Decarbonating Energy Systems: The Potential for Reducing CO_2 Emissions Through Reduced Energy Intensity in Canada

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The purpose of this paper is to discuss the potential in Canada for realizing the energy demand-side component of the 20% CO_2 reduction target proposed at the 1988 Changing Atmosphere conference in Toronto. It is argued that increased energy efficiency offers the greatest potential for reducing energy intensities and thus CO_2 emissions. A rough calculation suggests that achieving half the 20% target through increased energy efficiency is technically and economically feasible. However, this will require greatly increasing the rate of improvement in energy efficiency achieved by Canada over the past 15 years, and would involve significant transformations in energy use patterns. On the basis of an analysis of end-use efficiency potential and the carbon emissions associated with end-use consumption, several priority areas for efficiency improvements are suggested.

En 1988, lors de la conférence Changing Atmosphere *à Toronto, un objectif de diminution de 20% du CO_2 à été proposé et cet article se propose d'examiner dans quelle mesure le Canada peut satisfaire à la partie de cet objectif ayant trait à la demande d'énergie. Le meilleur potentiel pour la diminution de la consommation d'énergie et, partant, du dégagement de CO_2 réside en une efficacité accrue de cette consommation qui, d'après un calcul rapide, permettrait de réaliser, d'une façon technologiquement et économiquement viable, la moitié de l'objectif de 20%. Cependant, cela exigerait une augmentation considérable du taux d'amélioration du rendement d'énergie atteint au Canada au cours des 15 dernières années et rendrait nécessaires de profondes transformations dans la structure de l'usage de l'énergie. Plusieurs domaines prioritaires pour une amélioration de l'efficacité de la consommation sont suggérés à partir d'une analyse du potentiel de rendement d'usage final et du dégagement de carbone associé avec la consommation finale.*

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1. Introduction

In 1988, the report of the Toronto *Changing Atmosphere* conference issued a "Call for Action" which included the following statement:

- *Reduce CO_2 emissions by approximately 20 percent of 1988 levels by the year 2005 as an initial global goal.* Clearly the industrialized nations have a responsibility to lead the way, both through their national energy policies and their bilateral and multilateral assistance arrangements. About one-half of this reduction would be sought from energy efficiency and other conservation measures. The other half should be effected by modifications in supplies. (Environment Canada, 1988, p.5.)

The purpose of this paper is to discuss the potential for realizing the energy demand-side component of that target in Canada, a country which, as the above quotation suggests, should be in the vanguard of CO_2 emission reduction strategies. While the discussion will refer specifically to Canada, much of the analysis described below could be applied to any industrialized country.

This paper focuses on demand-side measures for CO_2 reduction for a number of reasons. First, and most important, increased energy efficiency—a major contributor to reduced energy intensity—is likely to be the largest, quickest and cheapest source of emission reductions, at least in the short and medium terms (Krause *et al*, 1988; Keepin and Kats, 1988). Moreover, to the extent that this efficiency is economic in relation to current and anticipated energy prices, it is worth achieving on its own merits, independent of its carbon reduction potential. This represents the single most powerful argument for undertaking serious action to reduce CO_2 emissions in the face of continued scientific uncertainty about climate change.

Second, reductions in energy use caused by reductions in energy intensity eliminate the CO_2 emissions associated with such use altogether, while supply-side strategies usually only reduce such emissions. Third, reducing energy intensity also makes an absolute contribution to a host of other environmental problems. Figure 1 shows the contribution of energy production and use to total emissions for several important pollutants in Canada. Clearly the environmental benefits of reduced energy intensity extend well beyond their potential contribution to CO_2 reduction. Fourth, and finally, reductions in the growth rate of energy demand buy time for other measures, such as fuel switching or scrubbing. They are also an indispensable first step in the transition to more environmentally benign energy systems based on renewable resources (Robinson *et al*, 1985).

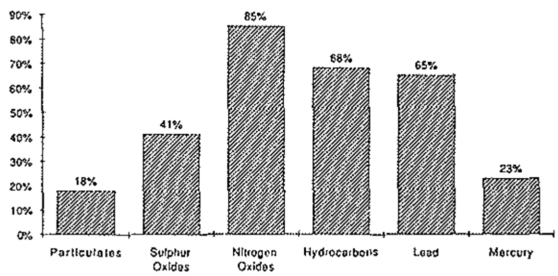

Figure 1: Contaminants from Energy Production and Consumption in Canada (as % of total pollution)
Source: Energy, Mines and Resources Canada (1989).

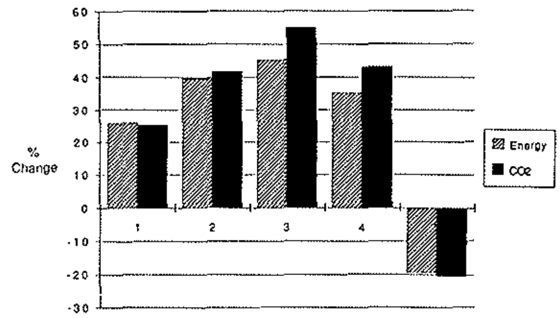

Figure 2: Energy Demand and CO_2 Emissions in Canada in Various Scenarios, 1987-2005. (See Table 1.)

2. The Size of the Challenge

It is important to recognize that the challenge posed by the overall 20% emission reduction target (which is itself presumably only a floor target[1]) implies the need for some fairly strong measures with respect to our energy systems. For example, Figure 2 shows the CO_2 emissions that would be associated with several future scenarios of energy use in Canada in the year 2005, compared with actual 1987 emissions (Ranney and Coletta, 1989). With the exception of scenario #5, which shows the results of a recent soft energy path analysis for Canada, all of the scenarios represent official government projections.

The important point illustrated by Figure 2, which presumably could be replicated with much the same results in other countries, is that none of the official government projections, which embody various levels of energy efficiency and economic growth (see Table 1), come close to meeting the 20% target in 2005.[2] Only the "soft energy path" scenario, which is usually considered a radical projection, meets the target.

