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COST-EFFECTIVE FUEL SAVINGS IN HEATING APPLICATIONS †

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Cost-Effective Fuel Savings in Heating Applications

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Abstract

Fuel end-uses in the U.S.A. are reviewed, and a large potential for fuel savings in heating applications in the range 60°C to 1650°C is established. Under present conditions of technology and economics, about 6.6 quads of primary fuels per year out of about 27.6 can be cost-effectively saved. The relevant technologies considered are thermal insulation and cogeneration. We estimate that $160 billion capital investment would be required to achieve these fuel savings. However, this investment is much less than the $260 billion that would have to be invested in developing equivalent new energy supplies. In spite of cost-effectiveness, fuel savings in heating applications may not proceed as fast as present conditions warrant because of institutional and financial barriers.

1. Introduction

In this presentation, our purpose is to emphasize that improved energy efficiency is a substantial option that would cost less than increasing new energy supplies, that would not result in curtailment of fuel end-use services, and that ought to be seriously considered in any balanced approach to the U.S. energy problem. To accomplish this purpose, we used well known principles of thermodynamics and have drawn on the results of published studies of simple, proven, and existing technologies for fuel savings in heating applications. We collected and integrated the results of these studies in order to show how large is the total potential for cost-effective fuel savings in the U.S. and hence to stress the importance for the economy of realizing these savings.

The rising price of energy, due to increased scarcity of cheap supplies of fuel, imposes strains on the U.S. economy. The response to this new energy situation can be composed of three elements:

1) Dedicate more resources for energy by paying higher prices for fuel, and higher development costs of new energy supplies;

2) Curtail fuel consuming activities that would be otherwise carried; and

3) Increase the efficiency of fuel use to derive the same amount of utility from a smaller amount of fuel.

Proper adaptation to the new energy situation should involve all three elements of response described above, in a balance such as to minimize total societal costs.

It seems however that the third possibility of improved efficiency is not well appreciated or its economic benefits not well recognized, and therefore many people's response tends to be of the first and second type. For example, the present policy of the U.S. Department of Energy (DOE), under Secretary J.B. Edwards, is mostly one of increasing energy production. Again, surveys of households show that many of them do not apply any energy conservation measures to their homes, and some energy intensive industries are experiencing periods of reduced production. For sure, some energy conservation projects are being implemented in the U.S. but there is room for saving much more energy than is currently realized.

Increasing energy production from new supplies and curtailing energy consuming activities usually imply increased costs to society, either in terms of higher prices paid for fuels, or in terms of loss of the utility previously derived from fuels. Increasing energy efficiency however can decrease these costs.

We will show that there is no fundamental physical barrier that would prevent the reduction of fuel use, while maintaining the same level of services previously provided by this fuel use, and that the room for improving the fuel consumption is large. We will also show the economic benefits of implementing fuel saving measures in heating applications, and discuss needed government actions to accelerate the adoption of these measures.

The fuel saving potential is gauged as the difference between (a) the minimum amount of fuel required to perform certain tasks, and (b) the amount of fuel consumed by existing processes that perform these same tasks. The minimum fuel requirements are evaluated by a careful application of the laws of thermodynamics. The result of this analysis shows that the overall effectiveness of fuel use in the U.S. is about 15%, hence leaving a large margin for improving fuel consumption without curtailing the end-uses of fuel. Of course, a 100% effectiveness can never be achieved in practice, but the size of the potential, and the benefits that would accrue from realizing even a small portion of it, ought to draw much more attention than it is currently given.

By analyzing the fuel savings, realizable by known existing technologies of insulation and weather-stripping in homes, and of cogeneration in industries, and the investments necessary to realize these savings, we estimate that about 6.6 quads of primary fuels per year out of 27.6 can be cost-effectively saved in heating applications. The capital cost of these fuel savings is estimated at about $160 billion, which is much less than the $260 billion that would have to be invested in developing equivalent new energy supplies of about 4 million bbl/day oil production capacity plus 17.6 GWe installed electric capacity. Implementing the fuel savings outlined in this presentation would save $19 billion per year from the society's bill for energy (net, after paying for the conservation projects). Considering the positive effects on the economy of such annual savings plus the initial capital cost savings, the pursuit of energy conservation should be one of the high priority items of U.S. energy policy.

In order to foster the realization of these fuel savings by improvement of efficiency, market imperfections—lack of information, limited access to capital, and sometimes inadequate incentives feedback—that hamper investments in fuel savings have to be countered by judicious government policies. The major policy recommendations to promote fuel savings are: 1) initiate information programs through a revived Residential Conservation Service and Energy Extension Service in order to increase national awareness about energy saving possibilities; 2) encourage the flow of capital from the energy production sector to the energy consuming sectors of the economy; 3) establish buildings and appliances efficiency code standards; and 4) follow a pricing policy that would reflect to consumers the true rising cost of energy.

2. Thermodynamic Efficiency of Heating Applications

An efficiency measure should tell us how well a resource is used in accomplishing a certain desired task. A perfectly efficient process should be one that uses up a resource in the least wasteful manner.

If a fuel is consumed in order to drive a process, it is the fuel's ability to do work that is consumed. This ability is equal to the fuel's change of availability, say A_1. On the other hand, the utility that we derived from the fuel is the work used to drive the process. The minimum amount of work required to drive a process is equal to the change of availability involved in the process, say A_2. Hence, in a perfectly efficient process, i.e. a process in which no fuel was wasted or in which no more fuel was used than the minimum amount required, we should have $A_1 = A_2$. In a less efficient process, more fuel than the minimum required would be consumed, and we would have $A_1 > A_2$.

The ratio ($\epsilon = \frac{A_2}{A_1}$) is called the "effectiveness" of fuel use. It is a measure of how well is a fuel used because it represents the fraction of the fuel that was consumed for useful purposes, i.e. the fraction of A_1 that was used for A_2, and is equal to 100% when no waste of fuel occurs.

The difference $(A_1 - A_2)$, is the potential for fuel saving, or the margin for reducing fuel consumption in a process. It measures how much fuel can be saved if a process consumed no more than the minimum amount of fuel necessary. Of course, real processes can never attain this ideal limit of minimum fuel use but they can move towards it, thereby reducing the difference $(A_1 - A_2)$.

The more commonly used factor of efficiency ($\eta = \frac{E_2}{E_1}$) is defined as the ratio of the energy required (E_2) to the energy consumed (E_1), and is related to the effectiveness by

$$\epsilon = \frac{A_2}{A_1} = \frac{C_2 E_2}{C_1 E_1} = \frac{C_2}{C_1}\eta \tag{1}$$

where C_1 and C_2 are the ***energy quality factors*** of fuel and required energy, respectively. For most fuels C_1 is close to 1 and therefore

$$\epsilon = \eta C_2 \tag{2}$$

Hence the effectiveness of fuel use reflects not only the energy use (η) but also the energy quality required (C_2).

