurate picture of the breakdown of energy consumption by activities and fuel types, some recording methods lead to counterintuitive results. For example, CFS Alert generates electrical power locally using diesel fuel flown in from Thule, Greenland. This fuel is captured under mobility fuel expenditures and CAS, rather than infrastructure fuel expenditures.

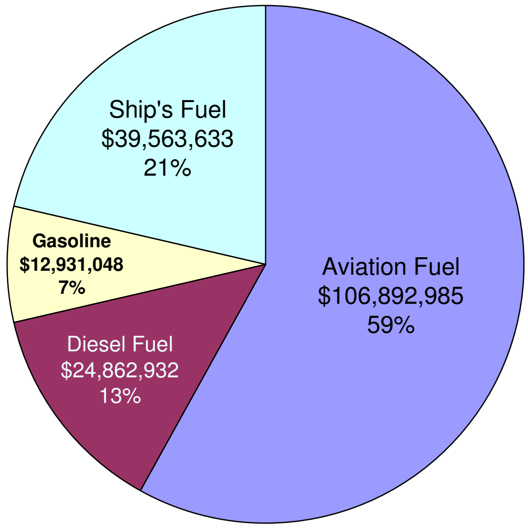

Figure 4 - Energy cost by source (Mobility - $184.3M) FY 2007/08

Where mobility operations are concerned, aviation fuel accounts for close to three-fifths of all costs; ship's fuel for about one-fifth; and land vehicle fuel (diesel and gasoline) for about one-fifth.

Figure 5 combines these two charts to offer a comparison of the relative cost of different energy sources across the Defence establishment. From a perspective of the total cost of energy to DND/CF, aviation fuel is the single most expensive item, accounting for about one-third of all DND/CF energy expenditures. This is followed by grid electricity (21%), natural gas (13%), and ship's fuel (12%). All other energy sources combined—diesel, gasoline, heavy fuel oil and liquid fuels (e.g., propane) for heating, cooking and power—account for about one-fifth of the Department's energy costs.

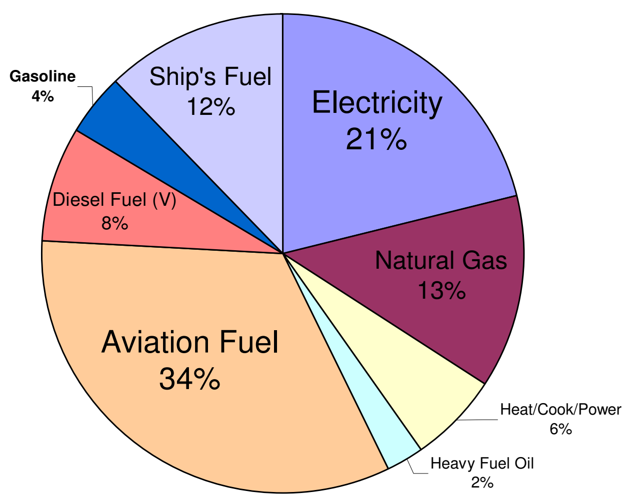

Figure 5 - Relative cost of different energy sources used by DND/CF, FY 2007/08

It is worth noting that increases and declines in the cost of energy over the past decade have had relatively little impact on how these costs are distributed. This reflects the stability of technologies used for mobility and infrastructure support. To a certain extent, there has been some change; for example, the move towards a single-fuelled vehicle fleet has led to a very slight decline in gasoline consumption as a proportion of overall fuel consumption; but aircraft still require aviation fuel, and military pattern vehicles and warships still burn diesel. Consumption patterns between fuels only change significantly when fleets change, and then only if the underlying technology changes drastically. The energy consumption patterns of infrastructure show a similar stability. DND/CF uses less heavy fuel oil for infrastructure heating now than several decades ago, but electrical consumption patterns are relatively unchanged. The overall combined consumption picture remains remarkably stable. A decade ago, in FY 98/99, grid electricity accounted for approximately 22% of the Department's total energy costs, while aviation fuel accounted for 48%. Absent significant changes in the way the Department builds, renovates, heats and powers its infrastructure, or in the power components of air, naval and ground vehicle fleets, the proportional breakdown of energy costs is likely to remain similar to figure 5 for the foreseeable future.

Accordingly, the best targets for cost savings through incorporation of alternative energy sources (to the extent that these are available) are aviation fuel; grid electricity; natural gas; ship's fuel; ground vehicle fuels (diesel and gasoline); and liquid fuels for heating, cooking and power generation.

2.1.2 Question 2: What sorts of energy does Defence consume?

As will be obvious from the charts provided above, DND/CF derives a large proportion of its overall energy requirements from fossil fuels. Figures 6 and 7 break down where energy is consumed in the Defence establishment, and from what sources that energy comes.

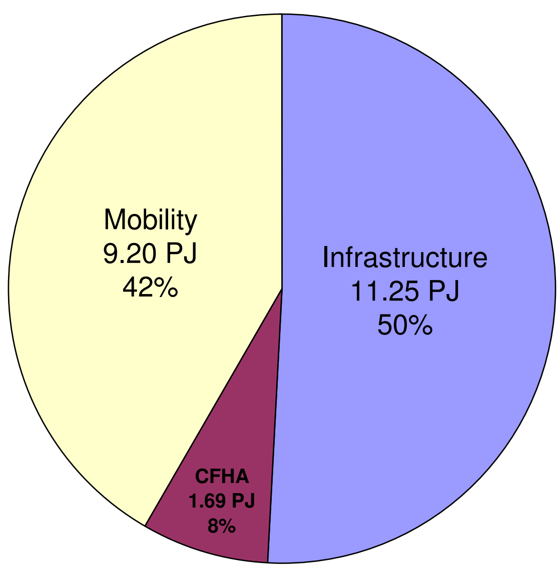

Figure 6 - Energy Consumption in DND/CF (quantity) FY 2007/08

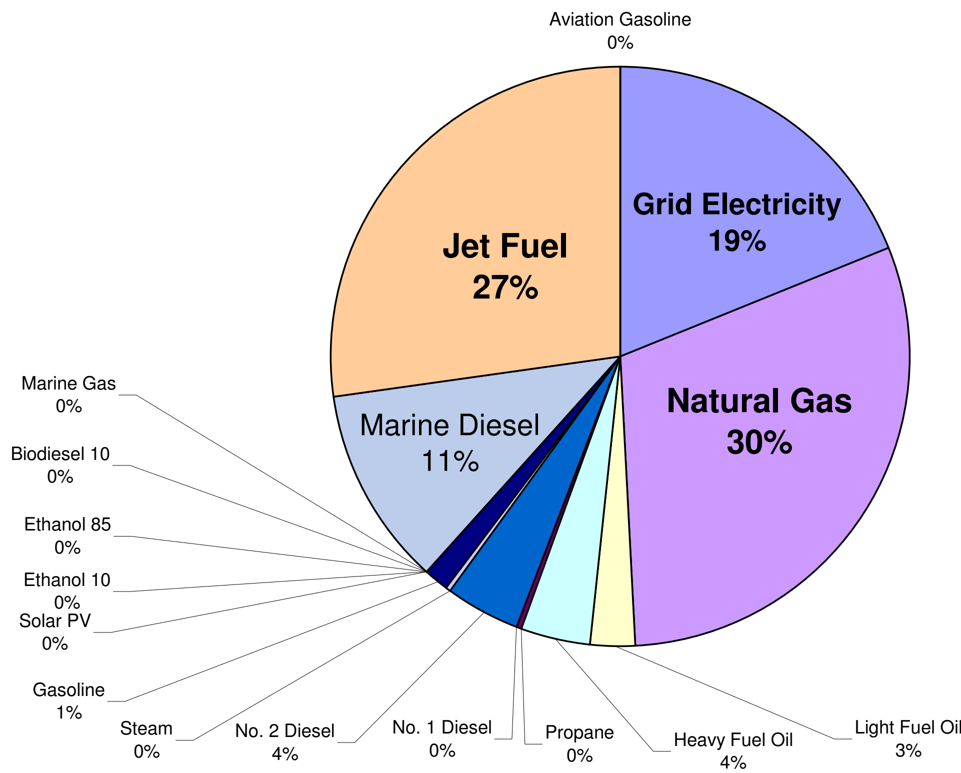

Figure 7 - Energy Consumption in DND/CF by energy type (quantity) FY 2007/08

Figure 8 demonstrates the extent to which Defence activities depend on consumption of fossil fuels. DND/CF consumes roughly 81% of its energy in direct consumption of fossil fuels, and about 19% in grid electricity.

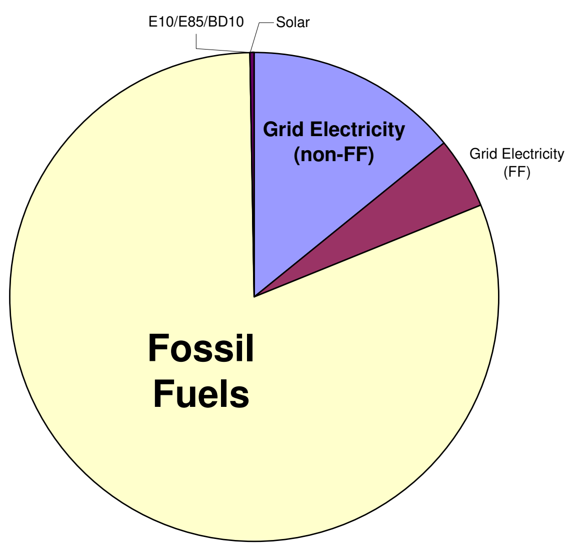

Figure 8 - Fossil fuel vs. Grid electricity consumed by DND/CF, FY 2007/08

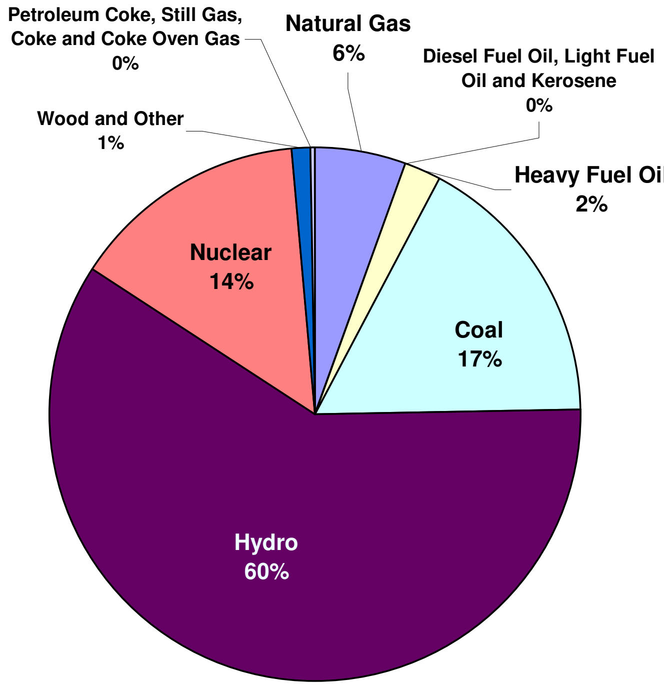

Figure 9 - Energy sources for generated electricity in Canada (2005) [7]

However, this proportion must be further broken down, as the manner in which grid electricity is produced in Canada varies regionally. In Quebec, for example, most grid electricity is produced via hydroelectric generation, whereas elsewhere in the country, a significant proportion of grid electricity is produced by burning fossil fuels or through nuclear generation.

Available data do not capture the origin of grid electricity consumed by DND/CF. However, because DND/CF maintains a nationwide presence, it is reasonable to posit that the grid electricity consumed by Defence is derived from the same proportional balance of energy sources as Canadian grid electricity in general. According to the Office of Energy Efficiency at Natural Resources Canada, fossil fuels account for approximately 25% of the electricity generated in Canada (see figure 9). Taking this proportional distribution into consideration, it may be seen that of the 22 PJ of energy consumed by DND/CF in FY 2007/08, roughly 85% came from direct or indirect consumption of fossil fuels, and roughly 14% from non-fossil fuel sources. Clearly there is plenty of scope for reducing the Defence establishment's overall reliance on fossil fuels to meet its energy needs.

As mobility tasks account for about two-fifths of the energy consumed by the Defence establishment, it is worthwhile to further examine the consumption patterns in this area of activity. Table 1 provides the quantities of energy consumed for mobility purposes in FY 2007/08; figure 10 displays this information in graphical format.

---

[7] Office of Energy Efficiency, Natural Resources Canada, "Energy Use and Generation by Energy Source," accessed at http://www.oee.nrcan.gc.ca/corporate/statistics/neud/dpa/tableshandbook2/egen_00_1_e_2.cfm?attr=0.

Table 1 - Fuel consumption for mobility purposes, FY 2007/08

Ser	Mobility Fuels	MJ
1	Propane	2282178
2	Diesel	726092953
3	Gasoline	313564584
4	Ethanol 10	25436704
5	Ethanol 85	20081
6	Biodiesel 10	8016120
7	Marine Gas	1135358
8	Marine Diesel	2428921895
9	Aviation Turbo[8]	5688796361
10	Aviation Gas	5642579
11	**TOTAL**	**9199908813 (9.2 PJ)**

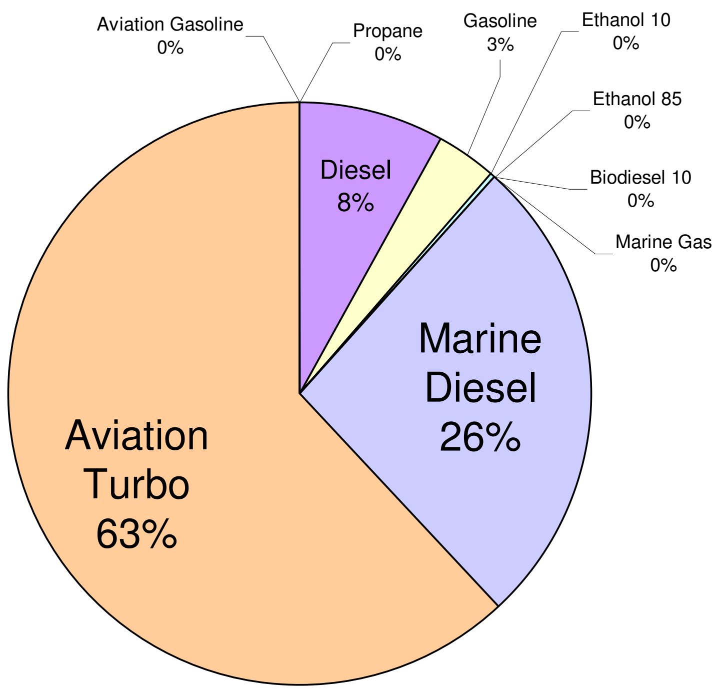

Figure 10 - Fuel consumption for mobility purposes, FY 2007/08

This breakdown helps to demonstrate where DND consumes energy for mobility purposes. The vast majority—nearly two-thirds—is consumed in the form of jet fuel. About one-quarter is consumed in the form of marine diesel fuel, and about one-twelfth in the form of diesel fuel consumed by land vehicles. Gasoline accounts for only about three percent of all of the energy consumed by DND/CF for mobility purposes. Clearly the greatest scope for replacement of energy from fossil fuels by alternative energy sources lies in the areas of jet and ship's fuel; and, to a considerably lesser extent, in the area of fuel for land vehicles (diesel and gasoline).

[8] The terms "Aviation Turbo" and "Jet Fuel" are used interchangeably throughout this study, as they are in the references. Both refer to JP-8.

In terms of total energy consumed, it would appear, from figures 7, 8 and 10, that DND/CF could make the greatest progress in reducing its heavy dependence on fossil fuels by reducing consumption in those areas where the Department relies most heavily on them: in the areas of natural gas, jet fuel, marine diesel fuel, and grid electricity. However, neither total consumption nor total cost tells the whole story; the cost-effectiveness of any energy source is a function of how much you get for what you pay. A comparison of energy consumption to cost figures on a Department-wide basis (see table 2) provides a useful benchmark for determining the relative cost-efficiency of the various forms of energy that DND/CF purchases on an annual basis.

Table 2 - Cost-effectiveness of the principal energy sources used by DND/CF, FY 2007/08

Ser	Energy Source	Total (MJ)	Cost ($)	Cost-Efficiency (MJ/$)
1	Natural Gas	6699083838	42347619	158
2	Heavy Oil	844101420	7944540	106
3	Grid Electricity	4178116372	67922475	62
4	Ship's Fuel	2430057252	39563633	61
5	Aviation Fuel	6046320940	106892985	57
6	Diesel	937930912	24862932	38
7	Infrastructure Fuels[9]	672482156	19048761	35
8	Gasoline	339022062	12931048	26

This comparison serves to demonstrate that DND/CF receives gets more for its energy dollar from some fuel sources than from others. Natural gas, heavy oil and grid electricity, all of which are purchased locally and in bulk, tend to be more most-effective than the fuels used for mobility purposes, which often entail costs arising from the need to transport fuels to the point of consumption. The purpose of this comparison is merely to note that, all other things being equal, DND would glean more financial benefit from identifying alternatives to cost-inefficient fuels like gasoline and diesel, than from attempting to replace cost-efficient fuels like natural gas. That said, of course, all other things are not usually equal.

At the end of the day, it should surprise no-one that DND relies heavily on fossil fuels to meet the bulk of its energy needs. From a perspective of gross energy consumed, the focus for reduction of fossil fuel reliance should logically be on natural gas, aviation fuel, and marine fuel, as these are the largest single fossil fuel consumption areas. However, from a perspective of cost-effectiveness, the Defence establishment gets better energy-per-dollar value from natural gas, heavy fuel oils, and ship's fuel, and may wish to focus its fossil fuel replacement efforts on areas where it gets less value for its energy dollar, e.g., gasoline, diesel, aviation fuels, and the liquid or other fuels used to provide heating, cooking and power at defence facilities.