1 / It has been suggested that the 20% target is probably too low to avoid significant climate warming (Mintzer, 1987). Moreover, it can be argued that industrialized countries have both a moral obligation, and the technical and economic resources, to take a larger share of the burden of reducing CO_2 emissions, perhaps in proportion to the extent that they have contributed to historical anthropogenic emissions (Krause *et al*, 1989; see also International Federation of Institutes of Advanced Study, 1989).

2 / In August 1989, the Federal/Provincial/Territorial Task Force on Energy and the Environment (1989) released a report which projected energy demand and CO_2 increases of 46% and 49% respectively, over the period from 1988 to 2005. This projection was based upon forecasts generated within Energy, Mines and Resources Canada.

Table 1: Key Assumptions Underlying Scenarios Shown in Figure 2

Scenario	Scenario 1 NEB Low Case	Scenario 2 NEB High Case	Scenario 3 EMR Low Price Case	Scenario 4 EMR High Price Case	Scenario 5 SEP Update (2005)
GDP growth rate (% per annum)	2.2	2.9	2.3	2.1	To 2005: 2.3
World oil prices in 2005 (per barrel)	$20 (1987 US $)	$30 in 2005 (1987 US $)	$24 in 2005 (1986 US $)	$32 (1986 US $)	$35 (1986 Cdn $)
Natural gas prices (real % increase per annum)	4.2	5.8	85-90 parity with oil	75-85 parity with oil	To 2000: 0.0 >2000: 1.25
Electricity prices (real % increase per annum)	0	0	slight decrease in real terms	slight decrease in real terms	1
E/GDP decrease (% per annum)	0.9	1	0.2	0.5	3.4
Population growth (% increase per annum)	0.7	0.7	0.6	0.6	To 2005: 1.2
E/capita (% increase per annum)	0.6	1.2	1.6	1.2	-2.3
Changes in economy	slight shift toward mfg	slightly larger shift to mfg	shift toward manufacturing	-	mid-1970s structure of economy maintained

Source: Ranney and Coletta (1989).

Moreover, the soft energy scenario not only implies levels of energy efficiency that go well beyond those in the official projections, it also embodies an important degree of fuel switching away from fossil fuels toward renewable energy resources (Torrie and Brooks, 1988).[3] These considerations suggest that, if we are to take the CO_2 issue seriously, we will have to consider stronger and more radical measures than have formed the basis of energy policy to date.

Turning specifically to energy intensity issues, a measure of the difficulty of the task implied in the Toronto target can be seen in Table 2, which shows the amount of reduction in primary energy intensity required in Canada by 2005 if reduced energy intensity is to provide half of the 20% emission reduction target. Assuming an average GDP growth rate in Canada of 3% over the period from 1988 to 2005, primary energy intensity would have to be reduced by 46% of its 1988 level if the target is to be met. This amounts to an average annual reduction in energy intensity of 3.6% over the whole period.[4]

3/ There is some uncertainty as to the importance in the medium-term of fuel switching relative to increased energy efficiency in reducing CO_2 emissions in Canada. Doucet (1988) has shown that scenarios embodying a mix of energy efficiency and switching to renewables were more effective in reducing CO_2 emissions by 2005 than scenarios embodying a greater level of efficiency alone. On the other hand, a recent analysis by ROBBERT Associates (1989) indicates that fuel switching is much less important in reducing CO_2 emissions by 2005 than are increases in efficiency. Given the size of the challenge, it seems likely that increased energy efficiency, while the most important component of a carbon reduction strategy, will not be sufficient in itself, even in the medium-term to 2005.

4/ Since the future intensity reduction calculations reported in Table 2 are purely arithmetic, and do not depend on the base year intensity levels but only on the assumed rates of growth of GDP, exactly the same results regarding required percentage intensity reduction apply to any country in the world.

Table 2: Energy Intensity Reduction Required to Meet 10% Target by 2005 in Canada

GDP in 1988 (10^9 1981 $)	GDP in 2005 (10^9 1981 $)		
	Average Annual GDP Growth Rate		
	2%	3%	4%
440.2	616.3	727.5	857.4
Primary energy use in 1988 (PJ)		8640	
Primary energy use in 2005 (PJ) (assuming 10% reduction in use)		7776	

E/GDP Ratio in 1988	E/GDP Ratio in 2005		
	Average Annual GDP Growth Rate		
	2%	3%	4%
19.6	12.6	10.7	9.1
Required reduction in primary energy intensity by 2005	36%	46%	54%

Primary Energy Use in 1973 (PJ)	GDP in 1973 (10^9 1981 $)	E/GDP	Intensity Reduction 1973-88
6901	248.7	27.8	29%

Notes:

1. Assumes one-half of 20% emission reduction target is met through reduced fossil fuel use.
2. Assumes that efficiency measures leading to 10% reduction in fossil fuel use create a 10% reduction in overall energy use.

Sources: Statistics Canada Catalogues 57-207, 57-003, 11-210.

The table also shows that the reduction in primary energy intensity in Canada over the period from 1973 to 1988 was only 29%, or an average reduction of 2.3% per year. Over the next twenty years, therefore, the Toronto target implies the need for Canada to achieve more than one-and-a-half times the annual rate of reduction in primary energy intensity that was achieved in a period which contained two oil price shocks. And this improved rate of improvement must start from a more efficient base year. We turn now to the question of how best this might be done.

3. Intensity and Efficiency

From the point of view of CO_2 emissions, any reduction in energy use is desirable since it reduces the emissions associated with that use and with the associated production, transformation and delivery of energy. However, there exist different ways through which energy use can be reduced. We begin by distinguishing among different ways in which energy **intensity** can change. These distinctions turn out to be important from the point of view of policy design. In particular, some forms of intensity reduction do not represent fruitful targets for emission reduction policies.