Heating applications are estimated to consume about 40% of primary fuel use in the U.S., as shown in Table 1 for heating with electricity, and Table 2 for heating with fossil fuels, for 1974 (The data are adapted from DOE's Energy Consumption Data Base (ECDB)[1]). The tables show also estimates of η, C_2, and ϵ. The overall effectiveness of fuel use for these heating applications is estimated to be less than 20% , hence leaving a large margin for improving fuel consumption without curtailment of the end-use demand.

3. Cost Effective Fuel Savings in Heating Applications

In this section, we turn to the economic aspects of fuel savings in heating applications, in order to show how much fuel savings can be economically realized. The numbers presented in this section should be considered as estimates, and not as precise measurements of fuel savings, since economic variables (e.g. prices) that are the basis of economic analysis change every day. We have always made conservative assumptions in our analysis, in order not to overestimate the fuel saving potential.

The energy use data presented in Table 1 and Table 2 are those of 1974. It would have been preferable to analyze more recent data in order to evaluate the potential fuel savings that represents as close as possible current conditions. However, 1974 data are the latest that are available from DOE, detailing fuel use by end-use categories, and they are used as a good approximation of more recent fuel use in heating applications.

3.1. Assumptions Used for Economic Comparisons

The cost-effectiveness of an investment in fuel savings was determined by comparing the levelized annual cost of this investment with the dollar value of expected annual fuel savings. In order to make valid economic comparisons, all costs were expressed and compared in constant 1980 dollars.

Initial capital costs were levelized using a capital recovery factor (R) with a 3% real (deflated) interest rate and a 10 year lifetime:

$$R = 0.117 \tag{3}$$

A 10 years lifetime is reasonable for a fuel saving investment considering the lifetime of buildings, water heaters, industrial furnaces, or the time required for new energy developments that are the alternatives to energy savings, like the time required for oil and gas exploration and development, for power plant construction, or for synthetic fuels plant construction. A real interest rate of 3% is moderately high, given that over the decade 1970 - 1979 the inflation rate had an average of 7.1% per year[2], while mortgage rates and bank prime rates had an average of 8.8% and 8.1% respectively[2], hence implying a long term real interest rate of only 1% to 1.7% per year.

For estimating the dollar value of expected annual fuel savings we assumed that fuel prices will escalate at the same rate as the general inflation, and hence that fuel prices remain constant in 1980-dollars. If we exclude the "oil shock" years of 1974 and 1979, then over the 70's decade the energy Consumer Price Index (CPI) rose an average 6.3% per year, and the total CPI rose on the average by 6.1% per year[3]. Hence the assumption made is reasonable in the absence of severe market disruptions, but is conservative given that disruptions occurred in the past, and may occur again in the future.

3.2. Fuel Savings in Space Heating

We have analyzed the economics of fuel savings in space heating in the residential sector, which consumes over 70% of fuels used for this purpose.

The consumption of fuels for space heating depends on the type of the residential structure being considered, and the climate in which it is located.

According to data from the Bureau of the Census[4], in 1974 about 68% of housing units in the U.S. were single family houses, 12% were low-rise multiple-family buildings (2 to 4 housing units per building), and the remaining 20% were larger multiple-family buildings and mobile homes. In our analysis, we have considered only single family houses and low rise multiple family units, both categories comprising about 80% of all housing units.

To account for regional differences in climate and construction, we have analyzed separately the space heating requirements of the four U.S. Census regions shown in Figure 1[4]. The West Region shows the most variation in climate, e.g. the winter in Montana is much colder than in Arizona. But the largest fraction of the West Region population is in Central and Southern California, and therefore the average figures used for the West Region reflect mostly conditions in California.

The average fuel use for space heating in typical residential units in each of the four U.S. regions is shown in Table 3[5]. Depending on the type of heating fuel used, for the same type of housing unit in one region, there is a variation in the average amount of fuel use due to differences in average furnace efficiency and in building construction. For example, electrically heated houses are typically newer and better built than oil or gas heated ones, and electrical furnaces have a higher efficiency than oil or gas furnaces.

To estimate the cost-effective fuel-saving potential in residential space heating we have analyzed the investments and resultant fuel savings in retrofitting existing houses with insulation (to reduce heat loss through the skin of the house) and weatherstriping (to reduce cold air infiltration in the house). Air conditioning needs were not considered, hence fuel savings resulting from insulating homes are conservatively underestimated since insulation for heating would normally also reduce fuel use for space conditioning in many regions. Some examples of retrofit costs (in 1980-$) and fuel savings are :

1. The National Bureau of Standards installed storm windows and insulation in walls, ceiling and floor of a large Washington D.C. suburban house, and achieved a 58.5% savings in space-heating fuel, for a retrofit cost of $4030[6].
2. A survey by the Department of Energy, of a national sample of 685 households that took various conservation actions in 1978-1979, shows that these households have achieved an average of 29% annual fuel savings, for an average initial cost of $635 [7].

3. The Canadian Office of Energy Conservation reports the results of two retrofits where in one case it saved 54% of the annual fuel consumption of a 2-story wood frame house with wood siding for a cost of $2,770, and in the other case it saved 44% of the annual fuel use of a wood frame bungalow with aluminum siding for a cost of $1,605 [8]. (Canadian climate and houses are similar to those of the northern regions of the U.S.)

4. In an experiment in 24 townhouses with identical floor plans in Twin Rivers,N.J., researchers from Princeton University saved from 20 to 30% of fuel use for space heating, for an initial cost of $440 to $570 per unit, depending on the contractor and the amount of insulation and weatherstriping installed[9].

5. In a more advanced experiment in one Twin Rivers townhouse, the fuel use for space heating was reduced 67% for an initial cost of $1790[10].

The costs and savings reported above are illustrated graphically in Figure 2. The labels used on the figure refer to the paragraph numbers above. The points generally fall on a curve of diminishing returns (solid line), a result to be expected. Point (5) on the figure illustrates that a well trained team of house specialists can drastically reduce the fuel use for space heating of a house, for a relatively low cost[10].

A retrofit investment is considered cost-effective when the levelized annual cost of this investment is less than or equal to the dollar value of annual fuel savings.