2.1.3 Question 3: Carbon emissions

The anthropogenic global warming (AGW) thesis postulates, first, that the world is at present undergoing historically unprecedented warming; and second, that human production of carbon dioxide is the principal cause of this. On the basis of this thesis, governments worldwide are

[9] This term refers to the variety of liquid and compressed gas fuels used for heating, cooking, local power generation, etc.

pursuing—with greatly varying degrees of vigour—policies designed to curb carbon dioxide emissions. This section examines DND/CF's calculated "carbon footprint" on the basis of how and where energy is consumed, in order to determine where the adoption of alternative energy sources might be most effective in helping to reduce the Department's aggregate carbon dioxide emissions.[10]

Table 3 - CO2 production of the principal energy sources used by DND/CF, FY 2007/08[11]

Ser	Energy Source	Quantity	Units	kg CO2/Unit	t CO2 Eq	%
1	Grid Electricity[12]	1160587881	kWh	0.5418	628807	35.21%
2	Aviation Turbo	168123528	L	2.62298	440985	24.69%
3	Natural Gas	175875134	m3	1.902	334515	18.73%
4	Marine Diesel	62795292	L	2.858	179469	10.05%
5	No. 2 Diesel	24041230	L	2.8567	68679	3.85%
6	Heavy Fuel Oil	20227688	L	3.1023	62752	3.51%
7	Light Fuel Oil	15329690	L	2.8397	43532	2.44%
8	Gasoline	9046892	L	2.434	22020	1.23%
9	Steam	32795048	lb	0.0813	2666	0.15%
10	Propane	1470169	L	1.5439	2270	0.13%
11	Ethanol 10	760667	L	2.2098	1681	0.09%
12	Biodiesel 10	209517	L	2.5	524	0.03%
13	Aviation Gasoline	167834	L	2.44729	411	0.02%
14	No. 1 Diesel	9200	L	2.5597	24	0.00%
15	Solar PV	13606	L	0	0	0.00%
16	Ethanol 85	825	L	0.42	0	0.00%
17	Marine Gasoline	32757	L	2.4077	79	0.00%
18	**TOTAL**				**1788412**	

Table 3 shows the calculated greenhouse gas production for the amount and types of energy consumed by DND/CF in FY 2007/08. Once again, the energy consumption figures are derived

[10] Although, as has been noted above, combustion produces many emissions other than carbon dioxide, data are not available on the aggregate non-carbon emissions generated by DND/CF's consumption of power and energy. Moreover, "carbon emissions" are the only emissions specifically referenced in the Partner Group document upon which this study was based. Finally, "carbon emissions" are the only emissions covered by the new government emissions reductions requirements aimed at reducing production of GHG. Accordingly, "carbon emissions" are the only emissions dealt with in this study. This study does not address carbon dioxide emissions generated by biological sources.

[11] The data in this table are derived from ADM(IE) calculations. The source shows a calculated total GHG emissions for DND/CF of 1,788,240 t CO2 equivalent in FY 2007/08. The variance between my calculation and those at the source (of about 1/10th of one percent) is due to rounding errors.

[12] These figures call into question the CSA GHG calculations. It does not seem logical that the 4.2 PJ of grid electricity consumed by DND/CF—75% of which comes from entirely non-emitting sources like hydro and nuclear—should be deemed to generate 628 kt CO_2 eq., while the 6.7 PJ of natural gas consumed by DND/CF—half again as much energy—should generate, according to CSA ratios, only 335 kt CO_2 eq. One wonders whether the calculated emissions ratio for grid electricity in Canada is an accurate reflection of Canada's power generation profile. However, as these are the official CSA conversion ratios employed by ADM(IE) as part of the government-mandated SDS, I am not in a position to argue with them.

from the data collected by ADM(IE) The GHG production ratios by energy type are those devised by the Canadian Standards Association (CSA).

Not surprisingly, GHG production ratios roughly mirror the Department’s energy consumption patterns by energy source. What is interesting is that, owing to the GHG conversion factors mandated by CSA, grid electricity, which amounts for only about one-fifth of the energy consumed by DND/CF, is responsible for producing more than a third of the Department’s calculated GHG emissions. Natural gas, on the other hand, accounts for 30% of the energy consumed by DND/CF, but only 19% of the Department’s carbon emissions. These variances demonstrate that some energy sources produce higher carbon emissions than others.

Just as table 2 offered a comparison of the “cost-effectiveness” of the principle energy sources used by DND and the CF, table 4 (below) offers a comparison of the “carbon effectiveness” of each of the principle energy sources used by DND and the CF, in terms of the ratio of the energy that each source provides to the ratio of the carbon emissions that each produces.

Table 4 - “Carbon efficiency” of principal energy sources in DND/CF, FY 2007/08

Ser	**Energy Source**	**Quantity**	**Uts**	**Conv-MJ**	**MJ**	**kg CO2 per unit**	**kg CO2**	**MJ/kgCO2**
1	Solar PV	13606	kWh	3.6	48981.6	0	0	N/A
2	Ethanol 85	825	L	24.34	20080.5	0.42	346.5	57.95
3	Natural Gas	175875133.6	m3	38.09	6699083838	1.902	334514504.1	20.03
4	Propane	1470168.5	L	25.53	37533401.81	1.5439	2269793.147	16.54
5	Steam	32795048.03	lb	1.27	41649711	0.0813	2666237.405	15.62
6	Biodiesel 10	209517	L	38.26	8016120.42	2.5	523792.5	15.30
7	Ethanol 10	760667	L	33.44	25436704.48	2.2098	1680921.937	15.13
8	No. 1 Diesel	9199.6	L	37.68	346640.928	2.5597	23548.21612	14.72
9	Marine Gas	32757	L	34.66	1135357.62	2.4077	78869.0289	14.40
10	Gasoline	9046892	L	34.66	313565276.7	2.434	22020135.13	14.24
11	Aviation Gas	167834	L	33.62	5642579.08	2.44729	410738.4699	13.74
12	Aviation Turbo	168123528	L	35.93	6040678361	2.62298	440984651.5	13.70
13	Light Fuel Oil	15329689.83	L	38.68	592952402.6	2.8397	43531720.21	13.62
14	No. 2 Diesel	24041230.4	L	38.68	929914791.9	2.8567	68678582.88	13.54
15	Marine Diesel	62795292	L	38.68	2428921895	2.858	179468944.5	13.53
16	Heavy Fuel Oil	20227688	L	41.73	844101420.2	3.1023	62752356.48	13.45
17	Grid Electricity	1160587881	kWh	3.6	4178116372	0.5418	628806514	6.64
18	TOTAL				22147163935		1788411656	
19					**(22.147 PJ)**		**(1.78 Mt)**	

This comparison creates a number of curious statistical artefacts. The comparatively high “carbon efficiency” of E85 is somewhat nullified by its commercial unavailability,[13] while the supposedly very low “carbon efficiency” of grid electricity, as noted above, seems out of place when one considers the very high ratio of non-fossil fuel power generation in Canada (as compared to, for example, the United States (Solar PV generation, apart from the emissions involved in fabricating

[13] It is also unclear whether the carbon emissions ratio takes into account the carbon emissions necessary to grow and process the organic feedstock to produce the ethanol.

SPV cells and panels, produces no carbon emissions, in theory making it "infinitely" carbon-efficient).

Notwithstanding these statistical outliers, the comparison in table 4 demonstrates that, in terms of the ratio of carbon dioxide emitted to energy produced, there is little divergence across the array of fossil fuels employed by DND/CF. The two end-points are, of course, natural gas and grid electricity—two of the three most heavily-used energy sources in DND. Of the principle energy sources used by the Defence establishment, natural gas produces the lowest ratio of kilograms of "carbon" per unit of energy produced, while the grid electricity consumed by the Department produces the highest ratio. This suggests that if the Department is interested in reducing carbon emissions, the most effective place to start would be to ensure that grid electricity is purchased solely from non-carbon emitting generating plants, and to move towards off-grid electrical generation using non-carbon emitting technologies. Even though it is the most "carbon-efficient" conventional energy source, significant benefits could also be achieved by replacing natural gas as a heating fuel with non-emitting heating technologies for infrastructure.

2.2 Defence Energy (II): Energy and the Defence Mission

There are many different ways to display statistical information regarding how DND/CF makes use of energy to execute the defence mission. The tables and charts offered in this section are intended to convey where the Department consumes energy in the context of Defence activities.

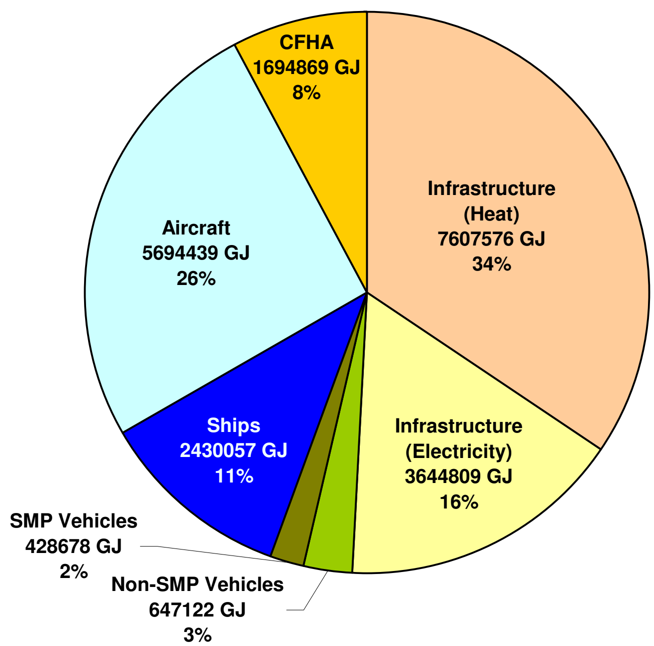

Figure 11 - DND/CF energy consumption by quantity and activity in FY 2007/08

Once again, these figures are derived from data collected, calculated and extrapolated by ADM(IE). To begin with, figure 11 displays the proportional consumption of energy (by quantity) across different activities in DND/CF in FY 2007/08.

Such a graphical representation displays the extent to which energy consumption in DND/CF is driven by infrastructure. Fully 50% of the energy used by the Department goes into providing heat, cooling, and electrical power to CF buildings and facilities; another 8% is consumed heating and providing electricity to living quarters administered by CFHA. Slightly more than one quarter is consumed by aircraft of all types, about one-tenth by naval vessels, and about one-twentieth by all of the ground vehicles operated by the Department. Standard military pattern ground vehicles—tanks, artillery, armoured fighting vehicles, and so forth—account for only two percent of the energy consumed by DND. Clearly, the greatest scope for reducing the quantity of energy consumed by DND/CF lies in the area of reducing the heating requirements of infrastructure, in finding replacements for grid electricity, and in reducing the fuel consumption of aircraft and, to a lesser extent, naval vessels.

Mobility accounts for some 42% of the energy consumed by DND/CF. Some three-fifths of this is consumed by aircraft. The figures do not support a further breakdown into expenditures due to operations as opposed to training, but clearly flying and, to a lesser extent, ground vehicle training must represent a significant proportion of the total energy consumed for mobility purposes. Any means of reducing energy consumption by aircraft or vehicles for training purposes (e.g., through simulation) would obviously be beneficial. As the vast majority of energy consumed for mobility purposes is consumed by aircraft, greater use of flight simulation would likely have the most pronounced impact.

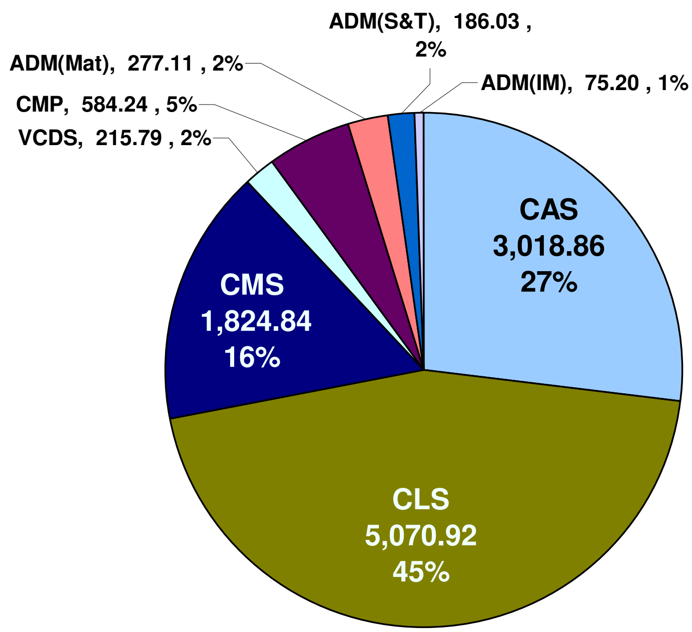

Figure 12 - Energy consumption of infrastructure, by ECS/L1, in FY 2007/08 (TJ)

Infrastructure consumption patterns may be broken out to provide finer degrees of resolution for analytical purposes. Figure 12 breaks energy consumption by infrastructure down by the Environmental Chiefs of Staff (ECS) and Level One (L1) managers responsible for maintaining and operating infrastructure throughout the Department.

The three ECSs account between them for approximately 88% of all of the energy consumed by infrastructure in DND/CF. This is not surprising, as these offices are responsible for operating the vast majority of CF Bases and facilities. To the extent that reductions in energy consumption by infrastructure are achievable, the most profitable targets are the buildings and facilities falling under the authority of the commanders of the Army, the Navy, and the Air Force. Among other things, this makes the ECSs key players in any attempt to transition DND/CF towards alternative energy sources for infrastructure.

Table 5 further breaks down the consumption of fuels (and, therefore, energy), the production of energy, and the calculated production of carbon emissions for the various classes of vehicles employed by DND/CF.

Table 5 - Fuel consumption and energy/carbon production by vehicle type, FY 2007/08

Ser	Data	Ground Vehicles			Ships	Aircraft	TOTALS
		On-Road	Off-Road	SMP			
1	**Number**	**7616**	**3182**	**9486**	**121**	**334**	**20739**
2	Gasoline (L)	8,993,791	53,081	0	0	0	9046872
3	Diesel (L)	5,488,776	2,233,655	11,059,362	0	0	18781793
4	Propane (L)	0	85,148	0	0	0	85148
5	Ethanol 10 (L)	759,350	1,267	50	0	0	760667
6	Ethanol 85 (L)	825	0	0	0	0	825
7	Biodiesel 10 (L)	75,289	110,712	23,516	0	0	209517
8	Marine Gasoline (L)	0	0	0	32,757	0	32757
9	Marine Diesel (L)	0	0	0	62,795,292	0	62795292
10	Aviation Gasoline (L)	0	0	0	0	167,834	167834
11	Aviation Turbo (L)	0	0	0	0	158,329,985	158329985
12	**ENERGY (GJ)**	**552,432**	**94,690**	**428,678**	**2,430,057**	**5,694,439**	**9,200,296**
13	**GHG (t CO2 eq.)**	**39,028**	**7,406**	**34,057**	**179,553**	**415,707**	**675,751**

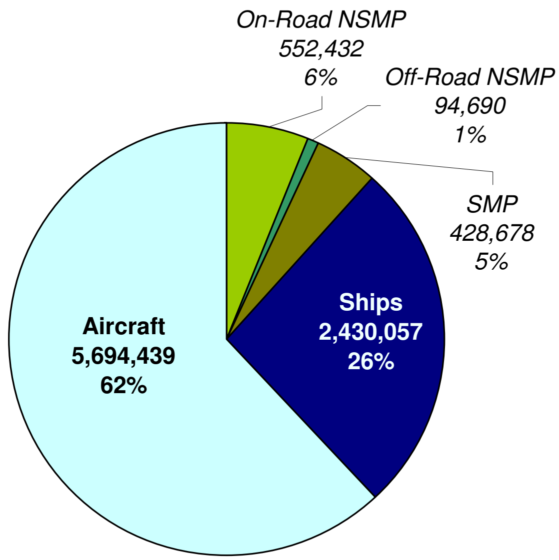

Figure 13 - Energy consumption by fleet, FY 2007/08 (GJ)

Figure 13 compares different vehicle fleets in terms of energy consumption (in GJ), while figure 14 compares them in terms of GHG production (in tonnes of CO2-equivalents).

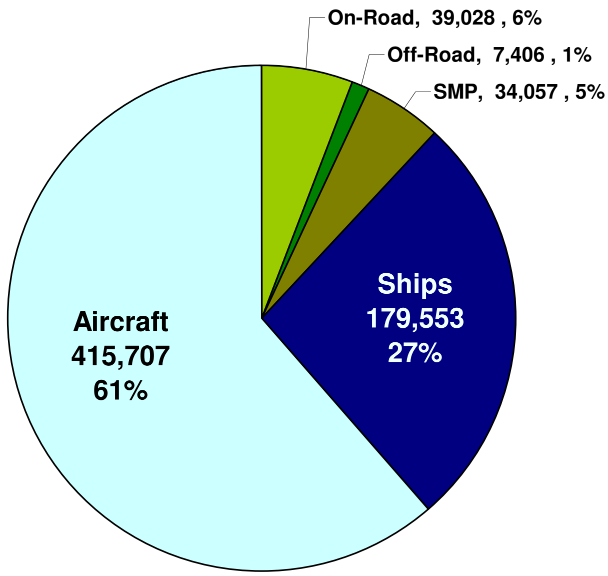

Figure 14 - GHG production by fleet, FY 2007/08 (t CO_2 eq.)

A comparison of energy consumption patterns between different vehicle fleets reveals, not surprisingly, that if reductions in energy consumption in the realm of mobility are desired, the greatest scope for improvement lies in the relatively small numbers of high-consumption equipment: the ships and aircraft operated by DND/CF. Simply put, nearly 21,000 ground vehicles use only half as much energy as is consumed by 121 naval vessels, and roughly one-fifth as much energy as is consumed by 334 aircraft. GHG production ratios are virtually identical, and again this is not surprising, as carbon content does not vary greatly across the four most common types of vehicle fuel used by DND/CF: aviation turbo (JP-8), marine diesel, ground vehicle diesel fuel, and gasoline.

Again, it is no surprise that aircraft consume the largest quantity of fuel, and produce the largest calculated GHG emissions of all DND/CF vehicle fleets, with naval vessels a distant second. DNDs fleet of on-road civilian pattern vehicles consumes more energy and produces more GHG than the significantly larger fleet of Standard Military Pattern (SMP) vehicles, suggesting that the latter fleet has a higher idle rate than the commercial-pattern fleet. Given that DND/CF is at present engaged in an operationally demanding combat mission in Afghanistan, however, this is a useful statistical result, as it suggests that greater savings, both in terms of energy consumption and of GHG production, could be achieved by reducing fuel consumption by civilian pattern vehicles (e.g. through the use of more fuel-efficient conventional vehicles, or through greater use, where appropriate, of hybrid vehicles) than by attempting to reduce the use of SMP vehicles.[14]

[14] It is important to recall that hybrid vehicles simply transfer energy consumption to other power-generation sources, which may be less clean-burning than a conventional internal combustion engine. This is particularly true in places where grid electricity is generated from non-renewable sources.