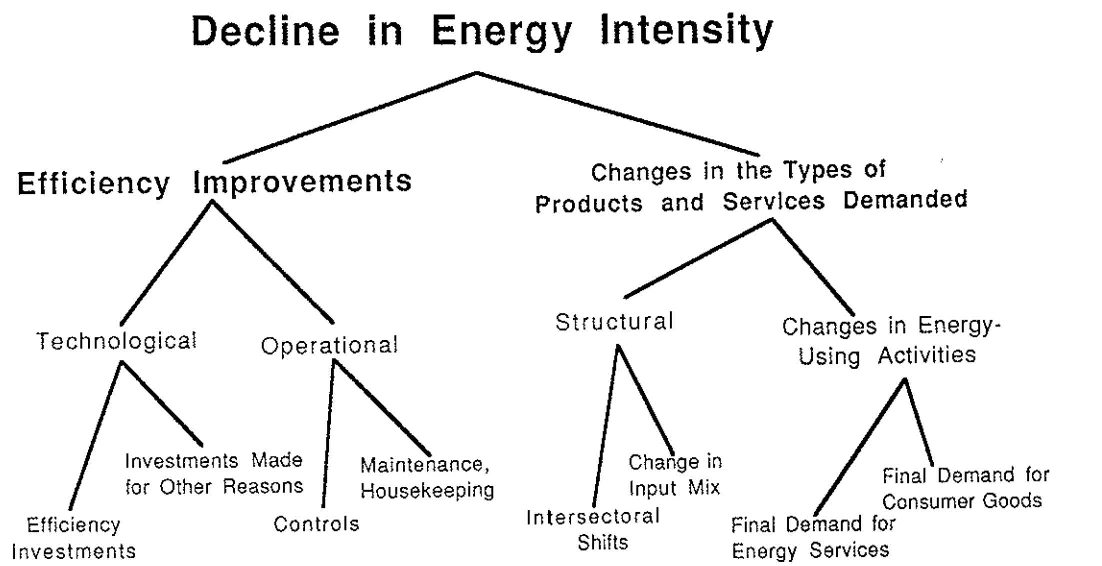

Figure 3: Decline in Energy Intensity

Energy intensity is a measure of energy use relative to some level of activity, usually economic activity or population. Commonly, it is measured in terms of primary energy use per unit of GDP. Changes in energy use per unit GDP are customarily used as a rough index of the energy efficiency of an economy. However, at the aggregate level of an economy as a whole, such changes are the result of a combination of factors, only some of which have to do with the efficiency with which energy is used and only some of which are appropriate targets for policy influence. For example, a reduction in energy intensity in a given country may be due to the effects of reduced economic activity (perhaps recession-induced), of changes in weather or climate, of changes in economic structure or processes, of changes in the types of goods and services produced, exported, imported or consumed, or of changes in the efficiency of energy-using devices.

For convenience, such changes in intensity can be aggregated into two overall categories: changes in the efficiency with which energy services are provided, and changes in the types of products and services demanded. In turn, efficiency changes can be either operational or technological, while the second general category of intensity changes subdivides into changes in the level of energy-using activity (e.g., changes in demand for energy services or for consumer goods), and all other changes (including changes in output and input mixes), which we will call structural changes. (See Figure 3.)

From a policy point of view, these different types of intensity reduction are rather different. Structural changes, for example, do not offer great potential for policy aimed at CO_2 emission reduction, despite their potentially significant role in reducing future energy intensities (Williams *et al*, 1987). There are two reasons for this. First, reductions in energy intensity that come from changes in industrial structure, or reductions in the energy content of net exports, are either not amenable to direct policy influence or else part of a larger set of complex policy issues that go far beyond energy policy issues. For instance, to the extent that alterations in export and import flows are within the control of national policy-makers, they are rather more likely to be decided upon in terms of more general economic policy issues than upon the basis of the energy content of the goods involved.

Second, and just as important, some structural causes of reduced energy intensity within a given country will not result in any overall reduction in CO_2 emissions globally. For example, changes in industrial structure or in the energy content of exports or imports may simply cause the displacement of goods production and thus of CO_2 emissions to other countries. Such displaced production may even be more energy-intensive than the production it replaces, causing a net increase in global CO_2 emissions. Indeed, there is an increasing tendency for high energy intensity primary industries to be located in third world countries, thus reducing the energy intensities, and CO_2 emissions, of industrialized countries while increasing those in third world countries. This not only fails to reduce CO_2 emissions globally, but also increasingly places the burden for such reductions on third world countries.

Similarly, changes in the level of energy-using activities also do not appear to offer great potential from a policy point of view. Except in the residential sector, reducing the level of energy-using activity or goods consumption has not typically been considered an appropriate goal for energy policy. Indeed, some of the early arguments in favour of increased energy efficiency were strongly criticized because of the undesirable lifestyle change and reductions in services that were supposed to be implied in such arguments. Perhaps for this reason, most technical and economic analyses of the potential for increased energy efficiency have tended to ignore potential reduction in the level of energy-using activities or goods consumption and have focused instead upon increasing the efficiency with which those activities are performed (e.g., Friends of the Earth Canada, 1983/4; Johansson *et al*, 1983; Goldemberg *et al*, 1988).

Finally, it seems to be the case that the potential for reducing energy intensities through increased efficiency is much larger than the potential for doing so through reducing energy-using activities or structural changes. For example, evidence concerning the causes of reductions in energy intensities in OECD countries over the past fifteen or so years suggests that the improved energy efficiency of energy-using equipment, processes and buildings has been the most significant contributor to reduced energy intensities (e.g., Hirst *et al*, 1983; Bending, Cattell and Eden, 1987; Jestin-Fleury and Pinto, 1988; Hamilton and Torrie, 1989). Summarizing a number of such studies, an IEA report suggests that improved energy efficiency has been the biggest contributing factor to the 20% decline in energy intensity observed in the 21 IEA countries between 1973 and 1985 (International Energy Agency, 1987). On the basis of a considerable research program analyzing energy use in OECD countries, Schipper (1987) supports this view. He argues that most of the efficiency improvements are due more to new investments than to operational factors, but adds that relatively little of the overall change to date has been caused by energy conservation policies.