The average retail prices paid in 1980 for residential heating are[11]:

$$C_{oil} = 98\ cents/gallon = 7.0\ \$/10^6 Btu \tag{4}$$

$$C_{gas} = 3.9\ \$/Mcf = 3.9\ \$/10^6 Btu \tag{5}$$

$$C_{electric} = 5.36\ cents/kWh = 15.7\ \$/10^6 Btu \tag{6}$$

Using these average prices and Table 3 for fuel use, the maximum cost-effective retrofit for each type of housing unit in each of the four U.S. Census Regions was calculated and the results are shown in Table 4. The combination of heating loads and fuel prices in the North Central Region justify the maximum investment considered practical ($3500 for single-family and $1400 for multiple-family units) for all heating fuels. In the Northeast, the maximum investment is warranted only for heating with oil and electricity. In the West region, the maximum investment is warranted for heating with oil and electricity in single-family houses, but only for oil-heating in multiple-family housing. Finally, in the South region, the heating loads are too small to justify the maximum investment. Gas prices are presently under control, and when these controls are removed gas prices are expected to go up, and equation (5) will tend towards (4). With higher gas prices the situation of course would be different, and higher retrofit investments would be justified.

We can also estimate the annual fuel savings (expressed as a percentage of annual fuel use before retrofit), as shown in Table 5.

Using Table 6 for the number of housing units, Table 4 for the retrofit investment, and Table 5 and Table 3 for fuel savings, the total cost of retrofit investment and the total fuel savings are estimated, as shown in Table 7. Oil, gas, and electricity savings are estimated to be about 1.0, 2.2 and 0.16 Quad per year, respectively, and the initial capital costs required to realize those savings are estimated at $35, $69, and $18 billions, respectively. Again, when controls are removed from gas prices, we can expect to see more retrofit investments become attractive. The equivalent cost, in constant 1980-$ and using the capital recovery factor of equation (3), of the fuels saved is

$$C_{oil} = \frac{34.6 \times 10^9 \times 0.117}{1038 \times 10^{12}} = 3.90\ \$/10^6 Btu = 55\ cents/gallon \tag{7}$$

$$C_{gas} = \frac{69.3 \times 10^9 \times 0.117}{2163 \times 10^{12}} = 3.75\,\$/10^6 Btu = 3.75\,\$/Mcf \tag{8}$$

$$C_{electric} = \frac{18.3 \times 10^9 \times 0.117}{161 \times 10^{12}} = 13.3\,\$/10^6 Btu = 4.5\,cents/kWh \tag{9}$$

These equivalent costs of the fuels saved are less than average retail prices paid in 1980 for heating fuels, equations (4) to (6), and therefore the retrofits considered are cost-effective.

3.3. Fuel Savings in Water Heating

The residential sector consumes 85% of the fuels used for water heating in the U.S. Hence, the economics of fuel savings in water heating have been analyzed using typical residential water heaters as models.

A typical electric water heater with a 50-gallons capacity uses about 6,600 kWh/yr of electricity[12]. By increasing the jacket insulation around the water heater, and by insulating 25 ft of hot-water distribution pipe, about 14% of the electricity use can be saved, for an initial cost of $57[12].

Thus the estimated equivalent cost of saved electricity is (using the capital recovery factor of equation (3)):

$$C_{electric} = \frac{57 \times 0.117}{0.14 \times 6600} = 0.72\,cents/kWh \tag{10}$$

This equivalent cost of electricity is much less than the U.S. average price, 5.4 cents/kWh — equation (6), and hence retrofitting water heaters with jacket and pipe insulation is cost effective.

Counting that there are about 15×10^6 electric water heaters in the U.S., it is possible then to save about $14 \times 10^9 kWh/yr$ of electricity with an initial capital investment of $855 \times 10^6 \$$.

Similarly, for gas and oil-fired water heaters, we estimate that the equivalent cost of fuel savings are

$$C_{gas} = 0.73\$/10^6 Btu \tag{11}$$

$$C_{oil} = 1.0\$/10^6 Btu = 14\,cents/gallon \tag{12}$$

Again, the equivalent costs of fuel savings, equations (11) and (12), are much less than the average retail prices, equations (4) and (5), and hence retrofitting gas and oil water heaters is cost-effective.

3.4. Fuel Savings in Process Steam Raising

The amount of fuel used for steam raising can be reduced in many ways. General measures for reducing this fuel use include preheating combustion air and input water with exhaust gases, insulating the boiler, plugging leaks in the steam system, and better re-utilization of the hot condensate. Steam-using industries can also modify their processes to reduce the use of steam, and are in fact pursuing these modifications such that the demand for steam is not expected to grow by much over the next couple of decades, despite the industries' expanding production[13].

The above-mentioned fuel-saving methods are specific to each industrial application, and cannot be analyzed in our broad evaluation of fuel-saving potential for all the industrial sector. Cogeneration, the simultaneous production of steam and electricity, is however a fuel-saving method that can be applied to all steam-using processes, and we have evaluated the fuel-savings that are realizable by this method. Steam can be generated in boilers fitted on the exhaust of oil-fired or gas-fired gas turbines, or it can be drawn from a back pressure steam turbine attached to a coal-fired boiler. Fuel savings accrue because the fuel required to produce electricity, beyond the fuel needed to produce the steam alone – called the effective heat rate, is in the range of 5000 to 6000 Btu/kWh for gas turbines, and about 4500 Btu/kWh for steam turbines, whereas electric utilities use on the average 10,700 Btu/kWh.

3.4.1. The Cost of Cogenerated Electricity

In evaluating the economical potential for cogeneration, we will use the following assumptions:

1. The electricity production by a cogeneration plant will not be limited by the on-site need of electricity, but rather by the cogeneration technology being considered. This assumes that electricity production in excess of on-site needs can be sold to the utility, which is guaranteed by the Public Utilities Regulatory Policies Act of 1978 (PURPA, PL95-617).
2. A cogeneration plant will be considered cost-effective when the cost of cogenerated electricity is lower than the marginal avoided cost (not the average cost) of electricity from the utility. This reflects realistically the PURPA regulation that requires utilities to buy electricity at this marginal avoided cost.
3. The industrial firm will continue to use for its cogeneration equipment the same fuel that it used previously for its steam-raising boilers. This assumption is realistic given that the Powerplant and Industrial Fuel Uses Act (FUA) of 1978 provides for cogeneration an exemption to the restrictions on oil and gas use[13]. Cogeneration based on coal saves more oil and gas than cogeneration based on oil and gas, but is limited now to very large plants that are already using coal for raising steam, because of the space and size requirements for conventional coal boilers. Future developments in advanced coal cogeneration technologies (e.g. pressurized fluidized bed combustors, coal-fired Diesel or Stirling engines) can help in overcoming this size restriction, and coal-based cogeneration should then become more prevalent[14].
4. Electricity production is charged with the full capital cost of cogeneration equipment. This is a conservative assumption that will tend to increase the cost of cogenerated electricity, because in some instances, where the steam boiler is due for replacement, cogenerated electricity should be charged only with the incremental capital cost of cogeneration equipment, i.e. what that equipment costs in excess of what the needed boiler would have cost alone. In the other instances, where the steam boiler still has some useful life, but is replaced nonetheless by the cogeneration unit, the cogenerated electricity should be charged with all the capital cost of the new equipment, and we will consider conservatively that all cogeneration is installed under such circumstances.
5. Electricity production is charged with only the incremental fuel use, i.e. the fuel that the cogeneration equipment has used in excess of what the steam production would have used by itself.
6. The investment in the cogeneration project will come 30% from debt and 70% from equity financing.
7. The return required on the debt financing (in constant dollars) is 3% per year, and the same return is also required on equity financing but after tax. Assuming that the tax rate (τ) is 50%, the return on equity must be 6% per year in constant dollars.
8. The capital is recovered over a period of 10 years, during which we will use a straight line depreciation.

With these assumptions, we estimate that the cost of oil-, gas-, and coal-cogenerated electricity is in the ranges

$$e_{oil} = 37 \quad to \quad 56 \quad mills/kWh \tag{13}$$

$$e_{gas} = 27 \quad to \quad 34 \quad mills/kWh \tag{14}$$

$$e_{coal} = 36 \quad to \quad 54 \quad mills/kWh \tag{15}$$

The marginal avoided cost of utility generated electricity, in oil or gas fired central stations that are not used as baseload units, is estimated to be

$$e = 62 \quad mills/kWh \tag{16}$$

This cost is higher than the cost of cogenerated electricity (27 to 56 mills/kWh, equations (13), (14), and (15)). Therefore, the cogeneration of steam and electricity is a cost-effective means of saving oil and gas.

3.4.2. Total Fuel Savings and Capital Requirements of Steam-Electricity Cogeneration

Because some steam loads may be too small or too irregular with time, it is conservatively estimated that only 50% of all process steam production can be practically associated with the cogeneration of electricity[13, 14]. About 50% of steam use occurs at plant sites that use more than 270×10^6 Btu of steam per hour, per site[14]. Therefore, if we associate cogeneration with the largest steam users, it is equivalent to associating cogeneration with steam use in excess of 270×10^6 Btu/hr site. Gas turbines used in cogeneration typically produce 200 kWh of electricity per 10^6 Btu of process steam, and back-pressure steam turbines typically produce 60 kWh/10^6 Btu of steam[14]. Hence cogeneration is considered practical on sites that can produce more than 54 MWe for gas turbines, and 16 MWe for steam turbines.

We thus estimate that it is cost-effective to install cogeneration plants that will provide about $240 \times 10^9 \; kWh/yr$ of electricity, and save about $1340 \times 10^{12} \; Btu/yr$ of oil and gas. The initial capital outlay for these cogeneration plants is estimated at about $16 billion.

3.5. Fuel Savings in Direct Heating

The assumptions used in evaluating fuel savings in process steam raising are considered to apply also to fuel savings in direct heating applications.

For evaluating the cogeneration potential, the direct heating applications are divided into two categories: heating where the temperatures required are under 1000° F, and heating where the temperatures required are over 1000° F.

3.5.1. Heating Under 1000°F

For the heating applications where the temperature required is less than 1000°F, the fuels can be used in gas turbines, and the exhaust gases from these turbines (typically 600 to 1100°F[14]) can be used for the heating processes. Most of the fuels used for the heating processes are gas and oil, and therefore suitable for use in gas-turbines.

The cost of electricity cogenerated with process heat in oil-fired and gas-fired units is estimated to be

$$e_{oil} = 34 \quad to \quad 52 \quad mills/kWh \tag{17}$$

$$e_{gas} = 24 \quad to \quad 30 \quad mills/kWh \tag{18}$$

Since the cost of cogenerated electricity, (17) and (18), are less than the utilities' marginal avoided cost of 62 mills/kWh (equation (16)), we conclude that cogeneration is cost-effective.

The total potential electricity production by cogeneration is about $196 \times 10^9 kWh/yr$, the total annual fuel savings are about $1,020 \times 10^{12} Btu/yr$, and the initial capital required is about $8 billion.

3.5.2. Heating Above 1000°F

As the heating temperature achieved in a furnace increases, so does generally the temperature of exhaust gases. When the temperature of the exhaust gases is high enough, they can be used to generate power, without an additional use of fuel.

The efficiency of high temperature fossil fuel fired furnaces is generally low. For example, the efficiency of glass furnaces ($T \simeq 3000°F$) and metal forging furnaces ($T \simeq$ 2000°F) is only in the range 10 to 20%[15]. Even for large steel heating furnaces ($T \simeq 1900$ to $2500°F$), with insulation and recuperation of heat from exhaust gases, the efficiency generally lies in the range of 30 to 40%[16]. However, not all the energy loss is in the exhaust gases. Some energy losses occur also through the furnace walls and doors, and by radiation. For small metal heat treating furnaces, only about 60%of the fuel's energy are estimated be lost in the stack[15, 17]. Because larger furnaces tend to be more efficient, we will assume 40% of the energy of fuels used for high temperature heating is present in exhaust gases.

In a survey of industrial furnaces, started in 1975 under ERDA and completed in 1978 under DOE, which covered all 2-digits SIC code major groups of industries, the temperature of furnaces exhausts was found to be typically in the range of 500°F to 1000°F, with a median of 675°F[18]. The exhausts are therefore suitable for use in commercially available steam turbines to produce electricity[18]. Using exhaust gases in this temperature range (500 to 1000°F), steam turbines typically have an efficiency in the range of 15 to 35%[18]. We will assume that the average efficiency achieved is 20%.

Therefore, if we assume that 40% of the fuel's energy is in the exhaust, that 20% of the exhaust energy can be transformed into electricity, and that only half the heating furnaces are practically suitable for the installation of cogeneration, the potential electricity production by cogeneration, in heating applications with $T > 1000°F$, is estimated to be about $37 \times 10^9 kWh/yr$.

Since this electricity is produced by the waste heat of exhaust gases with no additional fuel use, the fuel savings are 10,700 Btu/kWh, which were previously used by the electric utility. Hence the total fuel savings are about $396 \times 10^{12} Btu/yr$ ($= 37 \times 10^9 \times 10,700$).