Finally, figure 15 provides a breakdown of the energy consumption statistics for the various CF Bases and Wings operated by the ECSs. As noted in figure 12 (above), CF Bases and Wings operated by the Army, Navy and Air Force account for approximately 88% of all of the energy consumed for infrastructure purposes in DND/CF.

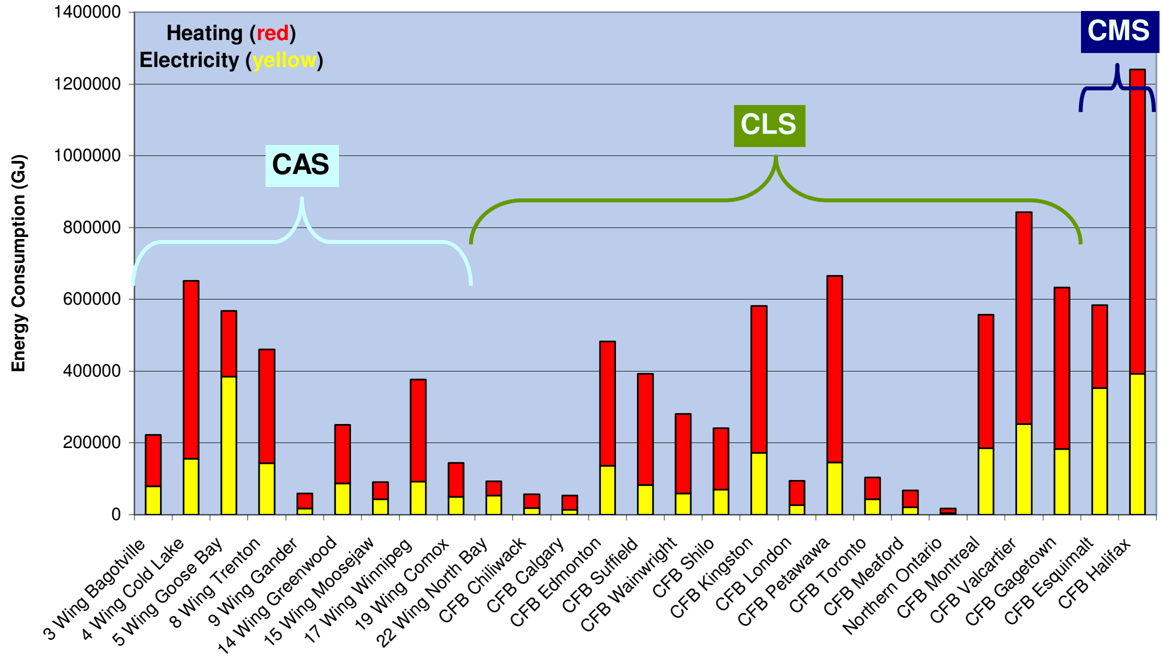

Figure 15 - Energy consumption by CF Bases and Wings, FY 2007/08 (GJ)

Not surprisingly, examination of the energy consumption statistics (and the energy intensity statistics vis-à-vis the aggregate area of the buildings supported by each base) reveals close correlations between energy consumed in heating and providing electricity to facilities, and the size of the facilities themselves (i.e., the floor area of buildings in m^2). Also, while the condition of facilities (especially insulation) certainly plays a major role in determining the requirement for heating, there is a reasonably close correlation between the energy consumed for heating and the general climate of the part of the country in which a given facility is located. For example, the lowest heating intensities (in terms of the quantity of energy consumed for heating per square metre of building space) may be found in CFB Chilliwack (the lower mainland of British Columbia) and CFB London (southern Ontario), both of which enjoy comparatively mild climates; while the highest heating intensities are found in CFB Suffield, CFB Cold Lake, and CFB Wainwright (in Alberta) and 9 Wing Gander (in Newfoundland), where winters are colder, and tend to last longer than elsewhere in the country.

In general, the facilities operated by the ECSs tend to consume far more energy for heating (6615 TJ in FY 2007/08) than for electrical needs (3298 TJ in FY 2007/08).[15] The consumption of energy for building heat would therefore appear to be the most potentially beneficial area in

[15] The exceptions are CFB Goose Bay, and CFB Esquimalt, both of which consume more electrical than heating energy. In the case of Esquimalt, this is easy to understand, as it enjoys a comparatively mild climate. The variance with respect to Goose Bay is due to the fact that this base uses electrical heating.

which to seek reductions in energy expenditures at CF facilities. Because heating requirements are to a large extent determined by climate, however, this precludes simply reducing energy consumption by lowering building temperatures; it suggests that a means must be found of using less energy to supply the same amount of heat to the facilities in question. There are a number of means of doing so, ranging from improving the thermal efficiency of buildings, to replacing less efficient heating and cooling systems with more efficient ones.

2.3 Summary

As noted at the beginning of this chapter, DND/CF spent some $322M on energy in FY 2007/08. While significant in terms of magnitude, at two percent of the Defence budget this represents a relatively small proportion of Defence’s overall annual expenditures. Nonetheless, a prima facie analysis of available data at the strategic level suggests some areas where a transition to alternative energy sources might prove beneficial by reducing the cost of energy, reducing the Department’s reliance on fossil fuels, and reducing its aggregate GHG emissions. These priorities are captured at table 6.

Costs. The Department’s energy costs break down into infrastructure (43%) and mobility (57%). The purchase of grid electricity accounts for half of all energy costs for infrastructure, while the purchase of natural gas for heating accounts for another third. Under the aegis of mobility, aviation fuel accounts for 60% of all costs, ship’s fuel for one-fifth, and fuel for land vehicles one-fifth. Overall, aviation fuel accounts for one-third of the Department’s energy costs (34%); grid electricity for one-fifth (21%), and natural gas (13%), ship’s fuel (12%), and land vehicle fuel (12%) for the bulk of the rest. Natural gas is the most cost-effective fuel in terms of energy per dollar; gasoline and diesel are the least cost-effective. The most appropriate target for research aimed at reducing energy costs, therefore, is finding lower-cost alternatives to (a) aviation fuel, (b) grid electricity, (c) natural gas, (d) ship’s fuel, and (e) fuel for ground vehicles.

Table 6 - Priority targets for meeting Defence alternative energy objectives

Ser	Priority	Strategic Objectives		
		Reducing the Cost of Energy to DND/CF	*Reducing DND/CF Reliance on Fossil Fuels*	*Reducing DND/CF Carbon Emissions*
1	***HIGH***	Jet Fuel	Natural Gas	Grid Electricity
2		Grid Electricity	Jet Fuel	Jet Fuel
3		Natural Gas	Naval Fuel	Natural Gas
4		Naval and Land Vehicle Fuel	Land Vehicle and other Fuels	Naval Fuel
5	***LOW***	*All other energy sources used by DND/CF*		

Fossil fuels. 81% of the energy used by the Department is directly consumed in the form of fossil fuels. Incorporating the fact that, in Canada, roughly 25% of grid electricity is generated from fossil fuels raises this total to about 85%. Overall, 30% of DNDs energy consumption is in the form of natural gas, 27% in jet fuel, 11% in marine diesel fuel, and 12% in gasoline, diesel and various fuel oils. Accordingly, if the goal is to reduce the Department’s reliance on fossil fuels, then the most attractive areas for research include alternative energy sources that will enable DND/CF to reduce reliance on (a) natural gas, (b) jet fuel, (c) ship’s fuel, and (d) fuel for ground vehicles.

Carbon emissions. Approximately 35% of the calculated carbon emissions produced by DND/CF in FY 2007/08 came from reliance on grid electricity to power Defence infrastructure. 25% come from the use of jet fuel; 19% from natural gas used to heat DND/CF buildings; and 10% from ship’s fuel. All fuel burned by ground vehicles accounts for only 5% of the Department’s total calculated carbon emissions. Accordingly, the most important targets for reducing the Department’s carbon emissions would appear to be (a) shifting the Department’s electrical consumption patterns to take greater advantage of non-carbon emitting electrical generation sources (e.g., hydro, nuclear, or “renewable” sources like solar energy, wind, tidal power and the like); (b) identifying non-carbon emitting alternatives to jet fuel; (c) moving away from the use of natural gas as the principal source of heat, and making greater use of non-carbon emitting technologies for providing heat to DND/CF facilities; and (d) identifying non-carbon emitting alternatives to ship’s fuel.

Based on the summary provided in table 6, the targets for meeting Defence’s stated objectives in investigating alternative energy sources should be finding lower-cost, non-fossil fuel, non-carbon emitting alternatives to the following energy sources, in descending order of priority: (a) jet fuel; (b) natural gas; (c) grid electricity; (d) naval fuel, and (e) land vehicle and other fuels.

3 Energy Alternatives for Defence

The preceding chapter provided a picture of where and how the Defence establishment uses energy. The purpose of this discussion was to provide a foundation for the addressing how DND/CF might leverage alternative energy options to (a) reduce the cost of energy, (b) reduce Departmental reliance on fossil fuels, and (c) reduce carbon emissions. The present chapter builds on this analysis by discussing the prospects for progress in each of these areas by leveraging existing, near-term and emerging alternative energy solutions to meet Defence's power and energy needs.

As was noted early on in Chapter 2, DND/CF energy consumption can be grouped under two general headings: energy for mobility; and energy for infrastructure. This chapter will address the three research problems outlined above in the context of these two general headings.

3.1 Alternative energy for mobility purposes

According to data compiled by ADM(IE), in FY 2007/08 DND spent about three-fifths of its "energy budget"—more than $184M—on purchasing more than 334M litres of petroleum-based fuels, and another 970,000 litres of E10, E85 and biodiesel. Of this total—about 335 million litres—roughly 250 million litres, or about 75%, was destined for mobility purposes. Close to two-thirds of this total quantity was "aviation turbo;" one-quarter, "marine diesel;" and one-tenth, diesel fuel and gasoline for ground vehicles. Less than one percent of this fuel was "renewable" (i.e., biodiesel or some ethanol-based fuel mixtures). All told, primary-source fossil fuel accounted for more than 99% of the fuel consumed by DND/CF in FY 2007/08.

Biodiesel and Ethanol-85 (E85) have made only very limited inroads in the Defence mobility sector.[16] This situation is not restricted to Defence; despite the entry into force of the *Alternative Fuels Act (AFA)* more than eleven years ago,[17] renewable fuels (or "Alternative Transportation Fuels," as they are referred to in the *Act*) have made very little progress within the Federal government. There are three reasons for this:

- They offer lower operational efficiencies than conventional fuels (according to CSA, the energy density of E85 is 24.34 MJ/l, as compared to gasoline at 34.66 MJ/l);

- They are more expensive to produce and consume than conventional fuels, both in terms of direct fuel costs and in terms of the premium on alternative fuel vehicles; and

- They are not widely available.

The AFA requires that three-quarters of the motor vehicles operated by Federal departments and agencies use ATFs, but only where it is cost-effective and operationally feasible to do so. The Treasury Board Secretariat, in its annual report to Parliament of the application of the AFA,

[16] Ethanol-10, or E-10, should not be considered a "renewable fuel", as it consists of 90% fossil fuel by volume.
[17] The Act entered into force on 1 April 1997.

provides some data and analysis to help explain why the total number of ATF vehicles operated by the Federal government has yet to come within several orders of magnitude of this figure.[18]

3.1.1 Problems with alternative transportation fuels

The first problem is the scarcity of ATF-capable vehicles and fuels. In FY 06/07, for example, no new factory-produced propane- or natural gas-propelled vehicles were available for purchase in Canada. After-market conversion kits were unreliable, and often resulted in higher GHG emissions than from comparable gasoline- or diesel-powered vehicles. Fuelling stations offering ATFs were a rarity; the only fuelling station to offer E85 commercially in Canada (located in Ottawa) ceased to sell that fuel in FY 06/07.[19] The Treasury Board report notes that "only a portion of the Federal government's 2042 E85 flexible fuel vehicles had immediate access to E85 fuel" during the reporting period.[20]

Even where ATF vehicles and fuels were available, operational effectiveness remained an issue. Some jurisdictions in Canada restrict the use of propane vehicles in certain areas, for example in underground parking garages or on airport aprons. Retrofitting conventional vehicles to contain ATF fuel tanks (which, due to the compression requirements for gaseous fuels and/or the lower energy content of alternative fuels, are often bigger than conventional fuel tanks) occasionally affects their operational capabilities by reducing passenger or cargo capacity.[21]

Finally, even where operational considerations could be overcome, cost-effectiveness remained an issue. The Treasury Board report notes that, compared to similar classes of conventional vehicles, ATF-capable vehicles carried a premium that ranged up to more than $1800 per vehicle. The cost-per-litre of E85 fuel was approximately 6% higher, on average, than gasoline throughout the reporting period; and, due to its lower energy content, consumption rates for vehicles using E85 ranged up to 30% higher than for conventional gasoline vehicles.[22] This made using alternative fuels a losing proposition from a perspective of costs, energy consumption, operational effectiveness, and GHG production.

The result, according to the Treasury Board report, was a "nil target" for acquisitions of ATF vehicles under the AFA in FY 2006/07. This lack of a target notwithstanding, 354 of the 4648 new vehicles acquired by the Federal government in FY 2006/07 were ATF vehicles—a total of 7.6% of all new vehicles purchased.[23]

All of the issues associated with ATF vehicles combine to make them an unattractive option for DND/CF, where operational effectiveness, reliability, worldwide operability, flexibility and cost tend to be important planning factors. As a result, these vehicles form a very small proportion of the DND fleet. In FY 06/07, for example, DND acquired 1398 new ground vehicles; only 22 of these were ATF vehicles (1.6%). Even hybrid gas-electric vehicles (which are not considered

---

[18] Treasury Board Secretariat of Canada, *Annual Report to Parliament: Report on the Application of the Alternative Fuels Act, Fiscal Year 2006-07* (Ottawa: Treasury Board Secretariat of Canada, 2007), p. 2.
[19] Ibid, p. 2. This may be the reason DND/CF purchased only 825 liters of E85 fuel in FY 2007/08.
[20] Ibid, p. 3.
[21] Ibid,, p. 2.
[22] Ibid.
[23] Ibid, p. 3.

ATF vehicles under the AFA) have thus far seen only limited employment; the Federal government acquired 385 in FY 06/07, and DND bought only 8 of these.

The Treasury Board report captures the problem of alternative fuels in a nutshell. "The availability of ATF vehicles and associated infrastructure," it notes, "has not yet materialized enough to make greater use of ATF vehicles."[24] It is important to understand that this problem—like the problems of the cost and the energy content of alternative fuels—will not be solved by government fiat. The energy density in terms of joules-per-litre (or kilogram) of alternative fuels is a technological problem that has yet to be solved; and the question of infrastructure is one that will be addressed by the market, if at all.

If ATFs and ATF-powered vehicles one day become technologically feasible and cost-effective to produce, operate and maintain, it will be the economic choices made by Canadians (and, more to the point, by Americans) that will determine whether ATF options become commercially viable, and whether the infrastructure necessary to support them will—or will not—be built. Fluctuations in the high price of oil (and hence of diesel fuel and gasoline) over the past year appear to have influenced consumer choices on conventional vehicles, but there is still no widespread, voluntary movement towards ATF vehicles, and it is questionable whether any of the relatively crude tools available to governments—the foremost of which are subsidies for producers of alternative fuels and ATF vehicles, and punitive taxes on producers and consumers of conventional vehicles and fuels—will be of any use in influencing the market in one direction or another. Government departments in general follow consumer trends, not lead them. This is especially true when selecting civilian-pattern vehicle fleets for general logistic support tasks.

Even if ATFs at some point become cost-effective, and the infrastructure to support their widespread use becomes available, there are at present no "carbon-free" alternative fuels. Biodiesel, propane and natural gas are hydrocarbons, while ethanol and methanol are carbohydrates that represent a technological "step backwards" in terms of net energy content. Carbohydrate-based biofuels are only economically competitive due to heavy government subsidies by Western governments, and rely on the diversion of food cropland for their production.

Nor are batteries or "hydrogen" a panacea; vehicles that run on hydrogen (either by combustion or in fuel cells) or on stored electricity may offer cosmetically "carbon-free" alternatives—but only to the extent that the power to charge their batteries, or to produce the hydrogen that they use, is generated by non-carbon emitting sources. Hydrogen and electricity are not, after all, energy sources—they are merely technologies for transporting energy. The energy to produce hydrogen or to charge batteries must come from somewhere else. If, as some have suggested, Canada were to move to a "hydrogen economy," there would have to be a vast increase in the country's electrical generating capacity in order to produce the power necessary to create, by hydrolysis of water, the hydrogen that would be required to replace the Exajoules of fossil fuels currently being consumed by the transportation sector.[25]

[24] Ibid, p. 5.

[25] The principal commercial means of producing hydrogen are through steam reforming or partial oxidation of methane. Both processes produce significant quantities of carbon (C, CO and/or CO_2) as a byproduct.

All of this, of course, applies only to fuels used for ground transportation—which, as noted above, amount to only about one-tenth of DND/CF’s fuel consumption. The Department has not, as yet, attempted to extend the use of renewable fuels to naval or air mobility requirements. There are some questions as to whether this is even feasible; DNDs own fuel experts, for example, have noted that biodiesel has different physical properties (inter alia, increased viscosity and a greater tendency to polymerize) at lower temperatures, precluding the use of mixed fuels by aircraft, ships or ground vehicles likely to operate in winter, at high altitudes, or in high latitudes. This is a significant problem for the military of an arctic country, and indeed for any country whose military personnel may be required to operate in cold conditions even in non-Arctic countries (e.g., the North Atlantic, or the Hindu Kush in winter).