Similar conclusions are suggested by an examination of the potential for various means of reducing energy intensity in the future. In the residential sector, for example, where significant attention has been paid to the potential for reducing activities through thermostat set-backs and other lifestyle changes, it seems clear that improving the efficiency of the house offers more potential for saving energy than changes in behaviour.[5] Typical estimates of the effect of different lifestyles suggest that energy use in a typical home can vary by up to a factor of two depending on the behaviour of the occupants (Gladhart *et al*, 1987; Socolow, 1978), but in the case of both home heating and the electricity use of appliances, energy use can vary by a factor of five to ten, depending on the efficiency of the building shell and appliances (Ficner, 1981; Norgard, 1984). Similar findings exist with respect to personal transportation. In one study, the distance driven per family within a particular community in the US was found to vary by less than a factor of two (Gladhart and Tortorici, 1987), while other studies indicate that the technical potential for improved vehicle efficiency is

5/ In one study of residential energy use in two communities in Sweden and the US, Erickson (1987) found that, despite great differences in energy-using behaviour between the two communities, more of the difference in overall energy use was due to technical (i.e., efficiency) factors than to differences in behaviour.

on the order of a factor of five or more (von Hippel and Levi, 1983).[6] Moreover, behavioral changes are transitory and liable to be reversed, while improvements in efficiency will last for the lifetime of the altered component.

To summarize, it appears that, from the point of view of reducing CO_2 emissions, the most fruitful course of action is to focus upon efficiency issues. In contrast to structural and activity level factors, energy efficiency is a variable that is not only amenable to policy influence but is also of interest because its primary impact is on energy use and production. It has proven to be significant in reducing energy intensities in the past, and presents high potential for doing so in the future. In contrast to structural changes, it does not cause displacement of CO_2 emissions but causes a global reduction in those emissions wherever it is practised. Moreover, increases in energy efficiency do not involve reduction in levels of activity which might be considered undesirable in themselves or unwarranted interference in lifestyles.[7]

4. Energy Efficiency and CO_2 Reduction

a) Energy Efficiency As a Policy Goal

It is useful first to consider briefly the multi-dimensional nature of energy efficiency.

Energy is not valued for itself but for the services, like comfort, illumination, mobility, etc., that it provides. The focus of attention for efficiency policy, then, is upon the efficiency of the end-use processes by which those services are provided. This in turn leads to an emphasis upon four sets of end-use processes: those by which fuels or electricity are converted to useful energy (heat, or work of various kinds), those by which useful energy is consumed in the performance of specific tasks (moving an automobile, heating a particular room, etc.), those by which a task performs a service (providing mobility in a particular automobile, or comfort in a particular building, etc.), and those by which material goods are produced (primary and secondary production, fabrication and assembly, and scrap recovery).[8] Changes in any of these processes may result in lower levels of energy use required to supply a given level of energy service.

There exists a large literature on the theoretical and technical aspects of this approach to energy efficiency.[9] For our purposes here, the key point is that this manner of thinking about efficiency implies a fundamental reformulation of ideas concerning the potential for energy demand-side policy (Lovins, 1977; Robinson, 1982a, 1987; Mills, 1988).[10] Instead of being seen as an inherently undesirable, and rather limited, option intended simply to buy time until new supplies can be brought onstream, increased efficiency becomes a large-scale and attractive alternative to such new supplies. The analytical focus shifts from trying to determine the need for increased efficiency to assessing its potential and desirability in particular circumstances, and the policy focus shifts to questions having to do with program design and implementation.

One form that this new approach to demand-

6/ It should be noted, however, that in both these cases we are comparing actual behavioral variation in a particular case with the potential for variation in efficiency that would be realized with adoption of existing energy-efficient technology.

7/ On the other hand, it can be argued that it is precisely because reductions in energy-using activity do have a direct effect upon lifestyle, and thus reflect a larger concern with the overall implications of environmental issues, that they should be encouraged. On this view it is the broader educational and political dimensions of energy conservation policy that are of interest. While recognizing the importance of these dimensions, this paper focuses on the narrower issue of maximizing the immediate potential for CO_2 reduction.

8/ This represents a rather compressed description of a complex set of processes. For elaborations, including attempts to define specific efficiency measures for each of these processes, and also for indirect energy flows, see Gardner and Robinson (1989).

9/ For a smattering of the key theoretical references see Ford *et al* (1975), Ayres and Narkus-Kramer (1976), Chapman (1977), Krause (1981) and Gaggioli (1983).

10/ It also implies a different approach to energy demand modelling and forecasting. See Robinson (1982b, 1988) and Gardner and Robinson (1989).

side policy has taken is in the emergence of the concept of least cost energy strategies, where the goal is to find that mix of energy demand management and supply measures that will provide energy services at the lowest total cost (Sant, 1979). The least cost concept has had its fullest expression to date in the electric utility field (Praul *et al*, 1982; Synergic Resources Corporation, 1987; Northwest Power Planning Council, 1986). It provides a powerful framework in terms of which policy issues can be organized.

A least cost approach to energy policy planning implies treating increased energy efficiency as a supply resource, to be compared on equal terms with more conventionally-defined supply sources such as new power stations or oil wells. The issue then becomes one of determining under what conditions, and at what cost, efficiency resources can be brought on line.[11]

These conceptual developments — the concept of energy services, the recognition of the different physical processes through which increased energy efficiency can be realized, the concept of efficiency as a supply resource, and the concept of least cost energy strategies — provide a general approach to energy efficiency issues that holds promise for realizing the actual potential for increased efficiency. From a CO_2 emission reduction point of view, however, it is necessary to determine where policy emphasis should be placed in order to maximize both the size of the efficiency contribution and its effect in reducing CO_2 emissions.

b) The Efficiency Potential: Priorities for CO_2 Reduction in Canada

While this paper cannot provide details as to the technical and economic potential for increased energy efficiency in Canada,[12] it is important to consider generally the sectors and end-uses where that potential exists most strongly. When combined with information as to where most CO_2 is emitted, we can begin to develop a priority list for carbon-reducing efficiency strategies.