To determine whether these fuel savings are cost-effective or not, we have to compare the cost of cogenerated electricity to the marginal avoided cost of utility generated electricity.

In 1980 dollars, the installed capital cost of rankine-cycle power systems varies between 2,280 \$/kW, for 0.5 MW unit operating with 675°F exhaust, and 1,520 \$/kW for units larger than 1 MW operating with 1000°F exhaust[18]. We thus estimate that the cost of electricity cogenerated with waste heat is

$$e = 36 \quad to \quad 51 \quad mills/kWh \tag{19}$$

Since the cost of this electricity is less than the marginal avoided cost of utilities electricity of 62 mills/kWh (equation (16)), the use of cogeneration, with the exhaust gases of high temperature heating processes, is a cost-effective method of saving fuel.

3.6. Summary of All Cost-Effective Fuel Savings in Heating Applications, and their Capital Requirements.

3.6.1. Fuel-Savings

The cost-effective fuel savings that were determined previously in this section, are summarized in Table 8. The first column in the table restates from Table 1 and Table 2 the fuel use (in 1974) for the heating applications for which cost-effective fuel savings were established. If we add to the total fuel use ($22,550 \times 10^{12}$ Btu/yr) the primary fuels consumed by utilities for generating the electricity that is later displaced by cogeneration

$(475 \times 10^9 kWh/yr)$, the total use becomes

$$F = 22,550 \times 10^{12} \frac{Btu}{yr} + 475 \times 10^9 \frac{kWh}{yr} \times 10,700 \frac{Btu}{kWh}$$

$$= 27,630 \times 10^{12} Btu/yr \qquad (20)$$

Hence the cost effective fuel-savings, 6640×10^{12} Btu/yr — second column in Table 8, expressed as a percentage of initial total fuel use are about $24\% \left(= \frac{6,640 \times 10^{12}}{27,630 \times 10^{12}}\right)$

The total initial capital investment necessary to realize those savings is estimated at $158.6 billion (fourth column in Table 8). The investment in fuel-savings are attractive, as shown by the last two columns in Table 8, because they "produce" energy cheaper than the present supply technologies. Thus, oil and gas savings in space and water heating are estimated to cost about 3.4 $\$/10^6$ Btu, whereas the supply of these fuels cost 4.9 $\$/10^6$Btu. Similarly, electricity savings in space and water heating cost about 3.6 cents/kWh, whereas the electricity supply costs 5.4 cents/kWh. Cogenerators can produce electricity at a cost between 3 and 4 cents/kWh, which is less than the marginal avoided cost of electricity from utilities, estimated between 5 and 7 cents/kWh. It is interesting to note that since cogenerated electricity is cheaper than utility-electricity, the oil and gas savings due to cogeneration come not at a cost, but rather with a profit.

Despite their cost-effectiveness, the realization of the fuel-savings outlined in Table 8 can be hindered by the initial capital requirements. There are two ways of looking at the initial capital requirements for fuel savings:

1) Compare the capital requirements for fuel savings in a sector of the U.S. economy to the total capital requirements of that sector; this comparison indicates the capacity of that sector to increase its capital expenditures to undertake these cost-effective fuel-savings investments.

2) Compare the capital requirements for fuel-savings to the capital requirements of the alternative of producing an equivalent amount of fuel from new supplies.

3.6.2. Capital Requirements of Fuel Savings

The amount of initial capital required to realize the cost-effective fuel savings in space and water heating in the residential sector is estimated at $126 billion. This is a large amount of capital, when compared to other levels of investments in the residential sector. For example, the total value of all new housing units put in place in the U.S. in 1979 was $78.6 billion[2]. If we add the expenditures for additions, alterations, improvements, maintenance and repairs of existing residences, then the total expenditures for residential structures in 1979 was $121 billion[2]. The capital required for insulation retrofits is therefore large compared to the normal level of expenditures in the residential sector. If we consider that the $126 billion retrofit investment is spread over a period of 10 years, it will require (in constant 1980 dollars) $12.6 billion per year for 10 years. This is still a large requirement, equivalent to increasing the capital spending of the residential sector by about 10%, and maintaining it at this higher level for 10 years.

The total amount of capital required for fuel savings by cogeneration is estimated at $32 billion. Again, this is a large amount of capital, when compared to other levels of investments in the industrial sector. For example, the total capital expenditures by manufacturing industries for new plant and equipment in 1980 was $90 billion[2]. In constant dollars, these capital expenditures have been growing by 3 to 4% per year over the period 1970-1980[2]. If we schedule the introduction of cogeneration over a period of 10 years, i.e. requiring $3.2 billion (1980 dollars) per year for 10 years, then it would be equivalent to requiring the manufacturing sector to double its increase in capital expenditures in one year, which would seem difficult to achieve.

Therefore, in both the residential and industrial sectors, the capital requirements, to implement the fuel savings outlined in Table 8, are high when compared to the levels of investments normally present in these sectors. The difficulty in raising capital would therefore hamper the implementation of the fuel-savings measures, despite their cost-effectiveness.

The capital requirements for the fuel-savings outlined in Table 8 are requirements in addition to the ones normally present in a sector, and in addition to other cost-effective fuel savings measures (the fuel savings analyzed in this presentation are by no means exhaustive). For example, insulation retrofits require capital in addition to the capital required for new housing or for repair of old housing. Similarly, the capital required for cogeneration is in addition to the capital required for the normal conduct of business, for expanding production, making new products, or replacing worn equipment, for restructuring and improving old processes, and for other conservation measures besides cogeneration. Because the sectors cannot easily expand their access to capital, fuel-savings are expected to be implemented slowly.

3.6.3. Capital Requirement of New Fuel Supplies

If fuel-savings measures are not adopted, new fuel supplies have to be developed in order to replace depleting old supplies and to allow for some expansion in consumption due to growth in population and/or the economy. It is interesting then to compare the capital requirements of fuel-savings to the capital requirements of fuel-supply, to see whether any capital would be saved if the fuel-savings measures are not implemented. Spread over a period of time fuel-savings were established to be cheaper than fuel-supply; but since fuel-savings require a large initial capital, the point studied here is whether some reduction in initial capital outlay can be made, if fuel-savings are not implemented.

Once the fuel savings measures are implemented, the fuels saved are available for consumption by other end-uses. Saving fuel is thus an equivalent and a replacement to supplying fuel. In space and water heating, the electricity savings are equivalent to a supply of 61×10^9 kWh/yr and the oil and gas savings are equivalent to a supply of $(3201 + 492 = 3693) \times 10^{12}$ Btu/yr. The advantage of cogeneration of course is that it reduces the total demand for oil and gas by displacing (albeit not 100% of the time) the utility's oil and gas based electricity generation. The oil and gas savings by cogeneration are thus estimated to be about $2,756 \times 10^{12}$ Btu/yr.