The characteristically lower energy densities of alternative fuels pose additional operational dilemmas. Fuel tank sizes, especially in combat vehicles and aircraft, are fixed; the use of fuels with lower energy densities means reduced operating ranges for vehicles that use them. Furthermore, the use of lower energy density ATFs increases the logistic burden on expeditionary forces, as more fuel must be supplied to produce the same amount of vehicle movement. DND/CF operations are vulnerable to negative synergies resulting from this problem, especially in circumstances where fuel must be burned in order to supply fuel to far-flung forces, e.g., in places like CFS Alert, where aviation fuel is burned to fly diesel fuel to a distant operating location; or in operational theatres, where fuel-burning trucks are used to supply fuel to distant troops. The use of electrically-powered vehicles in remote locations where fuel is scarce but electric power is plentiful (especially if locally generated through nuclear, wind or solar power) could do much to alleviate the problem of fuel shipments.

Unless these problems can be resolved, the widespread adoption of current alternative fuels by DND/CF will not be feasible. There is, of course, one exception to this conclusion, and this is nuclear power. This option would only be useful as a potential replacement for marine diesel (which, as noted in Chapter 2, accounts for 11% of the energy consumed by Defence [26% of the fuel consumed for mobility purposes], and 12% of the Department’s energy costs). This option, however, would only be technically feasible for larger ships, and would entail development of the infrastructure and expertise necessary to support sea-going reactor technology—something that took the US Navy decades and billions of dollars to create. It is questionable whether the costs of such a conversion could be justified, given that the nuclear-propelled fleet would consist of, at most, some three dozen surface and sub-surface vessels. Moreover, the nuclear option, as was seen in the debates that followed publication of the 1987 Defence White Paper, carries with it a heavy political premium.

At present, therefore, other than nuclear propulsion for major naval surface and sub-surface combatants, there do not appear to be any operationally, technologically or economically viable alternative fuel options available for mobility purposes in DND/CF. Should alternative fuel options become, as a result of market forces, more commercially widespread, then Defence may be in a better position to take advantage of them.

3.2 Energy for infrastructure

The Department of National Defence does not make use of renewable energy to any statistically significant degree; in this, DND/CF is more or less reflective of government in general, and

Canadian society writ large. The numbers tell the story. No renewable energy sources are used to generate heat energy for infrastructure; of the more than 7.6 PJ of heating energy consumed by Defence infrastructure in FY 2007-08, none was renewable. The Canadian Forces Housing Agency consumed more than 1.6 PJ of electrical and heating energy above and beyond the aggregate DND/CF figures, none of it from renewable sources. Out of all DND/CF facilities, only two CF Bases—Goose Bay and Petawawa—made use of renewable energy sources for electrical generation, in both cases through solar photovoltaic (PV) arrays. Even at these bases, the amount of energy generated via this means was statistically insignificant. Petawawa, for example, generated 7766 kWh of power via its PV systems, but purchased 40,331,108 kWh of grid electricity; while Goose Bay generated 5840 kWh, and purchased 106,982,696 kWh. The proportion of renewable vs. non-renewable electrical consumption even at these facilities is too small to portray graphically.

All told, DND/CF purchased more than 1 TWh—over a billion kilowatt-hours—in grid electricity in FY 2007/08, and generated only 13,606 kWh through Solar PV arrays. Clearly, there is considerable scope for the Department to make greater use of renewable energy sources in providing heat and electrical power to Defence infrastructure.

Chapter 2 of this paper identified where the greatest potential for improvement lies. In terms of cutting costs, grid electricity and natural gas for heating rank as the second- and third-highest priority areas for reducing energy costs, reducing fossil fuel dependency, and reducing carbon emissions. A number of technologies that are either in widespread use or currently under development could provide significant improvements over conventional energy sources in these areas. Co-generation of heat and electricity using fossil fuels, for example, is becoming increasingly popular for residential applications in Europe. Natural Resources Canada is currently conducting trials on packaged systems employing a Stirling engines (external combustion engine capable of burning a variety of different fuels—commonly diesel in Europe, and natural gas in North America) to power both a small generator and a hot-air blower. The system presently being evaluated is capable of providing 1 kW of electricity and 6 kW of heat—about half what is needed for an average Canadian home.[26] Other technologies being tested—for example, a black box catalytic system for deriving electrical energy from the combustion-free decomposition of natural gas into carbon dioxide and water vapour—are interesting as well. But while all of these technologies offer some efficiencies over conventional heating and electrical generating systems, they all share two basic problems: they all consume fossil fuels; and they all emit carbon.

For the purposes of this paper, therefore, an ideal alternative energy solution will be deemed to be one that reduces fuel costs; reduces reliance on fossil fuels; and reduces carbon emissions, compared to current energy consumption and GHG emissions patterns in DND/CF. Based on these patterns, the principal focus of research into alternative energy options for DND/CF should be on:

- Identifying a replacement for natural gas (and other fossil fuels) as a source of heat for DND/CF facilities; and,

[26] This data was recorded by the author during a research visit to the NR CAN testing facility in Kanata, Ontario, in September 2008.

- identifying a replacement for grid electricity to provide electrical power for DND/CF facilities.

3.2.1 Alternative energy for heating

Application of the criteria derived above (reducing fuel costs, reducing reliance on fossil fuels, and reducing or eliminating carbon emissions) leads to two possible alternative energy sources for the provision of heat energy to infrastructure: direct solar collection; and heat pumps.

3.2.1.1 Solar thermal heating

The Earth receives as much energy from the Sun in one hour as the human race consumes, from all sources, in a year. Thus, one might think that solar heating would be a potentially limitless alternative to the use of fossil fuels for providing heat to Defence infrastructure. The problem is that solar energy is diffuse, and that in order to be useful, it must be gathered over a large area, concentrated, and delivered to the point of consumption.

The average terrestrial insolation is about 250 watts per square metre, or about 6 kWh/m^2/day. Insolation, however, is affected by latitude, and locations further from the Equator receive considerably less solar flux. In the northern US states, for example, the average insolation is 4-5 kWh/m^2/day; in Canada, the average is considerably less. Table 7 provides insolation estimates derived by Natural Resources Canada (locations have been selected to reflect major CF Bases).

Table 7 - Mean Daily Insolation at various locations in Canada[27]

Serial	Location	Sample CF Base or facility	Mean Daily Insolation (kWh/m^2) // MJ/m^2
1	Edmonton, AB	4 Wing Cold Lake	4.2-5.0 // 15-18
2	Winnipeg, MB	17 Wing Winnipeg	4.2-5.0 // 15-18
3	Ottawa, ON	CFB Petawawa	4.2-5.0 // 15-18
4	Victoria, BC	MARPAC Esquimalt	3.3-4.2 // 12-15
5	Quebec, QC	CFB Valcartier	3.3-4.2 // 12-15
6	Fredericton, NB	CFB Gagetown	3.3-4.2 // 12-15
7	Halifax, NS	MARLANT Halifax	3.3-4.2 // 12-15
8	St. Johns, NL	5 Wing Goose Bay	3.3-4.2 // 12-15
9	Ellesmere Island, NWT	CFS Alert	2.5-3.3 // 9-12

These insolation figures allow some quick calculations as to the necessary "capture area" for a facility in order to use solar energy for heating. In the most common solar heating applications, a thermal mass or heat sink is used to store energy captured by a solar array, which is then used both to directly generate heating, and to store thermal energy to provide heating during sunless periods. Using 4 Wing Cold Lake as an example, the mean daily insolation of 15-18 MJ/m^2 in northern Alberta suggests that the annual insolation is 5475-6570 MJ/m^2. 4 Wing's annual heat energy consumption in FY 07-08, according to figures collected by ADM(IE), 495,917,450 MJ.

[27] Data derived from the interactive insolation maps at the NRCan website at https://glfc.cfsnet.nfis.org/mapserver/pv/index_e.php.

Accordingly, if solar energy could be captured and stored with 100% efficiency, 4 Wing Cold Lake would have to capture the energy from 75,482—90,578 square metres of land area at a minimum (roughly □ of a square kilometre). Regrettably, however, this is only a theoretical figure; no solar thermal plant is 100% efficient. Furthermore, the chief problem is one of heat storage; most heating energy is consumed during the winter months, whereas insolation is highest in the summer months (to say nothing of the thorny problem of planetary rotation, which means that energy captured during daytime hours must be stored and released to provide heat at night). At present, thermal storage technologies (inter alia steam generation, molten salt, graphite beds, phase-changing materials, etc.) do not permit heat storage for periods longer than a few hours.

It should be noted that the figures in table 7 are based on the assumption of basic SPV technology using fixed-array systems. Sun-tracking systems are proportionally more expensive to install, but also make much better use of solar availability. Such systems, in south-eastern Alberta and south-western Saskatchewan, for example, can reach an annual solar flux of 6.7-8.5 kWh/m^2, roughly half again as efficient as a fixed array.[28]

The need for much higher solar energy capture in the winter means that a solar heating facility must be concomitantly larger, both to meet the higher heating demand, and to account for lower seasonal insolation. It is not an accident that the most successful solar thermal generation systems in the US are located in California's Mojave Desert, where the mean daily insolation, according to US Government figures, is 7.0-7.5 kWh/m^2—more than twice the Canadian average. The utility of solar thermal heating as an alternative to fossil fuels at CF bases and facilities will depend on whether it is cost-effective.

3.2.1.2 Heat pump technology

Heat pumps leverage the Carnot Cycle to move heat from one place to another. The technology debuted with the development of refrigeration in the late Nineteenth Century, and exploded as domestic refrigeration and air conditioning became common in the post-Second World War period. Air-to-air heat pumps became popular in the 1970s, with air-to-ground heat pumps following swiftly behind them. At present, ground-source heat pumps (both water-based and the more efficient refrigerant-based direct-expansion, or "DX" systems) are becoming increasingly popular for a wide range of industrial, commercial and domestic applications in North America and Europe. During the 1990s, for example, the US Department of Defense installed more than 60,000 tons of cooling capacity using ground-source heat pumps (roughly 760 GJ of cooling capacity).

Unlike refrigerators and air conditioners, heat pumps are bi-directional. In its simplest form, two loops—a heat exchanger inside the building, and another outside the building (in open air or buried underground) serve alternately as evaporator and condenser. The system operates via the thermodynamic principle of differential temperatures. With the working fluid moving in one direction, the loop inside the building absorbs heat, concentrates it, and releases it into the exterior loop, cooling the structure. Through the use of a reversing valve, the system can be operated in the opposite direction as well; the exterior loop absorbs heat, concentrates it, and releases it into the interior loop, warming the structure. In Canada, ground-source or geo-thermal heat pump systems (GSHPs) are especially effective, as the average year-round ground

[28] *ibid.*

temperature a few metres below the surface is always lower than the ambient air temperature in summer, and considerably higher than the ambient air temperature in winter. Heat pump systems can also be equipped (e.g., with desuperheater and on-demand hot water systems) to scavenge waste heat for ancillary use, e.g., for space heating or the production of hot water, significantly improving the overall efficiency of the system.

The performance efficiency of GSHP systems makes them especially attractive. The standard measure for heating systems is coefficient of performance (COP), which in rough terms means the ratio of the amount of heat energy produced by the system to the amount of energy required to operate it. Electrical resistance heating is the standard, with an assumed COP of 1.0 (i.e., for every joule of energy that goes into the electrical resistance element, one joule of heat goes into the structure; it is assumed that none is lost via, for example, an exhaust or flue system). By contrast, natural gas and oil have lower COPs, running from 0.6 to 0.9, as even the most efficient combustion systems lose a small proportion of heat energy via exhaust gases. Heat pumps extract energy from the environment—which, in effect, is solar thermal energy stored in the ground or the air. The only energy input is the electricity necessary to run any pumps and compressors associated with the system. The fact that geothermal heat pumps can also provide cooling simply by reversing the system is an added benefit, as in addition to replacing heating equipment, they simultaneously replace air conditioning equipment as well.

Table 8 offers a comparison of the COPs of various heating technologies in comparison to heat pumps.

Table 8 – Comparative efficiency of alternative heating technologies[29]

Serial	System type	Energy Source	COP / AFUE
1	Oil furnace	Oil	0.82 AFUE
2	Natural Gas Furnace	Natural Gas	0.9 AFUE
3	Electrical Resistance Heating	Grid electricity	1.0 COP
4	Air-Source Heat Pump	Solar thermal	2.3-3.3* COP
5	Ground-Source Heat Pump (water)	Solar thermal	3.5 COP
6	Ground-Source Heat Pump (DX)	Solar thermal	4.0+ COP

Table 9 - Energy and Cost Comparison for 100% geothermal heating across DND/CF

Ser	Scenario	Energy Consumption			Energy Costs		
		Heat (PJ)	Electrical (PJ)	Total (PJ)	Heat ($M)	Electrical ($M)	Total ($M)
1	PRESENT	7.6	3.6	11.2	69.2	67.9	137.1
2	100% GSHP	0	5.4	5.4	0	101.8	101.8
3	**Delta**	**-7.6**	**+1.9**	**-5.8**	**-69.2**	**+33.9**	**-35.3**

What this means is that, in principle, for every joule of electrical energy put into, for example, a GSHP system, 3.5-4.0 joules of heat are delivered to the structure. This sort of conversion factor suggests that, in principle, if DND/CF converted to geo-thermal heating, the entire heat energy

[29] Data compiled from various sources at Natural Resources Canada and the Canadian Geoexchange Coalition. AFUE stands for Annual Fuel Utilization Efficiency, a ratio of the energy supplied to a furnace to the energy delivered to the structure.

requirement of DND/CF facilities (7.6 PJ in FY 2007/08) could be met with roughly one-quarter that amount of electrical energy (1.9 PJ). In such a scenario, the Department's electrical consumption would increase from 3.6 PJ to 5.4 PJ per annum, and its heat energy consumption would drop from 7.6 PJ to 0 PJ. This scenario is modelled at Table 9.

Thus, complete conversion of DND/CF facilities to high-efficiency GSHP heating and cooling would result in the elimination of the use of fossil fuels (natural gas and oil) for heating; a savings of 5.8 PJ of energy; and a net savings, at FY 2007/08 rates, of approximately $35M per annum. Such savings, of course, must be set against the conversion costs from conventional to geo-thermal heating systems—and this would not come cheap.[30] Conversion costs, however, can be incorporated into construction costs for new plant, and are mitigated when set against upgrade/replacement costs for antiquated conventional heating systems that are scheduled for replacement anyway. Moreover, the fact that geothermal heat pumps are a proven technology that eliminates both fossil fuel consumption and GHG emissions suggests that DND/CF should closely examine geothermal heating and cooling both when building new facilities, and when renovating old ones. In combination with local power generation technologies (e.g., solar, wind or nuclear generation), geothermal heating and cooling can enable a remote facility to operate independent of both electrical and fuel distribution infrastructure.

3.2.2 Alternative electrical generation

Applying the same principles to the use of alternative energy sources for electrical power generation (cost reduction, fossil fuel elimination, and GHG emissions reduction) leads to three options: solar generation, wind generation, and nuclear generation.[31]

3.2.2.1 Solar thermal generation

Solar power may be leveraged to generate electricity either through thermal means (using the Sun's heat to create steam to drive turbines connected to generators), or via direct photovoltaic (PV) generation. Solar thermal generation (STG) is, at present, more common. The potential electrical production capacity of a STG plant is a function of the insolation of the area being exploited, the size of the facility, and the efficiency of the energy gathering, conversion and storage mechanisms.

There are numerous examples of high-output STG systems currently in operation worldwide. In the US, the SEGS (Solar Energy Generating System) solar thermal plant in California consists of nine facilities located in the Mojave Desert, where insolation is among the highest of any place in the continental United States. The SEGS boasts close to a million parabolic mirrors occupying 6.5

---

[30] The actual conversion costs from conventional to geothermal heating/cooling are highly dependent upon a host of variables, ranging from geographic location, ground heat content, insolation and local weather patterns, to the size, shape and thermal properties of buildings and their contents. However, it may be safely stated that converting all existing DND/CF facilities to geothermal heating/cooling would in all probability cost hundreds of millions of dollars. New technologies must be phased in over time.

[31] Hydroelectric and tidal power generation also fall under this heading, and DND would be well-advised to move towards purchasing grid electricity from such sources wherever it is feasible and cost-effective to do so. However, actually becoming involved in constructing and operating such enormous, multi-billion dollar facilities would entail DND taking a significantly different approach to power generation.

square kilometres of land, with an installed electrical generating capacity of 354 MW,[32] comparable to a small conventional or nuclear generating station. The SEGS is the largest STG station in the word; smaller stations are operating elsewhere in the US (e.g. in Hawaii and at Las Vegas, Nevada), in Spain, Morocco, and Algeria, all of which have a generation capacity of 50 MW or less. The US has announced construction of about a dozen new STG facilities with planned outputs ranging from 50-500 MW, while Spain is planning to build about two dozen more, all roughly in the 50 MW range. Similar facilities are planned by Israel, South Africa, Iran, Egypt and Australia.

Obviously, all of these facilities have one thing in common: they exist in, or are being built by, countries with large areas of desert terrain enjoying relatively high insolation. Canada, as a northern country, starts at a severe disadvantage as regards STG; as noted above, the average insolation in Canada is roughly half that where most of these power plants are being built. This means that, in order to achieve comparable power production, a Canadian STG plant would require roughly twice the solar energy gathering infrastructure, making this form of collection proportionally more expensive than elsewhere in the world. In fact, the conversion ratio would be larger still, as insolation is adversely affected by weather factors―cloud cover, rain, snow, etc.―as well as latitude.

Take once again the example of 4 Wing Cold Lake, which consumes roughly 156 TJ (43.3 TWh) of electrical energy per year. This averages out to an hourly consumption of about 18 GJ of electrical power, or about 5 MW. Because electrical consumption is cyclical rather than steady-state, Cold Lake would probably require a minimum peak base load of at least 10 MW.[33] This is power on the order of magnitude of the planned output (20 MW) of PS20 Solar Power Tower currently under construction near Seville, Spain. Consisting of more than 600 heliostats (movable mirrors) designed to focus solar energy on a 115 m tower, the facility is expected to cost □35M (ca. $50M).