The overall technical potential for increased energy efficiency is of course very large. Various analyses of the degree to which individual energy-using tasks could be accomplished with less expenditure of useful energy have suggested that the "second law efficiency" for most energy-using activities in industrialized market economies is extremely low, usually amounting to less than 10% (Robinson, 1987). Such estimates, which reveal nothing about the practical feasibility or cost-effectiveness of improving efficiency, nevertheless indicate that we are not about to reach the technical limits of increased energy efficiency in the foreseeable future.

Of more immediate interest than the size of the technical potential is the subset of that potential that is economic at current or projected prices. One study for the 21 IEA countries suggests that a conservative estimate for future efficiency improvements would be a further 30% reduction in energy intensity relative to 1985 figures (International Energy Agency, 1987). Other analyses suggest an even bigger potential (e.g., Goldemberg *et al*, 1988). A detailed review of the various national literatures on the economics of energy efficiency is not attempted here. Instead, Table 3 sets out energy end-uses in Canada, a proposed set of key efficiency measures and technologies, and a rough measure of the economic potential for further efficiency increases, based upon previous work by Friends of the Earth Canada (1983/4), Torrie and Brooks (1988) and Greig *et al* (1988). Even at this general level of detail, it can be seen that there exists a significant efficiency potential, based upon a wide array of measures and technologies. The estimates of efficiency potential range from 22% to 53%, with the greatest potentials appearing in commercial lighting, heating and cooling in the residential and commercial sectors, and in several transportation modes.

11/ Given the high level of direct and indirect subsidies that are typically available to existing supply sources (ranging from tax incentives, R&D support, preferred access to capital and price regulation to infrastructure construction and subsidized delivery mechanisms) this imposes a particular burden on the analyst to compare costs equitably.

12/ On this topic, see Friends of the Earth Canada (1983/4); Robinson (1987); Torrie and Brooks (1988); and Greig *et al* (1988).

Table 3: Some Key Areas of Potential for Increased Energy Efficiency in Canada

Sector	End-Use	Measures	Sample Technologies	Efficiency Potential*
Residential	Space Heating & Cooling	• building shell improvements • heating system efficiency improvements	• insulation • sealing • superwindows	53%
	Appliances	• more efficient appliances	e.g., • insulation • bulbs • motors	30%
Commercial	Space Conditioning	• building shell improvements • better controls	• insulation • sealing • integrated control systems	53%
	Lighting	• improved lighting systems	• bulbs	60%
	Motors	• improved motors	• drives, controls, efficient motors	35%
Industrial	Process Heat	• heat recovery • improved heating systems	• insulation • cascading • advanced heating systems • cogeneration	32%
	Mechanical Drive	• improved motors	• variable speed drives • linkage systems • more efficient motors	22%
Transportation	Auto/Bus		• weight & size reductions	45%
	Trucks	• vehicle efficiency	• improved aerodynamics	35%
	Rail	• higher load factors	• improved engine efficiency	38%
	Air		• reduced rolling resistance	40%
	Marine		• variable speed transmissions	35%

* Rough estimates, averaging across new and existing buildings, processes and activities

Sources: Friends of the Earth (1983/4); Greig *et al* (1988); Torrie (1988).

The percentage savings shown in Table 3 refer to potential savings in energy use per unit of end-use activity for each end-use shown. They do not refer to absolute levels of savings, but must be combined with changes in the level of activity in order to determine the overall effect upon energy use. For example, a 33% efficiency saving in a particular end-use over ten years would be completely offset by a 50% increase in end-use activity levels over that period.[13]

Given our concern with CO_2 emissions, it is important to combine information regarding potential with information about the emission characteristics of various energy end-uses. Table 4 shows a rough estimate of the contribution of each sectoral end-use to CO_2 production in Canada. In that table, each end-use is assigned the carbon emissions associated with both its direct use of fossil fuels and its share of total fossil fuels used in electricity generation and by the electricity

13/ This is exactly what has happened in the transportation sector in industrialized countries over the past decade or so. Substantial increases in vehicle energy efficiency have been offset by significant increases in the overall distance driven, resulting in a roughly level pattern of energy use for transportation (Schipper, 1987).

Table 4: CO_2 Emissions Associated with Energy End-Uses in Canada in 1988

	Primary Energy Use (PJ)					CO_2 Emmissions (Tg C)					
	Coal	Oil	Gas	Wood	**Total**	Coal	Oil	Gas	Wood	**Total**	
Residential											
Heating/Cooling	204.2	291.0	685.8	116.1	1297.1	5.1	5.5	9.6	2.8	23.0	18%
Appliances	76.2	28.4	67.0	2.3	173.9	1.9	0.5	0.9	0.1	3.4	3%
Subtotal	280.4	319.3	752.9	118.3	1471.0	7.0	6.1	10.5	2.8	26.5	20%
Commercial											
Heating/Cooling	161.3	158.1	505.4	4.9	829.6	4.0	3.0	7.1	0.1	14.2	11%
Elec. Specific	60.7	22.6	49.4	1.8	134.6	1.5	0.4	0.7	0.0	2.7	2%
Subtotal	222.0	180.7	554.8	6.7	964.3	5.6	3.4	7.8	0.2	16.9	13%
Industrial											
Proc. Heat	256.4	304.3	816.7	375.0	1752.4	6.4	5.8	11.4	9.0	32.6	25%
Elec. Specific	361.3	134.6	294.2	10.9	801.1	9.0	2.6	4.1	0.3	16.0	12%
Subtotal	617.7	438.9	1111.0	385.9	2553.5	15.4	8.3	15.6	9.3	48.6	37%
Transportation											
Auto/Bus	1.8	1215.7	3.5	0.1	1221.0	0.0	23.1	0.0	0.0	23.2	18%
Trucks	0.0	493.0	0.0	0.0	493.0	0.0	9.4	0.0	0.0	9.4	7%
Rail	0.0	86.0	0.0	0.0	86.0	0.0	1.6	0.0	0.0	1.6	1%
Air	0.0	155.0	0.0	0.0	155.0	0.0	2.9	0.0	0.0	2.9	2%
Marine	0.0	99.0	0.0	0.0	99.0	0.0	1.9	0.0	0.0	1.9	1%
Subtotal	1.8	2048.7	3.5	0.1	2054.0	0.0	38.9	0.0	0.0	39.0	30%
Total	1121.9	2987.7	2422.1	511.0	7042.7	28.0	56.8	33.9	12.3	131.0	100%