The supply system equivalent to the fuel savings measures outlined in Table 8 should then deliver an amount of electricity of $61 \times 10^9 kWh/yr$ and a total amount of oil and gas of $6450 \times 10^{12} Btu/yr$.

Assuming that the space heating season is half a year, during which time power plants operate at 80% capacity, that water heating is done all year long, when power plants average 65% annual capacity factor, and that there is a 10% loss in electricity due to transmission and distribution, then the electricity savings are equivalent to an installed capacity of

$$K_e = \left(\frac{47}{0.5 \times 0.8} + \frac{14}{0.65}\right) \times \frac{10^9}{0.90 \times 8760} = 17,600 MWe \qquad (21)$$

The oil and gas savings, when expressed in terms of barrels of oil equivalent (boe) of 6×10^6 Btu per barrel, are $1.07 \times 10^9 boe/yr$. Assuming that fuel production facilities operate with an 80% annual capacity factor, and that there is a 5% loss of fuel for cleaning, refining and transporting the fuel, then the oil and gas savings are equivalent to a production capacity of

$$K_f = \frac{1.07 \times 10^9}{0.8 \times 0.95 \times 365} = 3.87 \times 10^6 boe/day \qquad (22)$$

Having determined the supply production capacity equivalent to the fuel savings, we can now estimate the initial capital requirements for this production capacity.

For electric power plants, a recent cost estimate by Commonwealth Edison is $1,150 per kilowatt capacity for nuclear plants, and $785 per kW for coal plants[19]. Because of the difference in fuel costs and other operating expenses, nuclear and coal plants come out to be equally competitive despite the difference in initial capital costs[19]. If we assume that on the average half the new power plants will be coal ones and the other half nuclear ones, then the average capital cost for new electric power plants is $968 per kW. The Commonwealth Edison estimates were developed for comparing the two types of plants, and hence costs of land, transmission terminals, and transmission lines were excluded since such costs are usually the same for both types of plants[19]. The capital costs of transmission lines and equipment in the U.S. tend to average about 50% of the capital cost of power plants[20]. If we add that amount to the capital cost of the plant, then the capital required for new electric supply is about 1,450 \$/kW. Hence the total capital requirements for an electric supply equivalent to the electric savings is about $\$25.5\ billion\,(= 1450 \times 17.6 \times 10^6)$.

For oil and gas supply, the production from conventional wells is projected to decline in the future, and new supplies are expected to come from reservoirs with difficult operating characteristics, from remote locations or areas with harsh operating environment, and from synthetic fuels[21]. Production of synthetic oil or gas is estimated to require an investment in the order of $60,000 per boe/day capacity, and the other competing options for replacing conventional oil and gas do not seem to be much cheaper[21]. Therefore, the capital required, for a supply that is equivalent to the savings considered, is approximately $\$232.5\ billion\,(= 60,000 \times 3.87 \times 10^6)$.

The total capital required for the supply of both electricity and fossil fuels that are equivalent to the savings is about $\$258\ billion$.

The initial capital cost of equivalent new supplies of energy is therefore higher than the initial capital cost of the fuel-saving measures. If the fuel savings are not implemented because of difficulties in funding their first cost, the alternative investments in new supplies will cost more.

3.6.4. Allocation of Capital for Fuel Savings

As we have demonstrated, fuel savings are cheaper than fuel supplies both in terms of (equivalent) energy costs (e.g. $\$/10^6$ Btu or cents/kWh) and in terms of initial capital cost. Hence it is economically more beneficial to invest in conserving fuels rather than in developing new fuel supplies. Yet, it seems that it would be difficult for the residential and industrial sectors to increase their capital spending to undertake fuel-saving investments. It is important to note here that in the residential and industrial sector capital spending for fuel savings has to be done in addition to other normal capital spending, whereas in the energy production sector capital spending for energy supply has to be done in place of (not in addition to) capital spending for fuel-savings. If fuel use is reduced, the needed expansion in fuel production is also reduced. Raising large amounts of capital is difficult in present economic conditions for all sectors of the economy. The difficulty is compounded by the fact that for fuel savings this large initial capital has to be raised by a large number of small operators. Traditional large energy-supply organizations on the other hand, such as public utilities or oil companies, have in the past handled large investment programs, and it is suggested that this expertise in raising and channeling capital be used in financing fuel-saving projects.

One way to encourage the flow of capital into the energy consuming sectors, is to allow the energy production sector to become energy-services[22] providers rather than just fuel sellers. Oil, gas, and electricity are not desired for themselves in a residence, but rather for the "services" they provide. e.g. warm house or hot water. The same amount of "energy-service" can be obtained with different amounts of fuel depending for example on the amount of insulation around the house or the water heater. If gas or electric utilities, or oil companies provide energy-services rather than just fuels, they can provide home owners with advice and financing for retrofits, repair and maintain in optimum conditions the energy using equipment, and maybe provide new more efficient equipment as it becomes available[22]. From our analysis, the economic benefits of such a scheme of encouraging energy producers to invest in fuel savings are threefold:

1. Society benefits from a reduced demand for capital since, as we have shown, producing a certain amount of fuels by conservation requires less initial capital than producing the same amount of fuels from new supplies.
2. Consumers benefit from a reduced bill for energy services, as we have shown that the levelized cost of fuel-savings investments is less than the price of fuels consumers are presently paying.
3. Energy producers earn a return on their money (a 3% per year real, above inflation, interest rate was assumed for our analysis. Higher rates can be used if desired, thereby increasing the returns for investors, and decreasing the savings for consumers).

A scheme for utility investment in residential retrofits has been successfully in place in Oregon since mid-1978, and has come to be known as the Oregon Plan[23]. The Pacific Power and Light Co. (PP&L) has financed the retrofits in about 10,000 homes by mid-1980[23]. The financing is done with a zero-interest loan to the home owner, and the loan becomes due whenever the house is sold or the title transferred. During the time that the loan is outstanding, it is included in the rate base so that the utility earns a return on the sum invested. All customers of the utility benefit from such an investment, and not just the owner of the retrofitted house, because the electricity produced by this conservation effort is estimated to cost about 3 cents/kWh, or about half of what consumers would pay for a new supply[23]. The success of the Oregon Plan indicates that energy suppliers can indeed successfully become energy-services suppliers, to the benefits of all those involved in the plan. Such financing of fuel-savings by traditional fuel suppliers should be encouraged.