In FY 2007/08, 4 Wing Cold Lake accounted for a little over 4% of the grid electricity consumed by DND/CF. On a purely pro rata basis, this means that powering Cold Lake cost roughly $2.9M in FY 2007/08. This suggests that the cost recovery period for a STG plant for Cold Lake similar to the PS20 facility being built in Spain would be more than fifteen years―assuming, of course, that the insolation is northern Alberta is sufficient to power such a facility; and that thermal and/or electrical storage would be adequate to ensure that sufficient power for round-the-clock operations would be available both during hours of darkness, and during the winter months, when insolation is considerably lower. The potential utility of STG systems for electrical power generation is worthy of further investigation, but the technical challenges deriving from attempting to exploit solar power in a northern country should not be underestimated.

---

[32] The SEGS website has further information. Go to http://www.fplenergy.com/portfolio/contents/segs_viii.shtml.

[33] This is a purely notional figure employed for demonstration purposes only. More accurate figures may be derived through detailed reviews of power base loads to support an engineering analysis of the potential for STG or Solar PV generation at CF Bases and facilities.

3.2.2.2 Solar photovoltaic generation

Like STG technologies, solar photovoltaic (SPV) cells consume no fossil fuels and produce no greenhouse gases (other, of course, than in the course of fabrication). They convert solar energy to electrical energy via the photoelectric effect. In the century and a half since the first SPV cell was constructed, the conversion efficiency from solar to electrical energy has risen from about 1% in the late 1880s, to roughly 4-6% by the 1950s. SPV cells have since become very popular for off-grid applications, in remote areas requiring small quantities of electrical power (such as railway crossings, emergency telephones, highway construction signs, and the like). Improvements in efficiency and automated manufacturing have brought the price of SPV cells from hundreds of US dollars per watt down to about $7 USD per watt. Interest in “green power,” along with heavy government subsidies in Western states, has led to increased use of SPV cells for domestic power applications. However, PV technology does not, at present, lend itself to efficient production of electrical energy on the scale necessary to power a major CF facility. In the context of the theoretical 10 MW base load of 4 Wing Cold Lake, for example, it is worth noting that the installed PV capacity of the United States was only about 30 MW in 1994; and that, by 1999, the total was still only about 320 MW (roughly twice the base load requirement of DND/CF). According to one estimate, the cumulative global installed capacity of PV cells is about 12.4 GW. Again, this is too small a proportion to represent graphically.

One current market leader in SPV technology is SunPower of San José, California, which claims a conversion efficiency ratio of 23.4% (this is a commercially available product; laboratory efficiencies of up to 40+% have reportedly been achieved). With an average daily insolation of (at most) 5 kW/m^2, and an electrical base load of 10 MW, 4 Wing Cold Lake would require an array of SunPower panels approximately 8600 metres square (roughly the size of two football fields). At $7-10 USD per Watt, such an array, even if technically achievable, would cost $70M-$100M USD—more than the annual electricity budget for the entire Department. And even such an expensive installation would do nothing to address the as-yet technologically infeasible problem of storing power for use during hours of darkness (this question is addressed more fully in the next section).

None of these analyses, incidentally, accounts for the environmental impact of PV panel manufacture. Among other by-products (some of them quite hazardous), the manufacturing process for solar PV cells produces a wide variety of GHG. The environmental impact of mass-manufacturing vital components like solar PV cells for power generation, or batteries for power storage, needs to be considered when evaluating alternative energy options.

In any event, barring some significant increase in the efficiency of solar PV cells, or a significant decrease in the per-watt installed cost of solar cell arrays, solar PV technology does not appear to offer, at present, a cost-effective alternative to existing electrical generation options. Depending on cost effectiveness, however, SPV generation may be used to augment conventional sources of electricity.

3.2.2.3 Wind generation

The use of wind turbines for electrical generation is widespread in many European countries, and produces, on average, considerably more electrical power than STG and solar PV technologies combined. In absolute terms, Germany is the world leader in wind power, with a little over 22

GW installed capacity. The US has 17 GW installed, Spain 15 GW, India 8 GW, and China 6 GW. Denmark, which comes next, is the world's largest per-capita user of wind power, with more than 5200 turbines in operation, most of them located in Jutland, and a total installed capacity of about 3,135 MW.[34] According to the Danish Wind Industry Association, in 2006, wind turbines produced about 6108 GWh, roughly 16.8% of all the electricity supplied to Danish households. This is expected to rise to about 25% when new turbine farms come on line in 2010.

In places where winds are constant and strong—like Jutland—wind power can be an economically viable and environmentally friendly power generation option. This is proven out by the US which, which has about two-thirds the installed capacity of Germany, but actually produces more electricity from wind than Germany does.

As is the case with solar generation, wind power is intermittent, and it is therefore instructive to assess the average availability of wind-power turbines. Denmark serves as an excellent example. If all of Denmark's wind turbine stations were functional and the wind blew 24 hours a day, 7 days per week, an installed capacity of about 3100 MW should produce slightly more than 27,150 GWh in a year. This means that the on-line availability and productivity of wind turbines (their "capacity factor," to use the technical term) in Denmark is about 22.5%. Wind turbines are generally assumed to have a capacity factor of 20-40%,[35] which compares very favourably with, for example, Solar PV stations at 12-19%; although not so well with gas (60%), coal (70-90%) or nuclear power plants (ca. 85% worldwide, and over 90% in the US).

"Capacity factor" makes installation cost an extremely relevant question. If a nuclear generating station was only capable of producing electricity one hour out of every four, nobody would ever build one.[36]

Wind power has also begun to make its way into the military milieu. Since 2005, Francis E. Warren Air Force Base in Wyoming, a facility belonging to US Space Command, has operated two 900 kW wind turbines, which were intended to provide about 10% of the facility's baseline power needs, and to pay for themselves in 12 years.[37] It is not clear that this option would necessarily be cost-effective for all Canadian military facilities. Almost by definition, an organic wind generation capacity would have to be located on base property, and according to Environment Canada, few bases are located in areas with exceptionally strong average wind energy.[38] Taking the aforementioned example of 4 Wing, CFB Cold Lake is located in an area rated at between 0 and 100 W/m^2 wind energy—the lowest rating in the country. CFB Suffield, on the other hand, rates much higher, at around 200-300 W/m^2 average annual wind energy, which is about the same level as Wyoming (see table 10). Clearly, this is an option that might be more useful some CF facilities than at others. For example, St. John's, Newfoundland, would appear to be an ideal place to attempt to take advantage of wind power.

---

[34] Rune Birk Nielsen, "Denmark's Largest Offshore Wind Farm Approved," Danish Wind Industry Association, 26 August 2008, accessed at http://www.windpower.org/composite-2031.htm. In 2007, Canada was #11 on the list, with about 1.8 GW installed capacity.

[35] See http://www.ceere.org/rerl/about_wind/RERL_Fact_Sheet_2a_Capacity_Factor.pdf.

[36] According to the US Energy Information Administration, the capacity factor of US nuclear power plants has, over the past three decades, risen to approximately 92%.

[37] Renewable Energy Access.com, "From Muskets to Missiles to Wind Turbines," 14 June 2005, accessed at http://www.renewableenergyworld.com/rea/news/story?id=33227.

[38] See the interactive online maps available at http://www.windatlas.ca/en/maps.php.

Table 10 - Mean Daily Wind Energy at various locations in Canada[39]

Serial	Location	Sample CF Base or facility	Mean Daily Wind Energy (w/m^2)
1	Edmonton, AB	4 Wing Cold Lake	100-200
2	Winnipeg, MB	17 Wing Winnipeg	200-300
3	Ottawa, ON	CFB Petawawa	0-100
4	Victoria, BC	MARPAC Esquimalt	100-200
5	Quebec, QC	CFB Valcartier	0-100
6	Fredericton, NB	CFB Gagetown	100-200
7	Halifax, NS	MARLANT Halifax	100-200
8	Goose Bay, Labrador	5 Wing Goose Bay	300-500
9	Ellesmere Island, NWT	CFS Alert	(200-300)[40]

As noted above, and as is the case with STG and solar PV technologies, installation costs are a significant concern. The installation project at Warren AFB in Wyoming, for example, cost $2.5M USD to supply 1.8 MW of power. At a capacity factor of 22.5% (the factor achieved by the turbine farms in notoriously windy Jutland), this translates into 3550 MWH of electrical power per annum. In FY 2007/08, CFB Suffield (to change examples for a moment) used 83,286 GJ of electrical energy, or about 23,135 MWh. Accordingly, assuming the same capacity factor could be achieved, Suffield would need to install 13 of the same turbines recently emplaced at Warren AFB in order to meet its electrical power needs (assuming, of course, that some means of storing electricity for non-windy periods were installed as well). This would cost approximately $20M (Canadian)—close to a third of DND/CF's annual expenditures on electricity. If the capacity factor can be improved, however, and if the lifespan of the equipment exceeds the payback period (and if the energy storage problem can be solved), this might not be a bad investment.

But it may not be an appropriate investment for all CF facilities. Unlike solar power technologies, wind turbines pose some unique concerns for military bases. Spinning turbine blades can negatively impact radars—especially ground-based air defence radars and air traffic control systems. The problem is sufficiently severe that private property owners who are considering installing wind turbines are obliged to consult with DND/CF if they are planning of building a turbine (a) within a 100 km radius of any DND Air Defence Radar; or (b) within a 60 km radius of any DND Air Traffic Control Search Radar. Furthermore, DND regulations prohibit construction of any wind turbine "within 10 km of a major military airfield."[41] This policy complicates the use of wind power at bases with airfields, or that are located close to major civilian airports (e.g. CFB Gagetown, where the base proper is less than 10 km from the Greater Fredericton Airport). That said, new technologies (such as altered turbine blade profiles and composite materials) can reduce interference; and there is nothing preventing turbines from being constructed further away, if transmission costs and losses do not degrade performance to the point that the turbine option is no longer cost-effective.

[39] Data derived from the interactive wind energy maps at http://www.windatlas.ca/en/maps.php. [See also https://glfc.cfsnet.nfis.org/mapserver/pv/index_e.php.

[40] No information is provided for Ellesmere Island; however, most of the Arctic archipelago has an average wind energy availability in this range).

[41] See http://www.airforce.forces.gc.ca/8w-8e/units-unites/page-eng.asp?id=692.

Finally, as is the case with STG and solar PV generation, the key problem with wind power is that it is an intermittent generation technology. Where continuous power is required (e.g., at military facilities), either a conventional backup system must be installed, or some means of energy storage must be used. Energy may be stored in potential (chemical, gravitational or electrical) forms, or in kinetic forms (i.e., heat, whether in conventional thermal reservoirs, or in advanced phase-change materials, as is already being used on an industrial scale in Canada).[42] As noted above, molten salt has been used as a thermal storage medium for some high-temperature solar thermal generation plants. Natural Resources Canada, for example, is currently conducting experiments on in-ground thermal storage using a variant of a geothermal well array, with the boreholes deliberately sited close together in order to conserve thermal energy that may later be withdrawn for heating purposes. For numerous reasons (e.g., the thermal capacity and characteristics of soil and rock, inconsistent subsurface geology, thermal losses due to ground water, etc.), it seems unlikely that such a method would work well enough for power storage purposes.

At present, electrical storage relies on conventional battery technology. The mass-manufacture and disposal of conventional batteries (whether lead-acid, nickel-cadmium, lithium, or more exotic types) entail significant environmental costs. Some emerging technologies, however, do look interesting; one concept, currently being investigated at NRCan, consists of an electrolytic reactor that uses electrical power from an intermittent source to separate one chemical into two component reactants. These are stored, and later recombined in the reactor to produce electrical current. The potential storage capacity is limited only by the size of the storage vessels. If such a system could be scaled up, it might prove a means of "smoothing out" the power production characteristics of intermittent technologies like wind and solar power. Finally, intermittent technologies like wind and SPV can be exploited to charge electrically-powered vehicles. With "smart-grid" technology, these vehicles may thereafter be used as an emergency power source, supplementing other available power sources.

3.2.2.4 Packaged nuclear generation

Since the advent of nuclear power generation, licensing and regulatory issues, costs and proliferation concerns have generally restricted the use of nuclear power plants to the sort of large scale facilities generally associated with hydroelectric, coal- and oil-fired generating stations. However, nuclear fission reactors are able to concentrate a considerable amount of power production capacity into a very small space (a feature most readily obvious in nuclear-propelled submarines). This has led researchers to investigate the potential for packaged nuclear generators capable of producing a few tens of megawatts of power, rather than the hundreds or even thousands of megawatt generation ranges characteristic of large-scale power plants.

In cooperation with Los Alamos National Laboratories in the United States, a company called Hyperion Power Generation, Inc., is engaged in developing for commercial sale a small, factory-sealed, mass-produced, easily transportable nuclear reactor for on-site power production. The design is based on TRIGA research reactor technology, and the design is reportedly targeted at industrial uses, disaster response, remote communities and infrastructure, and military facilities. Operating on a molten, low-enriched (ca. 10% U-235) uranium hydride core, the reactor is

[42] For a discussion of the use of phase-change materials for thermal storage, see the CANMET website at http://www.nrcan.gc.ca/es/etb/cetc/cetc01/htmldocs/Publications/factsheet_thermal_storage_etp_e.htm.

expected to measure 1.5 metres in diameter and 2 metres high; weigh 15-20 tonnes in shipping configuration; and generate 70 MW (thermal energy) and 27-30 MW (electrical energy).[43]

Hyperion is reportedly aiming to sell their reactors at a cost of $1400 per kW. This suggests that the price for the above-mentioned unit would be about $38M-$42M—a significant expenditure, to be sure, and about half of what DND/CF spends on electricity per annum, but not entirely unreasonable in the context of the ca. $3M that Cold Lake spends on electricity per year. The need for a turbine/generator station to make use of the steam generated by the reactor, as well as water supplies for cooling, would impose additional installation costs. These could be partially offset by using the waste heat produced by the reactor to replace heat energy currently supplied through conventional means. 70 MW of heat production equates to 613,200 MWh per annum, or roughly 2.2 PJ, more than four times Cold Lake's annual consumption of heat energy (496Tj). Costs could be further reduced by using the excess heat and electricity generated by the reactor to power on-base housing (CFHA figures show that Cold Lake housing units consumed more than 5M m^3 of natural gas, and more than 12.5 TWh of grid electricity, in FY 2007/08).

Nuclear power eliminates fossil fuel consumption and produces no greenhouse gases. Worldwide uranium reserves are known to contain sufficient fissile material to meet global power requirements for centuries. To the extent that nuclear power has disadvantages, these lie in the associated costs of infrastructure, the need for large amounts of cooling water (for large-scale plants, at least; information available on the Hyperion design does not include flow-rates for cooling water), and widespread public concerns, both valid and misplaced, about safety and reliability. Waste disposal is also an issue, although a relatively minor one; the Hyperion design reportedly produces only a "softball-sized" slug of waste every five years, which could easily be accommodated by the waste-disposal facilities at major Canadian nuclear generation plants. Security and proliferation are also matters of concern. Thus, while packaged nuclear reactors would appear to offer a viable alternative power generation solution, especially for remote, hard-to-power facilities (for example, CFS Alert), they bring with them numerous issues that would have to be addressed in the course of evaluating their feasibility as alternative power sources for DND/CF facilities.

3.2.3 Synthetic fuels and biofuels

This chapter did not address synthetic fuels derived, for example, from coal. Some of these are already being used or tested on a small scale. In August 2008, for example, the US Air Force completed operational certification of a blended synthetic fuel mixture for the KC-135 Stratotanker, and plans to certify the C-5 Galaxy, KC-10 Extender, and C-130 Hercules on synthetic fuel blends by the end of the calendar year.[44] Synthetic fuels of this nature, however, are still hydrocarbons derived from fossil fuels that evolve carbon dioxide when combusted. Furthermore, producing synthetic fuel from coal results in the emission of considerably more carbon dioxide than producing fuel from crude oil. Thus, while synthetic fuels may offer an answer to problems of energy independence and oil security, they do not meet the criteria specified in the tasking for this project.

---

[43] It is worth noting that this last figure accords closely with the average electrical base load of 4 Wing Cold Lake (ca. 10 MW) calculated above for discussion purposes.

[44] "Stratotanker certified to use synthetic fuel blend," *The Pentagon Brief*, 22 September 2008, accessed at http://www.pentagonbrief.wordpress.com .

Biofuels are popular with advocates of alternative energy because, in theory, they do not add to the "carbon load" of the atmosphere because they do not release subterranean or fossil carbon; they only release carbon previously sequestered by surface vegetation. The enthusiasm for biofuels is thus based almost entirely on the belief that human industrial activity, specifically consumption of fossil fuels, plays the dominant role in driving climate change. Regardless of the accuracy of the anthropogenic global warming thesis, the argument that surface carbon is less threatening than fossil carbon is not logically sustainable, as biofuels are almost exclusively produced from plant matter grown on land which must first be cleared of competing biomass which, one presumes, was already engaged in "sequestering" carbon dioxide (and, far more importantly from a human perspective, turning it back into oxygen, water, and complex carbohydrates). Biofuels have other problems as well: they have a lower energy density and are more expensive to produce than conventional fuels, and in many cases—for example, in the fermentation of grain sugars to produce ethanol—their production generates vast quantities of carbon dioxide.

Moreover, biofuels pose the same problems as synthetic fuels, and introduce some new ones as well. The production of biodiesel, like synthetic fuel (albeit by transesterification from vegetable or animal fats, rather than from coal) consumes energy, and produces carbon dioxide. The resulting product has a lower energy content by weight than standard diesel fuel (by up to 10%), and leads to challenges deriving from gelling (due to the presence of fatty acids of animal origin), viscosity and water contamination. All of these may pose serious operational problems when attempting to use biodiesel in high-performance, especially turbine, engines. Moreover, growing the vegetable matter to feed production facilities is a space-intensive operation. It has been estimated that the entire arable land mass of the United States—half of its physical area—would have to be shifted to feedstock production to meet America's fuel needs with biodiesel produced, for example, from soybeans. The production of biodiesel from algae, if perfected, could lower the total amount of land required to an area only slightly larger than Maryland.[45]

Finally, as the events of the spring and summer of 2008 demonstrate, the growing interest in, and government subsidies of, biofuels has a demonstrable economic downside. Biofuel production, as noted above, is highly demanding of arable land; should biofuels become more remunerative than, for example, growing food crops (which is what happens when governments subsidize biofuel producers), it is likely that farmers in a position to do so will switch en masse to production of feedstock crops. This is what happened in 2008. The result was scarcity of food grains, and therefore—in response to market forces—a significant and entirely foreseeable increase in their price. This especially affected basic food grains which, like corn, may be used either for food or fuel. This in turn led to a rise in food prices worldwide, and to widespread concern that the growth of the biofuels sector would lead to hunger and even starvation, particularly in impoverished countries.[46] The crisis was, ironically, averted by another; collapsing global financial markets led the price of oil to drop by more than 50%, largely eliminating the financial incentive underwriting the burgeoning biofuel industry (although not the government incentives supporting it).[47] The problem, however, has not gone away; it will resurface any time

[45] "A promising oil alternative: algae energy", *The Washington Post*, 6 January 2008, N06.
[46] Elisabeth Rosenthal, "U.N. Says Biofuel Subsidies Raise Food Bill and Hunger," *The New York Times*, 8 October 2008.
[47] In Canada, biofuels are exempt from Federal and many Provincial excise taxes. In its 2007 budget, the Federal government proposed replacing the excise tax abatement with a multi-year incentive program beginning at $0.20/l.

industrial feedstocks may earn farmers more per acre than producing food (regardless of whether this occurs through legitimate market forces or through government subsidization). Until alternatives such as algae-derived biofuels are perfected, the Western energy-consuming nations simply do not have enough arable land to produce both fuel and food. Choosing between the two should not be a difficult task.