Notes:
1. In this paper CO_2 emissions are measured by the number of teragrams (millions of metric tonnes) of carbon contained in CO_2. To convert to the weight of CO_2, these numbers should be multiplied by 3.67.
2. End-use consumption figures include pro-rated share of fossil fuels and wood used for electricity production for domestic use.
3. Consumption figures also include pro-rated share of fuel use by energy supply industry.
4. Carbon coefficients: Coal — 0.025 Tg/PJ; Oil — 0.019 Tg/PJ; Natural Gas — 0.014 Tg/PJ; Wood — 0.024 Tg/PJ.
5. All wood used for residential heating and in the forestry industry assumed to produce a net increase in CO_2 emissions.

supply industry.[14] It can be seen that the biggest sectoral contributors to CO_2 emissions are the industrial and transportation sectors but the biggest single end-uses are industrial process heat, residential heating and cooling and passenger transportation in autos and buses (essentially automobiles).

The information on CO_2 emissions shown in Table 4 allows a rough calculation of the amount by which those emissions might be reduced by 2005 through implementation of the efficiency potentials shown in Table 3. First, it is necessary to estimate what energy demand might be in the absence of such efficiency gains. This can be done by constructing a "frozen efficiency" scenario to 2005, where energy efficiencies and fuel shares are held constant at 1988 levels and primary energy use thus grows at the rate of growth of the economy as a whole. This produces an estimate of total primary energy use in 2005 broken down by end-use category, to which the efficiency potential numbers shown in Table 3

14/ No adjustment has been made for the different load factors of the different electrical end-uses, which would alter the degree to which those end-uses used fossil as opposed to hydro or nuclear electricity. Nor were regional differences in end-use and electricity production accounted for.

Table 5: Estimated Reduction in CO_2 Emissions Associated with Improvements in Energy Efficiency

End-Use	1988		Frozen Efficiency Scenario			Efficiency Scenario				CO_2 'Savings' in Efficiency Scenario			
	Primary Energy Use (PJ)	CO_2 Emissions (Tg C)	Primary Energy Use in 2005 (PJ)	Average Carbon Intensity (Tg C/PJ)	CO_2 Emissions in 2005 (Tg C)	Efficiency Potential (from Table 3) (%)	Primary Energy Use in 2005 (PJ)	Average Carbon Intensity	CO_2 Emissions in 2005 (Tg C)	Relative to Frozen Efficiency Scenario (Tg C)	Relative to Frozen Efficiency Scenario (%)	Relative to 1988 (Tg C)	Relative to 1988 (%)
Residential													
Heating/Cooling	1297	23.0	1974	0.0177	35.0	53	928	0.0177	16.4	18.5	53	6.6	29
Appliances	174	3.4	265	0.0196	5.2	30	185	0.0196	3.6	1.6	30	-0.2	-5
Subtotal	1471	26.5	2238		40.2		1113		20.1	20.1	50	6.4	24
Commercial													
Heating/Cooling	830	14.2	1262	0.0171	21.6	53	593	0.0171	10.2	11.5	53	4.1	29
Elec. Specific	135	2.7	205	0.0201	4.1	48	107	0.0201	2.1	2.0	48	0.5	20
Subtotal	964	16.9	1467		25.7		700		12.3	13.4	52	4.6	27
Industrial													
Proc. Heat	1752	32.6	2666	0.0186	49.6	32	1813	0.0186	33.7	15.9	32	-1.1	-3
Elec. Specific	801	16.0	1219	0.0200	24.3	22	951	0.0200	19.0	5.4	22	-3.0	-19
Subtotal	2553	48.6	3885		73.9		2764		52.7	21.2	29	-4.1	-8
Transportation													
Auto/Bus	1221	23.2	1858	0.0190	35.3	45	1022	0.0190	19.4	15.9	45	3.8	16
Trucks	493	9.4	750	0.0191	14.3	35	488	0.0191	9.3	5.0	35	0.1	1
Rail	86	1.6	131	0.0186	2.4	38	81	0.0186	1.5	0.9	38	0.1	8
Air	155	2.9	236	0.0187	4.4	40	142	0.0187	2.6	1.8	40	0.3	10
Marine	99	1.9	151	0.0192	2.9	35	98	0.0192	1.9	1.0	35	0.0	0
Subtotal	2054	39.0	3125		59.3		1830		34.7	24.6	41	4.3	11
Total	7043	131.0	10,716	0.0186	199.3	40	6407		119.8	79.5	40	11.2	9

Notes:
1. Frozen Efficiency scenario assumes annual growth in activity of 2.50%.
2. Frozen Efficiency scenario assumes frozen fuel shares.
3. Carbon intensities calculated from Table 4.
4. Efficiency scenario carbon emission calculations imply no changes in fuel mix from Frozen Efficiency scenario.

can be applied, and the resultant carbon emissions calculated. The results of such a calculation are shown in Table 5, for an assumed economic growth rate of 2.5% per year. It can be seen that full attainment of the efficiency potentials from Table 3 results in a 9% drop in CO_2 emissions relative to 1988, and a 40% drop relative to the "frozen efficiency" emission levels. This is consistent with Table 2, which suggests that intensity savings of between 36% and 46% are needed in order to create a 10% reduction in CO_2 emissions.[15]

The calculations shown in Table 5 are extremely rough and several qualifications should be noted. First, they deal only with total energy use. This amounts to assuming that fuel shares, and carbon intensities, would remain constant after implementation of the efficiency savings shown. In fact, both fuel shares and carbon intensities are likely to change, even independent of efficiency gains. Second, the numbers in Table 5 refer to primary energy use and thus assume that conversion losses and energy supply industry use remain the same relative to secondary energy use over the period from 1988 to 2005.