For the industrial sector, arrangements can also be made for the financing of cogeneration projects. Allowance of utility or third-party ownership of cogeneration equipment can help alleviate the financial difficulties faced by industries in implementing cogeneration[13, 14]. Financing energy savings in the industrial sector with capital from traditional energy producers, transforming the producers into providers of energy-services rather than just fuels, has the same advantages as in the residential sector: society benefits from a lower demand for capital, and from lower priced fuels, (fuels saved are available more cheaply than new supplies), industries benefit from lower production costs, and energy-services providers earn a return on their money. The difference between the cost of utility generated electricity and cogenerated electricity represents a profit that can be shared in many different ways between the industries and the financing organization, and hence providing an incentive for all parties involved to pursue cogeneration projects.

4. Market Imperfections and Energy Conservation

In this section we will examine the barriers that hamper investments in energy conservation, and propose the major elements of government policy initiatives that can help overcome these barriers, so that the economy can benefit more from fuel and cost savings opportunities.

The analysis completed in Section 3 shows that for heating applications society can make a better use of its resources, a better use that is reflected by a decreased cost, by investing in energy saving equipment and hence spending less on purchasing fuels and on developing new supplies of fuels. Other studies arrive at the same conclusion for other applications as well[22, 24, 25]. Yet there are many indications that the investments in energy conservation are sometimes not made despite their profitability, or that they are not made at a scale or rate commensurate with their profitability.

For example, Hirst et al.[7] report that in 1978-1979 half the U.S. households took no action whatsoever for energy conservation in their homes. Those who did, generally took low cost measures. Their median investment was only $194 per household, far below the levels of cost-effective retrofit investments, estimated in Section 3 to be in the range $800 to $3500. Hatsopoulos et al.[25] also report that many manufacturers turn down energy-saving projects despite economic benefits calculated on a similar basis as here (showing that other factors determine the choices).

In an ideal free market environment, where every economic actor tries to minimize his costs and maximize his profits, such a situation would not exist. Therefore, there must be some prevalent conditions in the "real" market that interfere with the implementation of fuel saving investments. These conditions are generally called market "imperfections" because they are the cause of why a real market diverges from an ideal or perfect one.

In this section, we will discuss three major market imperfections that hinder investments in fuel savings: lack of information and awareness, limited access to capital, and inadequate feedback of prices and/or profits. Each one of these market imperfections, in relation to energy conservation, is discussed in more details in the following.

4.1. Lack of Information and Awareness

Before the dramatic increases in energy prices during the last 10 years, energy consumption was not a major concern for the average consumer or business in the U.S. The serious concern for energy use is a relatively recent phenomenon, and it should not be surprising then to find a lack of information on what are the most appropriate responses to this new energy situation.

Without adequate information on energy saving possibilities, or energy-saving equipment and its cost and performance, the energy user may not see a fuel saving opportunity and therefore may not act to take advantage of it. For example, without a program that labels the fuel consumption of appliances or cars, the average consumer has no way of knowing reliably such a consumption, and therefore cannot make an informed decision about it.

In the area of residential energy conservation, the Princeton University study of the Twin Rivers community provides us with many insights into the needs of information for energy savings. Ross and Williams[26] found that even "the nations responsible professionals don't yet understand household energy performance well enough". We surely cannot expect this understanding from the average home owner. Ross and Williams also found that "in general, building owners do not know how best to spend money on conservation investment. They need expert advice."

In a survey of Twin Rivers residents, Darley[27] found that "in most instances people seriously overestimate the cost of an innovation that would reduce their energy consumption, and seriously underrate the energy conservation that innovation might achieve, and therefore underestimate the savings they might realize by adopting it." Darley also found that by installing simple monitoring equipment that relays to people their electrical consumption, they were able to achieve by themselves a 10% reduction in their electrical energy use, and when instructed on additional energy saving techniques, their savings rose to 15%.

The overestimation of costs and underestimation of savings come not only from the lack of specific factual information about energy saving methods but also from the novelty of such methods. When faced with a new and unfamiliar decision, people, and businesses, tend to be conservative. The information therefore has to be conveyed with enough credibility so as to overcome this conservative skepticism, and with enough persistence and wide reach so as to make it more familiar.

Information problems can arise also for commercial and industrial establishments. Businesses, especially small ones, can have some of the same problems as the residential sector, i.e. the technology and equipment for energy savings exist, but are not widely known or accepted, and the problem is to disseminate, with reliability and credibility, the information about these energy-saving technologies. But there can also be an "information" problem of a different kind, where the technology is well known to an industry for example, but the energy conservation project is rejected because of its novel or unfamiliar nature. Management is sometimes not well aware or sure of the advantages of energy conservation, and therefore prefers to give higher priorities to other more familiar projects in a plant. For sure, energy conservation is not the only concern of an industry, and may well be competing with other projects for an industry's limited supply of capital, engineers, workers, and other resources. Nonetheless, a better awareness of the competitive advantage that energy conservation can give in terms of reduced costs, would help in getting more energy conservation projects implemented more often.

4.2. Limited Access to Capital

The classical economic thinking is that there will (or should) always be money on the capital markets to finance good investments. The realities of the American market, and the way it raises and channels capital, are however different.

American business investment is mostly financed with retained earnings. When earnings are low, whether due to energy costs or other reasons, there are limited funds to finance new investments, either in energy savings or other projects. The risks involved in the American private enterprise system limit the borrowing capacity of American firms to a debt to equity ratio of about 30- 40% , which is a low ratio compared to (less risky) utilities that can have up to about 50% debt to equity ratio, or compared to large Japanese firms that can obtain up to 400-1000% debt/equity through (government backed) debt.

As we have seen in Section 3, the capital requirements for energy conservation tend to be large compared to the investments normally carried by industries. Since industries would probably have difficulties in raising the necessary capital many energy conservation projects would go unimplemented, no matter how good the returns on them may be.

The same situation is also true for individuals. Their limited capacity to borrow, or to save the necessary capital, may foreclose for them many profitable energy saving opportunities.

This however does not represent a normal market operation of optimal allocation of a limited capital resource, an operation that necessitates the foregoing of some investment opportunities because society does not have enough capital to implement all desired projects. As we have seen in Section 3, if energy conservation projects are not implemented, the alternative is investment in fuel supplies that will require more capital. The energy supply industries seem to be in a better financial position than other industries, or individuals, and hence enjoy a better access to capital, giving them a better chance to carry their investments. This situation represents a market distortion where capital is not optimally allocated for the least cost alternative.