3.3 Summary

3.3.1 Alternative energy options for mobility purposes

From the point of view of fuels for mobility purposes, there are few options available or on the horizon to significantly reduce DND/CF's expenditures, its reliance on fossil fuels, or its production of carbon dioxide.

Biofuels, especially biodiesel, can be incorporated into low-ratio fuel mixes for commercial-pattern ground vehicles with relatively few difficulties. However, such fuels are still not widely available (despite government subsidization); do not reduce carbon emissions; and may raise rather than reduce fuel costs. Furthermore, as noted above, when used in higher ratio mixes, they pose operational challenges ranging from viscosity, gelling and water content problems, to the fact that their lower energy density means that a tank, truck or APC won't get as far on the same quantity of fuel. Finally, as ground vehicle fuels comprise only a small proportion of DND/CF's expenditures, fossil fuel reliance, and GHG production, even a major shift in this area would have only a minor aggregate impact.

The use of biofuels, either alone or in blends, by naval vessels is slightly more promising. The same technical and operational challenges must be overcome, but the large bunkers aboard ship provide a greater margin for error in terms of the lower energy content of biofuels. Again, however, even a major shift will not make a large difference in terms of cost or GHG production.

Aviation fuels are the single costliest line item in the DND/CF energy budget. They also pose the greatest technical problem from a perspective of alternative fuels. The only available alternative to JP-8 at present are the synthetic fuel blends derived from coal currently being tested by the USAF. While the availability and use of such fuels is an important strategic option for the US, they answer none of the requirements of this project. The only problem they are designed to solve is the strategic imperative of reducing Washington's reliance on foreign oil. This is not a strategic concern for the country that owns the Athabaska oil sands.

The only alternative energy source for mobility purposes that eliminates both fossil fuel consumption and GHG emissions is nuclear power. Nuclear propulsion systems are, however, only practical for naval vessels at present, and for that matter, only for major vessels (e.g., aircraft carriers, attack submarines, fleet ballistic missile submarines, and cruisers). Canada has no such vessels, and no plans to build or acquire any in the future. Nuclear propulsion could certainly be adapted to frigates, destroyers, support ships and small submarines, but development of the expertise and infrastructure to support a naval nuclear propulsion program would require years of effort and entail enormous costs (as an alternative, Canada could buy or lease nuclear-propelled warships from the US, or have them built and serviced there). And, as was discovered when the 1987 Defence White Paper was issued, nuclear power for naval vessels poses carries a significant political price tag. While nuclear propulsion has much to recommend it, it is probably not a viable option for the foreseeable future.

Pluggable hybrid electric vehicles (PHEVs) or electric vehicles (EVs) may offer a means of moving away from fossil fuels for vehicular propulsion, provided that sufficient electrical power is available to operate them. The adoption by DND/CF of locally generated power (e.g., via packaged nuclear generation or one of the various renewable sources) offers the opportunity to make greater use of PHEVs/EVs. These vehicles are particularly well-suited for local, short-distance administrative tasks, and for exploiting intermittent technologies like wind and SPV generation; and, when parked, can serve as storage batteries for emergency use, feeding electrical energy back into local grids as required.[48] However, a number of factors at present augur against the widespread civilian/commercial adoption of EVs. These include, but are not limited to, cost, range, capacity, the lack of a national support infrastructure, and the current state of the North American electrical power grid, which is already operating at close to maximum capacity due to a failure to construct enough generating stations to keep up with demand.[49]

3.3.2 Alternative energy for heating

This is probably the single easiest question to answer. One-third of the energy consumed by DND/CF is used to heat buildings, which is not surprising in a northern country. What is surprising is that greater use is not being made of commercially available technology in this area to significantly reduce DND/CF's energy costs, reliance on fossil fuels, and carbon dioxide production. The place to begin is with existing technology for improving the energy efficiency of buildings, principally by altering construction design to improve insulation, and to make better use of passive solar energy techniques to reduce reliance on external energy for heating in winter and cooling in summer. "Green Building" guidelines and policies are already in place, and should be continuously improved as new research leads to new energy-saving technologies and techniques.

Geothermal heating and cooling systems use small amounts of electricity to leverage far larger amounts of solar energy stored in the ground in order to heat buildings in the winter, and to extract heat from buildings in the summer. The technology is mature and is growing in popularity, both with government departments and in the civilian building field (as noted above, the US military is making increasing use of geothermal cooling). The coefficient of performance of water-based GSHPs runs from 3.0 to 3.5, roughly four times as efficient a use of energy as even the most energy-efficient natural gas furnace (AFUE 0.9); DX GSHPs are more efficient still (COP 4.0+) due to the fact that their single-loop design eliminates the requirement for two separate compressor systems. Furthermore, geothermal systems can be designed for differential heating based on facility usage patterns, leading to greater energy savings, and can even scavenge and reallocate waste heat during cooling cycles to save more power. Geothermal systems tend to have high up-front installation costs, but their relatively low maintenance requirements (in comparison with conventional heating and cooling systems) and their guaranteed energy savings

[48] A fleet of PHEVs/EVs may be used for transportation, or for emergency power storage, but not both. Buying an electric vehicle fleet simply to serve as a means of storing emergency wind-generated power when batteries would do the job is as inappropriate as buying a fleet of Cadillac's to store gasoline.

[49] For an appreciation of the scope of this problem, see "Lights Out In 2009?", Neaten Energy Council, September 2008, accessed at http://scienceandpublicpolicy.org/other/lights_out_in_2009.html.

over time ensure recovery of investment costs. They require significant investment in non-mobile infrastructure (the ground loop portion of the system) and thus are not suitable for deployable applications.

More esoteric options should also be explored. Solar thermal heating may be possible at some locations in Canada; and should DND/CF decide to investigate the packaged nuclear generation option below, waste heat from reactors could be used to provide heat to buildings. These options also offer the benefits of eliminating both reliance on fossil fuels and carbon dioxide emissions. The most important questions will be whether these options are feasible, and whether they are cost-effective in terms of savings vs. installation costs.

This study has not considered cogeneration technologies, all of which, at present, involve combustion either of carbohydrates or of hydrocarbons, and therefore produce carbon dioxide. While such technologies should be further investigated (and are, indeed, already in use at some CF bases, e.g., CFB Petawawa), they are only means of obtaining slight increases in efficiency from existing fuel-combustion systems, and as such do not represent a transformative technology. That said, high-performance cogeneration systems involving, for example, Stirling engines, and capable of producing kilowatts of electricity and heat, are being produced in very small, packaged units for domestic use. Stirling external combustion engines can be optimized to burn virtually any combustible fuel. Such systems might prove valuable to DND/CF for deployed operations; for example, to provide both electrical power and heating to a deployable headquarters or a field hospital, while burning considerably less fuel than a traditional generator.

3.3.3 Alternative energy for electrical power

Of the four alternative energy options for electrical power generation discussed above, three—solar PV generation, STG and wind power—have high installation costs; have varying feasibility depending upon weather characteristics and insolation at different geographical locations; and are intermittent in nature, thus requiring efficient thermal or electrical energy storage to provide uninterrupted power at night or when the wind is not blowing. Furthermore, wind turbine generation poses the additional problem of interference with air defence and air navigation radars, and thus would pose installation challenges at some DND/CF facilities. While each of these alternative energy options should be evaluated for potential applicability to reduce reliance on fossil fuels, present technology does not permit any of them to serve as the exclusive energy source at any DND/CF facility. Given that grid electricity is a major source of energy consumption for DND/CF, however, as well as the most "carbon inefficient" of DNDs energy sources, any move to solar or wind power, however small, would prove beneficial in terms of reducing costs, reliance on fossil fuels, and carbon dioxide emissions. As with all investigations of incremental power sources, the key question will be cost-effectiveness.

The only electrical generation technology presently available that eliminates dependence on fossil fuels, produces no GHG emissions, and is continuous and reliable, is nuclear generation. DND/CF should examine emerging packaged nuclear generation technology as a potential means of moving large electrical consumers like CF Bases, especially remote ones, entirely off the grid. Installation costs will be a significant factor, but these can be partially offset by adapting infrastructure to make use of waste heat, and by selling excess generated electrical power and/or heat energy back to local grids. The scientific and technical infrastructure for nuclear power generation is already in place in Canada, and political sensitivities are likely to be less acute than would be the case if the Department sought nuclear-propelled naval vessels. This option should be further evaluated with a view to determining where packaged nuclear generation might prove most cost-effective for DND/CF.

4 A strategic approach to alternative energy

Any strategic framework to guide the investigation and eventual adoption of alternative energy options by DND/CF will be circumscribed by largely non-technical factors. These include, but are not necessarily limited to, political and legal constraints; strategic factors; the need to ensure security, sustainability and diversity of energy supplies; pollution and environmental considerations; the question of relative costs of energy; and operational factors peculiar to the Defence establishment. This chapter will discuss how these various factors could impact the alternative energy options available to DND/CF. Based on this assessment, the chapter will conclude by positing a hierarchical array of strategic principles and ancillary considerations to help channel investigative efforts into, and eventual exploitation of, alternative energy options. Taken in conjunction with the conclusions already arrived at (concerning the most important areas of energy consumption and GHG production in DND/CF, and the most efficient means of addressing them), these principles will serve as the foundation for the strategic framework sought as the outcome of this paper.

4.1 Political and legal factors

The political and legal factors that circumscribe and, in many cases, constrain questions of energy consumption and power production are legion, and are highly relevant to any program of research into alternative energy options for DND/CF. These have been addressed in great detail elsewhere, most notably in the Department's own Sustainable Development Strategy (SDS) and its copious environmental guidance and associated documentation. It would therefore be superfluous to review them in the context of this paper. It is sufficient to recall that, as a Government Department, Defence is governed not only by national legislation and federal regulations in all areas of energy consumption and emissions control, but is also subject to policies applicable to Federal Departments and Agencies (such as the Green Building initiative), as well as to the provincial legislation and regulations in force wherever the Department maintains facilities, or conducts training and/or operations.

Much of the Department's internal documentation advocates a role for Defence as a "leader" in environmental stewardship, and to the extent that this is possible without compromising DND/CF's ability to execute its primary functions (e.g., defending the nation and generating effective, combat-capable, sustainable forces for air, land, sea, joint and special operations), this is a laudable aim. However, it must be recognized that environmental "leadership" is a self-imposed aim, and, as such, Defence leaders and managers must be equipped with a mechanism for de-conflicting competing priorities and devising trade-offs between them. This is particularly germane in when finite resources must be allocated, or in cases where it becomes necessary to determine which of several mutually exclusive priorities must fall by the wayside in order to ensure that Defence's key assigned missions are accomplished.

Defence—by virtue of its unique status as the arm of government charged with using force in defence of Canada's national security interests at home and abroad—enjoys slightly greater latitude than many other Government Departments in this respect. The operational exemption in the *Alternative Fuels Act* is only one example thereof. The present interest in new environmental legislation and/or regulations, especially in the area of controlling carbon emissions, could impose a heavy operational and financial burden on Defence, and could limit, either by accident or by design, the range of possible choices for examining and implementing future alternative energy options. Leaders and managers in DND/CF need to remain abreast of all such legislative and regulatory initiatives in order to ensure that those charged with preparing and enacting legislation and regulations are aware of the potential impact on Defence's energy and power needs, and therefore upon its operational capabilities. In many such cases, working to achieve a national security exemption for Defence activities may be the preferred option.

Finally, it is important to recall that Defence conducts all of its business in full public view; this, ultimately, is the rationale underlying the Defence establishment aspiring to "leadership" in all things environmental. Public opinion will inevitably play an important role in any decision by DND/CF to adopt alternative energy options, particularly if the options in question are technologically novel. Public sensitivity about government activities, expenditures, pollution, etc. can have a significant impact on program. Decision-makers would do well to keep public opinion in the forefront of their minds when moving ahead with any plan to investigate and/or adopt alternative energy options.

4.2 Strategic factors

4.2.1 Executing the defence mission

According to the DND *2008-2009 Report on Plans and Priorities*, the Department's principal strategic function is to "generate and sustain relevant, responsive and effective combat-capable integrated forces." This breaks down into four strategic sub-activities: generating and sustaining "forces capable of maritime effects;" "forces capable of land effects;" "forces capable of aerospace effects;" and "joint, national, unified and special operations forces."[50] It goes without saying that bringing "effects" to bear in any of these environments or areas of specialization requires power, and therefore entails the consumption of energy. Thus, any examination of alternative energy sources for DND will inevitably have an impact on one or more sub-activities within the Department's overall key strategic mission.[51]

Maintaining situational awareness, conducting operations at home and abroad, providing advice to the Government of Canada, engaging in defence research and development, and all of the other myriad tasks within the Department require power, and therefore imply the consumption of energy to generate that power. Even so limited an objective as reducing the cost of energy could have a significant aggregate effect across the broader department. There are no aspects of the Defence establishment or the Defence mission that will not be impacted by the investigation and eventual adoption of alternative energy sources.

Accordingly, one of the key considerations in investigating and adopting any alternative energy option will be an objective and comprehensive assessment of the extent to which doing so is likely to affect the Department's principal strategic functions. Another is the fact that, as the

---

[50] Department of National Defence, *2008-2009 Report on Plans and Priorities* (Department of National Defence: Ottawa, 2008), p. 32.
[51] Indeed, if it were not intended to have an impact on one of these activities, it would be difficult to justify engaging in such a research and development program.

government's "force of last resort," the ability of the Defence establishment to react to crises must not be vulnerable to failure of civilian infrastructure. DND must retain the capacity to conduct domestic operations despite the loss of grid electricity or natural gas due to a natural disaster, a terrorist attack, or some other unforeseen event. Alternative energy sources—off-grid power generation and the use of local energy sources for heating—can offer an important back-up to civil energy sources, and enable DND to maintain operations despite widespread infrastructure failures.

4.2.2 Sustainable development

DND, like other Government Departments, has, in accordance with Federal direction, crafted and implemented a Sustainable Development Strategy (SDS). The fourth iteration of the DND SDS, which came into effect on 1 April 2007, contains four strategic commitments derived from Federal guidance on sustainable development: sustainable land management; promoting the application of "green building" principles; implementing a comprehensive "green procurement" program; and preventing "environmental impacts of specific activities over which Defence can exercise a mitigating influence."[52] A performance measurement system has been put into place to provide precise (in some cases, very precise) technical standards that must be met.

Any examination or adoption of alternative energy sources will have to conform to the Department's SDS. This includes meeting the strictures of the 16 sub-commitments that DND has adopted (detailed at table 1 of the document).[53] Some of these have few or no implications for alternative energy research and implementation; others may have a significant impact. Strategic Commitment (SC) 2.1, for example, commits the Department to greater implementation of "green building" practices in infrastructure construction and renovation. Among other things, this could be taken to imply that all future construction and renovation should meet EnergyStar standards for insulation and heat loss. SC 3.1 requires DND to "support the Federal green procurement agenda", which could impact the Department's ability to exploit energy sources that do not meet Federal standards for, e.g., carbon dioxide emissions. SC 3.4 commits DND to "using and maintaining greener vehicles", a criterion that could, if taken beyond the limited practical indicators listed in the table, lead the Department to greater reliance on biofuels before such fuels are commercially feasible (or on PHEVs/EVs before these are capable of replacing existing civilian-pattern vehicles), and before the technical challenges associated with these fuels and alternative energy systems have been satisfactorily resolved.

The most significant "sustainability challenge" for DND, however, likely derives from SC 3.5, which requires DND to reduce GHG emissions by 15% by the end of FY 2009-2010. There are only three means of achieving a significant reduction in GHG emissions from vehicles burning conventional fuels: switch to a non-GHG emitting power source for vehicular transport (which is not technically feasible at present); vastly improve the efficiency of internal combustion engines (which does not appear to be in the cards; nor is it a panacea, as the "perfect" combustion even of a "clean-burning" fuel like methane still produces one molecule of carbon dioxide and two molecules of water vapour, both of which are greenhouse gases, for every molecule of methane

[52] 2008-2009 RPP, 78.

[53] "Environmentally Sustainable Defence Activities: The National Defence Sustainable Development Strategy: 4th Edition" (Ottawa: Department of National Defence, 2006), pp. 23-30.

burned); and/or to reduce the operating time of the existing vehicle fleet by 15% or more. This latter measure will be difficult to achieve in a period of high operational tempos.

It is likely for this reason that SC 3.5 is restricted to DNDs “commercial pattern road vehicle fleet.” While this protects DNDs operational capability from the requirement to achieve a 15% reduction in GHG emissions, it also results in the target being virtually meaningless. DNDs civilian pattern fleet runs almost entirely on gasoline and diesel fuel, and as shown above, all of the gasoline and diesel fuel consumed by DND accounts for only 5% of the Department’s energy expenditure—and that includes diesel fuel burned by military pattern vehicles, both in Canada and on operations. The civilian-pattern fleet consumes only 7% of all of the energy consumed for mobility purposes, and accounts for only 7% of all of the GHG produced. While the SDS reduction guidelines protect DNDs operational capability, the result is a miniscule target for GHG reductions.