Third, the projections assume an average annual growth rate of 2.5%/year over the period from 1988-2005. This might be considered unlikely. Fourth, and probably most important, the projections implicitly assume that no changes will occur in the structure of the economy or in the consumption patterns of Canadian consumers (i.e., in the factors shown on the right-hand side of Figure 3).

Despite these considerable oversimplifications, the numbers shown in Table 5 are a useful indication of some of the opportunities and challenges posed by the CO_2 problem. They suggest that, even without structural and final demand changes that reduce energy intensity, there does exist the technical and economic potential to meet something like the 10% reduction in CO_2 through efficiency measures that was proposed at the Toronto *Changing Atmosphere* conference. On the other hand, it should be remembered that the emission reductions shown in Table 5 assume successful implementation of all of the efficiency potential shown in Table 3. In turn, this indicates the importance of implementation

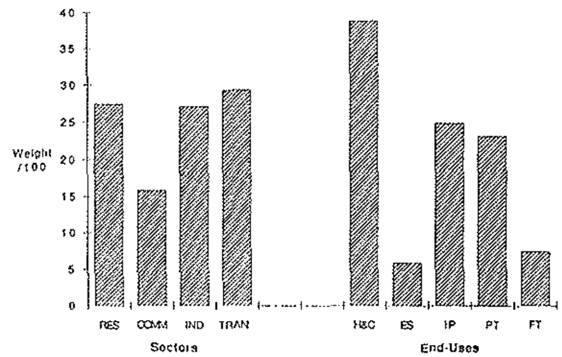

Figure 4: Relative Weight of Sectors and End-Uses in Reducing CO2 Through Increased Efficiency

RES — residential sector; COMM — commercial sector; IND — industrial sector; TRAN — transportation sector; H&C — heating and cooling; ES — electricity specific; IP — industrial processes; PT — passenger transport; FT — freight transport.

issues, discussed further below.

Table 5 also suggests something about the relative importance of efficiency savings for each sector and end-use. Of particular interest are the results for the industrial sector, which is the only one to show an increase in CO_2 emissions relative to 1988. The large amount of CO_2 emissions associated with industrial energy use in 1988, together with the relatively modest savings potential, mean that this sector may be a particularly hard nut to crack.

Another way to combine the information shown in Tables 3 and 4 is to use it to determine where the greatest opportunity lies for reducing CO_2 emissions. Such a procedure is illustrated in Table 6, which shows the results of multiplying the efficiency potential for each end-use from Table 3 by the percentage contribution of that

15/ When converted from carbon to carbon dioxide, the numbers shown in Table 5 are also roughly consistent with those presented by the consultant hired by the Federal/Provincial/Territorial Task Force cited in note 2 above, which shows a technical potential of 72 Tg of CO_2 in the form of carbon relative to no efficiency improvements in 2005 (The DPA Group, 1989). However, caution should be exercised in comparing these results, since they were based on entirely different methods of analysis.

Table 6: Energy Efficiency and CO_2 Reduction in Canada

Sector	End-Use	Efficiency Potential (%)	Contribution to CO_2 Emmissions (%)	Weight[1]	Weight/100
Residential	Space Heating & Cooling	53	18	9	23
	Appliances	30	3	1	2
Commercial	Space Conditioning	53	11	6	14
	Elec. Specific	48	2	1	2
Industrial	Process Heat	32	25	8	20
	Mechanical Drive	22	12	3	7
Transportation	Auto/Bus	45	18	8	20
	Trucks	35	7	3	6
	Rail	38	1	0	1
	Air	40	2	1	2
	Marine	35	1	1	1
Total[2]			100	40	100

Notes:
1/ Weight = Efficiency Potential x Sectoral Contribution to CO_2 Emissions x 100.
2/ Totals may not add due to rounding.

Sources: Tables 3 and 4.

end-use to total CO_2 emissions from Table 4. The results of this calculation indicate the relative weight to be assigned to efficiency increases in each end-use in terms of their potential to reduce CO_2 emissions. This calculation implies that, in considering overall potential for CO_2 reduction, the efficiency potential has the same weight as the contribution to CO_2 emissions.

The key findings of Table 6 are summarized in Figure 4, which shows in graphic form the overall rating for each sector and end-use category. It can be seen from Table 6 and Figure 4 that the greatest potential for CO_2 reduction lies in residential heating and cooling, followed by automobiles and industrial process heat, and then by commercial sector heating and cooling. No other individual end-uses are significant.

Again, the results shown in Table 6 are preliminary, and rather coarse. For example, they reveal nothing about costs (or non-CO_2 benefits), or about the speed with which efficiency gains can be realized. Nor do they reveal anything about how these potentials are to be achieved. They also do not shed any light on the effect at the margin of the various measures, or indicate anything about important regional differences in carbon intensity.[16] Nevertheless, these results suggest the desirability of combining information about efficiency potential with information concerning CO_2 contribution in making decisions about priorities for CO_2 reduction. For example, commercial electricity specific applications represent the highest potential for efficiency gains in percentage terms but make little contribution to CO_2 emissions so the overall rating of this end-use is low.[17] Conversely, industrial process heat, which strongly dominates

16/ For example, if the marginal supply source for a particular end-use is different than the current average source of supply, or if a province has a very different electricity supply mix than the national average, the aggregate findings shown on Table 6 would need to be modified.

17/ However, insofar as the marginal electricity supply source is coal, as it is in many provinces, then all of the electricity specific end-use should have a higher rating than shown on Table 6 and Figure 4.

contributions to CO_2 emissions, drops to a tie for second place in overall reduction potential when efficiency potential is taken into account.