Finally, SC 4.5 commits DND to the very specific target of reducing, by 2010, overall GHG emissions by 134,900 tonnes of carbon dioxide equivalent below the 1998 baseline, in the areas of infrastructure and married quarters. The Department is to accomplish this by using “green power” wherever available and economically feasible; promoting energy conservation; adopting higher standards for heating, refrigeration and air-conditioning; and reducing the amount of building space requiring heating and lighting.[54] This is not an insignificant target. According to figures gathered and calculate by ADM(IE), DNDs total calculated GHG emissions from infrastructure in FY 2007/08 was roughly 967.6 Mt of carbon dioxide equivalent (an increase from 957 Mt in 1998-99), the result of heating buildings and producing grid electricity.

Table 11 - SDS 2006 requirement for GHG reductions (SC 4.5)

Ser	Activity	kt CO2 eq.	
		1998	2008
1	Infrastructure	957.07	967.6
2	CFHA	255.92	144.89
3	TOTAL	1212.99	1112.49
4	Delta from 1998		-100.5

As can be seen from table 11, most of the mandated reduction—100.5 of 134.9 kt CO_2 eq.—has, due to the divestment of large numbers of CF housing units, already been achieved. The remainder—34.4 kt CO_2 eq.—represents a reduction from current infrastructure emissions levels of about 3.1%. This should be achievable.

But achievable how, exactly? There are three means of reducing by the aggregate GHG emissions from heating and power-generating systems that consume fossil fuels. The first is to convert at least some of the Department’s fuel-consuming heating systems to non-fossil fuel options. One way to do this would be to greatly reduce the Department’s consumption of grid electricity. It is difficult to see how this could be achieved through “efficiencies,” as doing so equates to shutting down Departmental operations for a proportional period of time.[55] The only other practical means

[54] DND SDS 2006, 30.

[55] Moving from natural gas to an electrically driven option like geothermal heating and cooling will only achieve partial efficiencies in this area in view of the oddly high GHG conversion figures for grid electricity that are used and promulgated by CSA.

of reducing GHG emissions resulting from electrical power generation is to move to new, non-emitting electrical generating technologies such as SPV, STG or packaged nuclear generation. The near-term replacement of a significant proportion of the Department's demand for electrical power with alternative, non-carbon emitting technologies would, as noted above, come with a significant price tag, even assuming that outstanding technical concerns could be resolved (e.g., siting wind turbines, storing electrical power, etc.). This is not meant to be an argument against making use of such technologies to help meet DNDs target for GHG reductions; it is simply meant to ensure that any solutions predicated on such options take into consideration the full costs of doing so.

Another means of achieving a significant reduction in GHG emissions would of course be through a proportional reduction in operations. Taken altogether, grid electricity and the use of natural gas for heating account for more than half of the Department's GHG emissions. A comprehensive reduction in infrastructure held and operated by DND/CF would lead to a significant drop in GHG emissions. Put another way, the simplest means of consuming less fossil fuel and emitting less GHG is to reduce the facilities, capabilities, commitments and operational tempo of the Department. It is of course up to the Government to decide whether maintaining the Department's operational capabilities and the current level of domestic and overseas commitments is more, or less, important than reducing Departmental GHG emissions.

Finally, it is important to note that all legislation, regulations and policies—whether Departmental, Provincial, Federal, or for that matter, international; and whether extant or contemplated—that are aimed at reducing GHG emissions, are predicated solely upon the continued validity of the anthropogenic global warming thesis. Falsification of the AGW thesis would entirely eliminate the justification for efforts to reduce GHG emissions.[56]

4.2.3 Interoperability with allies

As a key security partner to the US and a founding member of NATO, Canada's strategic paradigm for expeditionary operations is of necessity focussed on fighting almost exclusively I a coalition or allied context. In combined operations, interoperability is a paramount logistic concern, to the point that NATO has spent decades struggling to achieve standardization in such areas as artillery calibres, rifle ammunition, and fuel supply. While questions of logistics would normally be an operational concern, it is highly unlikely that Canada will ever engage in expeditionary operations other than in the company of its key international security partners. The continued ability of the Canadian Forces to operate in conjunction with allies will for the foreseeable future remain a key strategic concern for Canada.

Accordingly, the investigation and eventual adoption of alternative energy sources should be undertaken on a basis of close communication between Allies. Situational awareness of each others' activities in this area is not sufficient; the continuous exchange of information, results and plans will be necessary in order to ensure that interoperability is at a minimum maintained, and enhanced wherever possible. It must not be jeopardized.

[56] For a more in-depth discussion of the scientific, political, strategic and economic implications of the AGW thesis, see D.A. Neill, "'Ugly Facts': Ringing down the curtain on the great climate panic," unapproved, unpublished draft DRDC Technical Memorandum.

In practical terms, this will mean close cooperation with US military research and development in the field of alternative energy sources. The two most likely areas for cooperation will be the identification of new fuels for operationally deployed forces (aviation fuel as a priority, followed by fuel for naval vessels and ground vehicles), including the security, stability and delivery thereof; and the provision of electrical power, especially for electronic and air handling equipment, to deployed forces.

From the perspective of the Defence Science community, the maintenance of close liaison with the industrial and academic communities, both at home and abroad, will be similarly important. The investigation of alternative energy technologies will be an undertaking of enormous scope, with nationwide, even global implications. DND should ensure that it is in a position to both contribute to, and profit from, non-defence research in the fields of power and energy, and to both benefit from, and contribute to, research and other relevant activities being undertaken by other Government departments. A key goal of such contacts should be to ensure that alternative energy technologies are viable and self-sustaining within the civilian economy, before making heavy investments of Defence resources in them.

4.3 Security, sustainability and diversity of supply

A number of other strategic factors play a role in influencing the investigation and eventual adoption of alternative energy sources. The first of these (in no particular order of relevance or importance) is ensuring a secure, sustainable and diverse supply of energy for conversion into the types of power that the Department needs.

Security refers to the ability of the energy consumer to neutralize or overcome any vulnerabilities in the energy supply chain, from production to consumption. While terrorist attack is the threat most commonly alluded to, energy supply chains are equally, if not more, vulnerable to natural phenomena, especially those deriving from weather events. The 1998 Central Canada ice storm, for example, destroyed or damaged significant swathes of the electrical grid of southern and eastern Ontario, Quebec and New Brunswick. Many customers were without electricity for days, and in some areas, it was months before power could be restored. Similarly, the vulnerability of Gulf Coast oil platforms to hurricanes, and of oil super tankers to storms, underscores the vulnerability of many parts of the petroleum supply chain.[57]

This is not to say that human threats to security of supply do not play an important role. Oil and gas infrastructure in Iraq (and elsewhere in the Middle East) has been a preferred target of jihadists, especially Al Qaida. In recent years, natural gas pipelines in Western Canada have been struck by (largely ineffectual) attacks on several occasions; and the recent hijacking of a Saudi oil tanker by Somali pirates off the Horn of Africa may be an indication of things to come. Alternative energy options will not offer a useful alternative to conventional energy sources if they are more vulnerable to existing threats than the energy sources that they are intended to replace.

Sustainability is another strategic concern. While there are at present no candidate alternative energy options that fall into this category, those charged with evaluating the potential for any

---

[57] Energy infrastructure is an area of key focus in the critical infrastructure protection planning of Public Safety Canada. See http://www.publicsafety.gc.ca/prg/em/cip/strat-part1-eng.aspx.

given alternative energy option must ensure that the proposed replacement technology will last as least as long as the conventional energy source it replaces. This is a challenging proposition, given that, for example, global coal reserves are estimated to be sufficient for some hundreds of years; and that, historically, exploitable oil reserves have grown in lockstep with oil consumption. Any candidate alternative to nuclear power should ideally promise cheaper power for at least as long as proven supplies of uranium are likely to last—some forty centuries.

Finally, diversity of supply needs to be taken into consideration. Diversity often flies in the face of operational considerations which, for example, attempt to streamline logistic burdens through standardization. In recent years, this has manifested itself in single-fuel initiatives: attempts to put all ground vehicles, for example, or all air vehicles, or even both, onto a single-fuel option in order to simplify the resupply challenge. Energy homogenization, however, can bring strategic costs as well as operational benefits. Just as a single weapons system may be obviated by a single technological advance by the enemy, a fleet that uses a single fuel type could fall victim to an economic, political or technological development that renders that fuel type either unavailable or useless, grounding all vehicles that employ it.[58] Accordingly, all investigations of alternative energy options should include a vulnerabilities analysis to assess whether adoption of that energy source might not lead to greater energy supply chain vulnerabilities than is the case at present.

4.4 Pollution and environmental considerations

Human activities, especially the consumption of energy, indisputably impact the environment. DND/CF plays a significant role in the overall impact of Government activities on the environment, in three ways: through land use and management; through energy consumption and pollution; and through the use of hazardous industrial and military materials not commonly used by other government departments or by civilian industry.

The Department is the largest land user in government, and the manner in which it uses much of its land (e.g., for military training) can be especially disruptive of the natural environment. While DND/CF can, and in fact does, take steps to mitigate the environmental impact of training and operations, there is little that can be done to minimize the effect of things like mechanized warfare training, the use of high explosives, and the burning of large amounts of fuel. Training and simulation technologies offer a means of reducing these impacts somewhat, and to the extent that such technology enhances the training experience and improves operational effectiveness, further integration of such technologies into operational training should be explored. But it is unlikely that field training, especially prior to operational deployment, will ever be entirely eliminated.

Where more research is required is in the area of mitigating pollution that is relatively unique to DND/CF, inter alia the impact on the environment of degradation-resistant toxic chemicals, heavy metals from munitions and other sources, fuel spills in the course of operational training, and waste disposal. The Department has a unique "emissions footprint" resulting from the aggregate of the environmental impact of training and operations, not only in Canada, but also in the nations

[58] One possible scenario is the reported attempts to develop genetically engineered bacteria capable of "eating" petroleum products. Such an organism would likely have very specific capabilities, and thus would be an ideal means of targeting the fuel supplies of an adversary that used a single fuel type for all of its military needs.

where the CF trains and operates. Improvements in this area would also contribute to the health of members involved in training or operational deployments, by reducing exposure to potentially hazardous materials. Enhancing the Department's ability to prevent the release of long-duration toxic chemicals; to prevent, or otherwise neutralize, heavy metal releases from munitions; to prevent, respond to and quickly mitigate fuel spills; and to dispose of waste in an environmentally neutral fashion, would all go a long way towards reducing DND-specific forms of pollution, safeguarding the health of personnel, and enhancing the Department's reputation as a conscientious environmental caretaker.

Any program to investigate alternative energy options for DND/CF should include elements aimed at identifying any novel emissions or pollution problem that new energy sources would entail, and devising means of countering or neutralizing them as part of the larger adoption strategy. Any such strategy will have to be grounded in a robust business case identifying all costs, benefits and risks—both actual and potential—in order to enable managers to make informed decisions about trade-offs between competing priorities.

4.5 Cost

A predominant strategic consideration will of course be the incremental cost of exploiting novel energy sources. It bears repeating that the Department operates on a limited budget allocated by government in order to accomplish a set task list; and that the tasks that DND/CF are assigned tend to result in missions where compromise or failure can bear harsh human and/or political costs. For this reason, as noted above, Departmental operations are often exempted from aspects of government policy, legislation and regulations that might degrade the Department's ability to perform its assigned duties. The *Alternative Fuels Act*, as has already been noted, contains a built-in operational exemption for Defence (and, for that matter, all other Government Departments), in that it requires that 75% of newly-acquired vehicles be capable of using alternative fuels only where it is "deemed both cost-effective and operationally feasible" to do so.[59]

This exemption reflects the reality that until emerging alternative energy technologies are commercially viable (without, as is presently the case with all alternative fuels, extensive government subsidization), any move to integrate them into operations will invariably involve higher operating costs, as well as risking significant exposure in the case of failure of the new technology (or failure to achieve widespread public adoption thereof, which amounts to the same thing). The Department experienced this to a certain extent with the incorporation of small numbers of propane-fuelled vehicles in the 1980s and 1990s; and, in the National Capital Region at least, the Government is experiencing it again with the abortive attempt to incorporate hundreds of ethanol-fuelled vehicles into operations—an initiative that was imperilled when E85 fuel became unavailable due to its commercially non-viability. With oil prices falling again and gasoline back to pre-shock prices, what economic pressure there may have been to drive a sustained, widespread transition to biofuels has declined considerably. As history has repeatedly

[59] *Alternative Fuels Act* (1992), paragraph 4(2).

demonstrated, political pressure to adopt a new technology rarely succeeds in the absence of a durable market incentive to do so.[60]

Cost, therefore, will remain a strategic consideration driving—or auguring against—any incorporation of alternative energy technologies into DND/CF operations. Simply put, it is not economically rational to make a conscious decision to pay more in order to acquire the same capability from exotic sources that one already achieves from conventional sources. And by the same logic, it is even less rational to pay more to obtain *less* capability.

4.6 Operational factors

As noted in the introduction, this paper is aimed at deriving strategic considerations to guide the examination and adoption of alternative energy sources by DND/CF. It deliberately does not address factors that tend to be associated exclusively with the planning and conduct of military operations; these should be more thoroughly investigated through follow-on research. That said, the aggregate impact on operational capability of any move towards alternative energy is *itself* a strategic factor, at least to the extent that adopting alternative energy sources may potentially enhance or degrade the operational capability of the Canadian Forces, either directly (e.g., through base closures or upgrades, through reductions in operating tempo aimed at achieving GHG emissions reductions, or through the purchase of vehicles and equipment that may be more —or less—capable than existing fleets), or indirectly (e.g., by spending a significant proportion of a limited Defence budget on alternative energy sources, thereby reducing funding available for personnel, operations, training and capital equipment purchases).

Accordingly, a follow-on study examining the potential direct and indirect impacts on operations and training of any examination or adoption of alternative energy options should be a priority. Such a study would ideally focus *inter alia* on the impact (either obvious or potential) of the adoption of alternative energy solutions on (1) combat effectiveness; (2) the transportability of fuels and power sources; (3) the logistic burden of transitioning to and maintaining a new suite of fuels and power supplies (set against the logistic burdens associated with current practices); (4) the activities of allies in this area, and means of ensuring continued fuel and power interoperability; (5) the role of training and simulation in reducing energy consumption, and the impact of alternative energy solutions thereupon; (6) potential benefits for, or risks to, safety and human health; and (7) the potential environmental benefits of introducing new fuel and/or power technologies into domestic and expeditionary operations. The study should also identify how reduction in operational capability resulting from the adoption of an alternative energy source can be overcome in order to maintain the overall operational capacity of the force.

The conclusions of such a study would be a valuable component of the overall strategic framework governing how the Department should approach the question of alternative energy sources.

[60] It is important to note that market pressures are not the same thing as artificial disincentives like taxes or penalties—or the sort of emissions trading schemes currently under way in Europe, and being contemplated by *inter alia* the Obama Administration.

5 Conclusion: The Way Ahead

Power and energy are the enablers of all human activity, Defence included. Without energy, vehicles don't move, planes don't fly, ships don't sail. Defence cannot recruit, train, house or move personnel, purchase and ship their equipment and supplies, conduct operations, engage and destroy enemy forces, move or treat casualties, or command and administer the force without energy. Energy is not merely a necessary prerequisite for maintaining and operating a defence force; it is the *sine qua non* of national existence. Without energy, there would be nothing to defend. If maintaining the capacity to use force to protect and advance the state's vital interests is a matter of national security, then it is no less a matter of national security to ensure that the organization charged with this task has unfettered access to the power and energy resources it needs to do the job. **Alternative energy 'solutions' must therefore be assessed on a basis of full costs and benefits; and should have, as their overarching goal, the maintenance, and if possible the enhancement, of the operational capability and effectiveness of the CF.**

5.1 Summary of conclusions

The foregoing sections of this paper offered the following conclusions about DND/CF's energy consumption patterns:

- The ***most costly*** areas of energy consumption are aviation fuel (34%); grid electricity (21%); natural gas (13%); ship's fuel (12%); and land vehicle fuel, i.e., gasoline and diesel (12%). Natural gas is the most cost-effective fuel in terms of energy per dollar; gasoline and diesel, the least cost-effective;

- 85% of the energy consumed by DND comes either directly or indirectly from fossil fuels. The Department's ***greatest reliance on fossil fuels*** derives from its consumption of natural gas for building heat (30%); jet fuel (27%); ship's fuel (11%), and gasoline, diesel and various fuel oils (12%).

- The ***largest areas of GHG emission*** result from the Department's consumption of grid electricity (35%); jet fuel (25%); natural gas (19%), and ship's fuel (10%). Fuel burned by ground vehicles accounts for only 5% of the Department's total calculated carbon emissions. It is worth repeating that the GHG conversion ratios for grid electricity seem inordinately high for a country that derives 75% of its generated electricity from non-carbon emitting sources.

In view of these conclusions, the investigation by DND of alternative energy sources should focus—in descending order of priority—on finding lower-cost, non-fossil fuel, non-carbon emitting alternatives to (a) jet fuel; (b) grid electricity; (c) natural gas; (d) naval fuel, and (e) land vehicle and other fuels. Available or near-term options in these areas are:

- Heating (and cooling) infrastructure: ***geothermal heating and cooling*** and, to a lesser extent, solar thermal heating, should be incorporated into new plant or when renovating existing facilities. In a northern country with relatively low insolation, the geothermal option is likely to be more cost-effective. When building new facilities or renovating old ones, DND should make maximum use of green building and passive solar technologies to improve the thermal efficiency of structures;

- Producing electricity: ***packaged nuclear generation***, solar thermal generation, solar photovoltaic generation and wind generation. All options other than nuclear require thermal or electric storage technologies that do not appear, at present, to offer cost-effective alternatives to grid electricity; thus these options could likely only be employed to augment rather than replace conventional generation. Packaged nuclear generation, while not yet commercially available, is the only option that promises to replace conventional electrical generation technology, eliminating both fossil fuel consumption and GHG emissions entirely;

- Ships fuel: ***nuclear power*** is the only available non-fossil fuel, non-carbon emitting propulsion technology for naval vessels. Creation of the supporting infrastructure and expertise for nuclear propulsion in Canada would likely be prohibitively expensive given the small size of Canadas surface and sub-surface fleets. This could be partially mitigated by purchasing nuclear-propelled vessels from, and having them serviced and refuelled by, the US. ***Biofuels*** emit carbon dioxide, but may offer a non-fossil fuel alternative for naval vessels, if identified technical challenges can be overcome; and

- Aviation fuel: at present ***there are no non-carbon emitting, non-fossil fuel alternatives presently available***. Biofuels emit GHG, and significant technical challenges will have to be overcome before they can be used widely in aircraft. More research is necessary to identify technologically feasible, cost-effective alternatives to JP-8.

Due to the many and serious economic, social and ecological problems deriving from diversion of food cropland to production of feedstock for biofuels like grain-based ethanol, DND/CF should avoid these options. If the Department decides to investigate biofuels, it should confine the examination to fuels produced from waste biomass. The potential utility of emerging biofuel technologies that do not involve diversion of food grains (e.g., algae-based biodiesel) should be further investigated.

It is important to note that because energy consumption patterns are budget- and cost-driven, none of the alternative options identified above are likely to be cheaper than the options in use at present—and some are likely to be vastly more expensive. This is particularly true in areas where technologies are emerging, experimental or not yet commercially viable without government subsidization. Even in cases where alternative energy options are likely to pay for themselves over the longer term through significant reductions in operating and maintenance costs (e.g., in the case of geothermal heating and cooling or packaged nuclear power generation), the initial capital investment in such technologies is almost always going to be significantly higher than for conventional technologies offering similar performance. Such cases should always be subjected to cost-benefit analyses in order to determine whether employing an alternative energy solution will be economically feasible. In this context, it is important to note that, from a Defence perspective, the only factor driving adoption of biofuels are policies aimed at reducing GHG emissions. Canada has no shortage of fossil fuels; and by any measure, fossil fuels are cheaper to use than biofuels, and are likely to remain cheaper for the foreseeable future. Absent the GHG factor, there is no strategic pressure driving DND to investigate or adopt either biofuels, or any other non-fossil fuel energy options.

Adopting alternative energy solutions is almost always going to be more expensive over the short run than continuing to use available conventional options. Amongst other things, this means that if the Department intends to invest in alternative energy options in major consumption areas like building heat and grid electricity, it will have to alter its budgetary model to allow for the long-term recovery of higher up-front installation costs; otherwise, alternative energy options are likely to always be rejected as too expensive.

5.2 A strategic framework for alternative energy

Based on the foregoing, a strategic framework for the investigation and adoption of alternative energy options by DND/CF should consist of a combination of principles, priorities, factors and caveats. These are listed below.

5.2.1 Strategic Principles

Research into and the eventual adoption of alternative energy options should follow the following four strategic principles.

> **Operational Principle:** an alternative energy option **must** maintain or enhance the Department's ability to carry out its fundamental operational missions.
>
> **Cost Principle:** subject to the Operational Principle, an alternative energy option **must** provide power at a proportional cost equivalent to or lower than existing energy sources (taking into consideration the recovery of installation costs through lower operating and maintenance costs over the life cycle of the equipment). Business case analysis must take into account the fully-burdened costs of any proposed new technology. DND should exercise extreme caution when considering any alternative energy technology that has not proven competitive in the broader civilian economy.
>
> **Environmental Principle:** subject to the Cost Principle, an alternative energy option **should** have a net environmental impact no greater than existing energy sources.
>
> **Political-legal principle**: an alternative energy option **must** conform to legal, regulatory and policy constraints. Where these would preclude exploitation of an alternative energy option that meets the operational, cost and green principles, DND should be willing to seek changes to legislation, regulations or policy, as appropriate.

It is important to note from the outset that squaring the circle created by these four principles will not be easy. If there were an energy source in existence that offered greater operational capability at lower cost with less pollution, Defence (and everyone else) would already be using it. Close cooperation with industry to identify emerging technological solutions may be one means of resolving this problem, so long as the risks associated with adopting novel technologies are identified and understood.

One of the policy questions to be addressed in follow-on studies is how these strategic principles should be prioritized—or if, indeed, they should be prioritized at all. Another will be to develop a matrix for decision-makers to assist them in deciding how to apply trade-offs between these principles when investigating alternative energy options.

5.2.2 Strategic Priorities

This study has identified a number of areas where high costs, high fossil fuel consumption, and high GHG emissions combine to suggest the most fruitful areas for the investigation and adoption of alternative energy options. DND/CF should focus its alternative energy research efforts on the following three priority areas:

> **Alternatives to natural gas for heating DND/CF facilities** (focussing on geothermal heating and cooling; solar thermal generation; improved "green building" standards; and the use of waste heat from packaged nuclear power generation);

> **Alternatives to grid electricity** (focussing on packaged nuclear power generation; the potential for augmenting conventional electricity sources through solar thermal and solar photo-voltaic generation; wind generation; and the increased use of co-generation in conventional heating plants); and,

> **Alternatives to fossil fuels for vehicular propulsion** (examining the use of hybrid vehicles for appropriate, non-operational roles; the use of biofuels from waste biomass or biodiesel derived from algae for ground vehicles and naval vessels; the use of biofuels as a replacement for aviation fuel; and a full-spectrum assessment of the costs of nuclear propulsion for major naval vessels).

As noted above, there do not at present appear to be any alternatives to JP-8 fuel that are cheaper, are non-fossil fuel in origin, or that offer lower carbon dioxide emissions; nor are there any that offer greater operational capability. Nonetheless, in view of the fact that aviation fuel is the single most costly form of energy used by DND/CF, the potential payoffs from any developments in this area could be significant. This fact alone is sufficient to justify DND/CF participation in any allied scientific research aimed at identifying alternatives to JP-8.

5.2.3 Strategic Factors

Any investigation into or eventual exploitation of alternative energy options by DND/CF should be structured to take into consideration the following strategic factors (offered in no particular order):

- Conforming, where required, to political, legal and regulatory obligations;
- Maintaining the primacy of the Defence mission;
- Avoiding any increase in pollution, and reducing the emission of pollutants wherever possible;
- Working in close cooperation with allies, especially the US;

- Focusing on secure, sustainable and if possible, diverse alternative energy supplies;
- Minimizing the environmental impact of activities unique to Defence;
- Incorporating, where appropriate, public opinion into decision making;
- Providing power to Defence assets at consistent or, if possible, lower cost;
- Maintaining or, if possible, enhancing the operational effectiveness of Defence forces; and
- Exercising strategic patience, examining the full costs and benefits, both actual and potential, of any alternative energy solution before committing to it.

5.3 Areas for further research

The foregoing conclusions suggest the following areas for further activity:

- Cost-benefit analyses:
    - As a priority, ensure that all planned and future DND/CF facilities, and all renovation programmes, meet “Green Building” standards;
    - Incorporate analysis of geothermal heating and cooling into new plant construction;
    - Conduct a cost-benefit analysis for the conversion of existing DND/CF office and base infrastructure from conventional heating and air conditioning systems to geothermal heating and cooling;
    - Examine the options, costs, feasibility and challenges of moving to nuclear propulsion for the surface and sub-surface fleets;
    - Examine the potential for conventional co-generation (electrical and heat) at DND/CF facilities;
    - Examine the US military experience in exploiting alternative energy sources;
- Engineering analyses:
    - Examine the feasibility of using biofuels produced from waste biomass in naval surface and sub-surface vessels;
    - Examine the potential for wind, solar thermal, and solar-photovoltaic generation of electricity at DND/CF facilities;
    - Examine the potential for packaged nuclear generation at DND/CF facilities;

- Forecast, to the extent possible, the impact on DND/CF energy needs due to emerging technologies, *inter alia* emerging computing and robotics technologies;

- Operational research:

  - Quantify the logistic and dollar costs of delivering fuel to operational theatres, with a view to identifying less expensive means of accomplishing the same ends;

  - Quantify the economic, social and environmental impact on Canada of DND/CF energy consumption patterns during domestic operations;

  - Quantify the economic, social and environmental impact on host nations of DND/CF energy consumption patterns during deployed operations;

- Pure and applied research:

  - Work to resolve the technical problems with the use of biofuels produced from waste biomass in aircraft engines;

  - Work to identify lower-cost, non-emitting, and/or non-fossil fuel alternatives to JP-8;

- Strategic analyses:

  - Quantify the impact of DND/CF domestic operations on vulnerable environments, both at home (e.g., the Arctic) and abroad;

  - Examine the impact of energy security questions on domestic and allied operations; and,

  - Identify the potential strategic impact on DND/CF capabilities and operations of domestic and international efforts to mitigate climate change.

This paper has not discussed energy storage and transportation technologies (e.g., batteries, fuel cells, hydrogen, etc.). As these technologies are central to the investigation and adoption of alternative energy sources (especially if intermittent energy sources, like solar and wind power, are to have a meaningful future), and are of particular operational relevance, any research into the latter should be closely integrated with research into the former.

5.4 Governance

All parts of the Defence institution consume energy and generate GHG. As such, the consumption of energy, and the mitigation of the environmental impacts thereof, is a matter of Departmental concern. Efforts to identify and adopt alternative energy sources therefore require a Departmental champion. The Associate Deputy Minister would appear to be the logical office to champion a Department-wide effort in this area.

Infrastructure consumes the lion's share of energy within DND, both in the form of building heat, and of grid electricity. These consumption areas are also the largest generators of GHG.

Accordingly, the logical lead agency for a Departmental program to identify and adopt alternative energy solutions is the Assistant Deputy Minister (Infrastructure and Environment) (ADM IE). Key stakeholders will include the Environmental Chiefs of Staff (as the managers of the facilities doing the consuming and emitting), especially the Chief of the Air Staff, whose aircraft consume fully one-third of the Department's energy budget. The key enabler will be Assistant Deputy Minister (Science and Technology), as the source of scientific expertise, and the Departmental scientific liaison with allies, industry, and the academic community.

The program structure and any consequent research projects emerging from a Department-wide effort to identify and adopt alternative energy sources must conform to Federal legislation, regulations and policy re: energy production, energy consumption and emissions standards.

Finally, it must be emphasized that the exploitation of alternative energy sources will not be unique to DND; other government departments have a similar stake in exploiting alternative energy sources to reduce costs and consumption of fossil fuels. A whole-of-government approach to alternative energy—perhaps coordinate by Deputy Ministers—would help to avoid gaps or overlap as many different departments work to achieve results in this area.

This page intentionally left blank.

List of symbols/abbreviations/acronyms/initialisms

ADM(IE)	Assistant Deputy Minister (Infrastructure and Environment)
ADM(S&T)	Assistant Deputy Minister (Science and Technology)
AFA	*Alternative Fuels Act of 1995*
AFB	Air Force Base (US designation)
AFUE	Annual Fuel Utilization Efficiency
AGW	Anthropogenic Global Warming
APC	Armoured Personnel Carrier
ATF	Alternative Transportation Fuel (as defined in the AFA)
ATP	Adenosine tri-phosphate
CFB	Canadian Forces Base
COP	Coefficient Of Performance
CSA	Canadian Standards Association
DX	Direct Expansion (a single-loop GSHP operating solely on refrigerant)
E85	An alternative fuel consisting of 85% denatured ethanol by volume
ECS	Environmental Chief(s) of Staff
EV	Electric Vehicle (see PHEV)
FMAS	Financial Management and Accounting System
FY	Fiscal Year
GCM	General Circulation Model
GHG	Greenhouse gas
GJ	Gigajoule ($1x10^9$ joules)
GSHP	Ground-Source Heat Pump
GW	Gigawatt

GWh	Gigawatt-hour
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
kJ	Kilojoule ($1x10^3$ joules)
kW	Kilowatt
kWh	Kilowatt-hour
L1	Level 1 manager
MJ	Megajoule ($1x10^6$ joules)
Mtoe	Mega-tonnes of oil equivalent
MW	Megawatt
MW	Megawatt
MWh	Megawatt-hour
NATO	North Atlantic Treaty Organization
NRCan	Natural Resources Canada
NSMP	Non Standard Military Pattern (vehicle)
PHEV	Pluggable Hybrid Electric Vehicle (see EV)
PJ	Petajoule ($1x10^{15}$ joules)
PNG	Packaged Nuclear Generation
PV	See "SPV"
SC	Strategic Commitment (within the SDS)
SDS	Sustainable Development Strategy
SEGS	Solar Electrical Generating System
SMP	Standard Military Pattern (vehicle)
SPV	Solar Photovoltaic

STG	Solar Thermal Generation
t CO_2 eq.	tonnes of carbon dioxide equivalent
TJ	Terajoule ($1x10^{12}$ joules)
TPES	Total Primary Energy Supply
TRIGA	□Training, Research, Isotopes, General Atomics□□a reactor design
TWh	Terawatt-hour

This page intentionally left blank.

Distribution list

Document No.: DRDC CORA TM 2009-010

Information

Internal

1 Section Head Strategic Analysis
1 DRDC CORA Library

External

10 DST IC

This page intentionally left blank.

DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (The name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Centre sponsoring a contractor's report, or tasking agency, are entered in section 8.) Centre for Operational Research and Analysis Defence R&D Canada 101 Colonel By Drive Ottawa, Ontario K1A 0K2	2. SECURITY CLASSIFICATION (Overall security classification of the document including special warning terms if applicable.) UNCLASSIFIED

3. TITLE (The complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S, C or U) in parentheses after the title.)

A strategic framework for exploring alternative energy options in DND/CF

4. AUTHORS (last name, followed by initials ranks, titles, etc. not to be used)

D.A. Neill

5. DATE OF PUBLICATION (Month and year of publication of document.) March 2009	6a. NO. OF PAGES (Total containing information, including Annexes, Appendices, etc.) 78	6b. NO. OF REFS (Total cited in document.) 60

7. DESCRIPTIVE NOTES (The category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

Technical Memorandum

8. SPONSORING ACTIVITY (The name of the department project office or laboratory sponsoring the research and development include address.)

DSTIC
Defence R&D Canada
305 Rideau Street
Ottawa, Ontario K1A 0K2

9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.)	9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.)
10a. ORIGINATOR'S DOCUMENT NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document.) DRDC CORA TM 2009-010	10b. OTHER DOCUMENT NO(s). (Any other numbers which may be assigned this document either by the originator or by the sponsor.)

11. DOCUMENT AVAILABILITY (Any limitations on further dissemination of the document, other than those imposed by security classification.)

Unlimited

12. DOCUMENT ANNOUNCEMENT (Any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in (11) is possible, a wider announcement audience may be selected.))

Unlimited

13. ABSTRACT (A brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual.)

This study offers a strategic framework for the investigation of alternative energy sources by the Department of National Defence and the Canadian Forces. To this end, it consists of three chapters. An examination of the energy consumption patterns of DND/CF reveals that DND could derive the greatest benefits (in terms of reducing costs, reliance on fossil fuels, pollution and greenhouse gas emissions) by identifying and implementing non-fossil fuel, non-emitting alternative energy options to heat buildings, generate electricity, and provide motive power to naval vessels and aircraft. It assesses that the most promising technological options in these areas are geothermal heating and cooling for infrastructure; packaged nuclear reactors for electrical generation; and nuclear power for naval vessels. As there are no non-emitting, non-fossil-fuel alternatives to aviation fuel available at present, this would be a fruitful area for pure research. The paper proposes a strategic framework for the investigation and assessment of alternative energy sources by DND/CF, consisting of a series of strategic principles, strategic priorities, strategic factors for consideration in developing any alternative energy program, and a number of caveats, and cautions that the cost and timelines involved in implementing significant technological changes across the entire Defence establishment require a robust, durable strategic rationale and careful, deliberate action by leaders and managers. The paper concludes by providing some suggestions for further research and analysis, and recommends a governance structure for a way ahead based on an alternative energy research program championed by the Associate Deputy Minister, with Assistant Deputy Minister (Infrastructure and Environment) as the lead level one manager, and Assistant Deputy Minister (Science and Technology) as the key enabler.

Ce document technique présente un cadre stratégique pour l'examen de sources d'énergie de remplacement par le ministère de la Défense nationale (MDN) et les Forces canadiennes (FC). Le document compte trois chapitres. Un examen des modes de consommation d'énergie au MDN/FC révèle que le MDN pourrait tirer profit (en terme de réduction des coûts, d'utilisation de combustibles fossiles, de réduction de la pollution et des émissions de gaz à effet de serre) en identifiant et en mettant en œuvre des moyens d'utiliser des combustibles autres que des combustibles fossiles, des options de consommation d'énergie renouvelable pour chauffer les bâtiments, produire de l'électricité et servir de force motrice pour les navires et les aéronefs. Il précise que les options technologiques les plus prometteuses sont le chauffage et la climatisation géothermiques pour les infrastructures; les réacteurs nucléaires pour la production d'électricité; et la propulsion nucléaire pour les navires militaires. Comme il n'existe, à l'heure actuelle, aucun carburant de remplacement qui serait sans émission ou exempt de combustible fossile pour les aéronefs, il s'agirait là d'un domaine dans lequel on pourrait orienter les recherches. Ce document technique propose un cadre stratégique pour l'examen et l'évaluation de sources d'énergie de remplacement par le MDN/FC, qui consiste à appliquer une série de principes, de priorités et de facteurs stratégiques, dont il faudra tenir compte dans l'élaboration de tout programme relatif aux énergies de remplacement. Il faudra également tenir compte d'un certain nombre de restrictions et prendre des précautions en ce qui a trait aux coûts et aux délais à prévoir pour la mise en œuvre de changements technologiques importants dans l'ensemble du ministère de la Défense, et cela nécessitera une justification stratégique solide et durable, ainsi que des actions prudentes et délibérées de la part des décideurs et des gestionnaires. Le présent document technique conclut en fournissant des suggestions relatives à la recherche et à l'analyse, et recommande une structure de gouvernance quant à la voie à suivre qui sera basée sur un programme de recherche sur les énergies de remplacement appuyé par le sous-ministre adjoint (Infrastructure et Environnement) à titre de gestionnaire de l'échelon 1, et le sous-ministre adjoint (Science et Technologie) à titre de facilitateur clé.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

Energy, Alternative Energy, Climate Change, Pollution, Greenhouse Gas, Global Warming, Carbon Dioxide, Nuclear Power, Biofuel, Aviation Fuel, Energy Security, Energy Strategy

DEFENCE DÉFENSE

DRDC CORA

www.drdc-rddc.gc.ca