It appears from Table 6 that the priorities for CO_2 reduction are driven slightly more by end-use contributions to CO_2 emissions than by efficiency potentials. This follows from the relatively wider spread of the former category. Table 5 suggests that the single biggest sectoral potential lies in transportation. On the other hand, when sectors are combined, the most important end-use, in terms of reduction potential, is heating and cooling. The lack of any single dominant sectoral end-use in the final column of Table 6 suggests the desirability of developing carbon reduction strategies for several key end-uses simultaneously. However, if a key policy goal is to reduce CO_2 emissions as much and as fast as possible, then, subject to the qualifications noted above, these results suggest the desirability of efficiency programs targeted to residential space heating, industrial process heat and automobiles.

5. Some General Implementation Issues

Once some program priorities have been determined, the next step is to translate specific information on potential into the improvement of existing efficiency policies and the development of new ones, targeted to CO_2 emission reduction. In particular, industrial and transportation sector programs can be strengthened. It seems sensible to suggest that researchers work to develop priority target areas and program design proposals tailored to the conditions applying in each end-use sector. It would not be very difficult to develop sample lists of programs and program design principles that could be used to initiate aggressive efficiency programs, making use, where appropriate, of experience from those places where programs have been most successful (Robinson, 1990).

For this to occur in Canada, however, there would have to be a reversal of the virtual abandonment of energy efficiency program development by the federal government. While Canada was an acknowledged leader in energy efficiency program development at the end of the 1970s, virtually all such initiatives were dismembered in the 1980s. Since 1984, the federal government has cut program spending in the area of energy efficiency and renewable energy development by about 75%. The effect of this abandonment has been clear. Whereas Canadian builders, for example, were at the leading edge of energy-efficient housing and office building construction ten years ago, today Canada has been overtaken by others.

Nor has the efficiency torch been picked up at the provincial level, where programs have also typically been cut drastically. The only current efforts in Canada that represent attempts to capture a significant proportion of the economic potential for increased energy efficiency are occurring in the utility industry. Ontario Hydro and BC Hydro in particular are beginning programs that are intended to increase electrical efficiency in their systems substantially, at an anticipated cost of several billions of dollars (Energy, Mines and Resources Canada, 1989).[18] However, these programs will of course apply only to electricity use. They are far from the kind of response required if Canada is to even come close to meeting the 20% CO_2 reduction target. In fact, to the extent that utility programs are successful, just because they are only aimed at electricity use, they will create a serious asymmetry in the energy demand market, with electricity use efficiencies improving much faster than efficiencies for oil, gas or coal.

It seems clear, therefore, that whether or not substantial energy efficiency programs will ever be implemented, and whether their implementation will represent a sufficient demand-side response to the problem of CO_2 emissions, will depend in large part upon the degree to which these problems are perceived as important at the political level in Canada. At present, this seems to depend upon how serious the problem is per-

18/ Ontario Hydro is currently projecting efficiency savings of 2000 MW by the year 2000 (about 7% of projected peak demand in that year) at an expected cost of over 3 billion dollars (Ontario Hydro, 1989).

ceived to be by the public. In this regard, it might be useful to define efficiency program objectives at least partly in terms of desired CO_2 emission reductions. Despite all of the obvious difficulties involved in measuring success in relation to such objectives, they would serve to provide highly visible and, one suspects, politically popular targets for efficiency policies.

A CO_2 emission reduction index, attached to specific programs and aggregated to an overall national total, would represent a concrete, visible and vivid symbol for such programs. This would serve the dual purpose of helping to promote the efficiency programs both to the intended recipients and to policy-makers themselves. That is, a major lesson of the program evaluation and behavioral literature — that programs need to be marketed strongly and effectively — applies not only to efficiency programs themselves, once they are put in place, but also to the question of whether such programs are needed in the first place. We need to market not only efficiency, but also the need for efficiency.

6. Conclusions

The goal of reducing CO_2 emissions in 2005 by 10% from 1988 levels through increased energy efficiency will not be easy to achieve. While efficiencies have improved significantly in industrialized countries over the past fifteen years, little of this appears to have come about due to efficiency programs. Moreover, the strong price effects characteristic of the 1970s and very early 1980s are not now operative, and opinions vary as to the likelihood of significant price increases in the near future. In the absence of such strong price effects, energy efficiency programs are going to have to become much more effective very quickly if we are to have any chance of attaining the 10% demand-side target.

This prospect may seem rather daunting, but several points should be remembered. First, as discussed above, there are factors other than increased energy efficiency that reduce energy intensity. While few of these represent appropriate targets for energy policy, they are nevertheless likely to continue to act in such a way as to reduce overall energy intensities in industrialized countries (Williams *et al*, 1987). In Canada, for example, the combined effect of changes in the factors shown in Figure 3 has caused energy demand to remain almost flat over the past decade (Hamilton and Torrie, 1989). In fact, energy-related CO_2 emissions in 1988 were below those in 1980 and only about 10% higher than in 1974 (Torrie, personal communication).

Second, much of the effect of energy efficiency programs is yet to be felt due to the slow penetration of efficiency improvements into long-lived capital stocks (Schipper, 1987). In this connection, Geller *et al* (1987) suggest that substantial future energy efficiency improvements can be expected from research already undertaken. And third, as argued above, there exists a very substantial potential for increased energy efficiency that is economic in the light of current and anticipated energy prices. When this potential is applied to a rough projection of primary energy use in 2005, it appears as if full attainment of currently available cost-effective energy efficiency would reduce CO_2 emissions by roughly the amount suggested at the Toronto *Changing Atmosphere* conference in 1988.

Of course, there is a big gap between identifying potential and causing that potential to be realized. It was suggested above that, if that potential is to be realized, there is a need to mobilize the political will to develop significant policies and programs in the area of increased energy efficiency. However, the institution of new energy efficiency policies will not itself be enough, and may indeed be counter-productive, if these policies and programs are not based upon a thorough understanding of the behavioral basis of energy use decisions and the lessons of the past fifteen years of energy efficiency program development (Robinson, 1990; Stern, 1986; Stern and Aronson, 1984). Thus the next step must be the development of extensive sets of sector and end-use specific efficiency programs in each country, which build upon the experience described above, and turn the extensive efficiency potential described in a multitude of technical and economic studies into a reality.

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