Government policy initiatives that would encourage the channeling of capital to energy conservation projects can help in correcting this distortion. Making capital available for energy conservation projects will not place an additional burden on society's capital requirements, thereby draining capital from other needed projects, but rather relieve some of the pressure on the capital market since less money needs to be spent on energy conservation compared to new fuel developments.

4.3. Inadequate Feedback Mechanisms

In a successful free market operation, proper incentives guide the actions of individual economic actors such that while each tries to maximize his own individual benefit, the total societal benefit is also maximized. This successful operation depends heavily on each economic actor receiving a proper feedback from his actions, in the form of profits or losses as determined by costs or prices set by the market. If an economic actor does not receive the proper feedback of his actions, for example if a landlord does not benefit from his building insulation investment because the tenants pay for heating costs, it is unlikely that this actor's actions will maximize societal benefit although they may maximize his own benefit.

In many instances in energy conservation, the costs and benefits of conservation (or of the lack of it) are borne by different groups of society, and hence many conservation investments are not made because of the lack of adequate feedback incentive. For example, as cited above, a landlord pays for insulating a building but does not benefit from this investment because tenants usually pay the fuel bill. A similar example is when customers pay the fuel cost that is simply passed onto them by a firm, while the firm benefits from reduced capital spending (on energy saving equipment). Price controls reduce the conservation incentive when they artificially hold fuel prices down. Rolled-in or average pricing practices of utilities in effect share over all customers the cost of the increased consumption of only some of them.

There are therefore many situations in energy conservation where the cost-bearers are different from the beneficiaries, and the feedback between them is weak. In those situations, the incentives for investments in energy conservation are small, and hence fewer energy conservation projects will be realized than if perfect market feedback mechanisms were in operation. Government actions to restore incentives or to provide new ones can help in overcoming this lack-of-feedback hindrance to energy conservation.

4.4. Major Elements of Government Policies to Counter Market Imperfections

The United States does not have a truly laissez-faire free market economy (nor do other Western democracies). Government interventions in many areas of the economy have been instituted in the past in order to counteract the undesirable effects of a free market. The U.S., like other Western democracies, has often opted to intervene by government actions when the market failed to produce the results society wanted, or the market produced results that society would not tolerate. Many of the government interventions have been in the area of capital and labor, two most important factors in economic life. Some examples of government interventions in the area of capital are: banking regulation by the Federal Reserve Board, insurance of bank deposits by the Federal Deposit Insurance Corporation, and regulation of the financial and stock markets by the Security Exchange Commission. In the area of labor, examples of government interventions are: legislations for increased employment, regulations concerning union organization and collective bargaining, workmen's accident compensation, unemployment insurance, old-age pensions, regulation of factory conditions, fair-labor-relations acts, and other laws prohibiting discrimination, and setting minimum wages.

Reducing energy costs is an important and desirable outcome for the economy. As shown by the analysis in Section 3, a better use of society's resources can be made, as reflected by a reduced total cost, by investing in energy saving opportunities. However, many real barriers impede the realization of these investments, and hence the economy continues to suffer from high energy prices. Government intervention to help overcome these barriers seems well justified then, since such interventions, to produce socially beneficial effects that the market by itself would not produce, are not unprecedented, have been used many times in the past, and seem to enjoy a strong public consensus.

The major elements of a government intervention policy, to foster investments in energy conservation, are presented below. This intervention policy is intended to help overcome the three barriers to investments in energy conservation discussed earlier: lack of information, limited access to capital, and inadequate feedback incentives. Government policy initiatives are needed in all three areas cited above, and some that are designed to overcome a barrier in one area may also help in overcoming the barriers in other areas, thus increasing the impact of government policies. For example, disseminating information on financial assistance also improves the access to capital. Also, setting performance standards for buildings, to substitute for the lack of incentives for the developers or landlords to increase the energy efficiency of their structures (since this increases their cost while ultimate users later benefit from reduced fuel cost), may also help to disseminate information about energy saving possibilities in buildings. Hence government programs to counter market imperfections in all three areas need to be well coordinated together, and may not be as independent of each other as the following discussion may seem to imply.

4.4.1. Information and Awareness

Information is an essential tool for implementing energy conservation projects, and its dissemination, to increase the awareness about energy savings, is very effective in promoting investments in energy savings. DOE estimates that for $1 spent on information, education, and so-called "reach-out" programs, $5 of conservation investments are generated, whereas for $1 cost in tax incentives, only $2 of conservation investments are made[28]. Dissemination of information about energy savings can help energy users in making informed decisions about savings and hence foster investments in conservation. Manufacturers of energy-saving equipment have a vested interest in selling their products, and therefore their information may be viewed with some conservative skepticism. The government however does not suffer from such a credibility problem, and therefore it can play an important role in disseminating such information, a not-to-be missed opportunity to help the economy reduce its fuel bill.

Government can also have an important role in building a national consensus about the energy situation facing the U.S., where increased efficiency is an important aspect of adaptation to increased energy prices. Such a consensus would help making conservation the "accepted current wisdom", thereby giving conservation more chances of a wider adoption.

In order to counter the lack of information in energy conservation, government programs with the following major elements are recommended:

1. Set up services that can provide the residential sector with information on energy conservation measures in homes, offer home energy audits and recommendations for retrofits, and assist in securing financing and installation of retrofits. Some inspection service of retrofits may also be helpful to insure retrofits quality and maintaining customers confidence in the service. The Residential Conservation Service (RCS) was a cooperative program between DOE and utilities that offered similar services to the ones described above, until it was terminated in FY82. Some utilities continue to offer such services to their customers, for example in Massachusetts, Oregon, and California, but reinstating the RCS program can greatly help in spreading these services to all the U.S.
2. Offer similar services of advice on how to save energy, to small businesses which are less likely than larger ones to be well informed on such matters. The Canadian federal Office of Energy Conservation has operated for over 5 years now such a successful service that has helped small and medium size business reduce their energy costs, by offering a free consulting service on how to save energy and money in space heating and ventilation, lighting, electric load scheduling and power factor reduction in order to reduce peak demand and utility charges, recuperation of waste heat, insulation and covering of hot wash tanks, etc. Offering a similar advisory service to small American businesses can improve their know-how of energy savings and therefore help them in reducing their energy costs.
3. Revive the Energy Extension Service (EES) with the cooperation of the states to provide educational programs and demonstration projects (the EES was terminated in FY82). The EES offers a good opportunity to provide, with a responsiveness to special regional needs, energy-saving education not only for the home owners and businesses, but also for the training of home and small business energy auditors necessary for the two recommendations discussed above. The EES would also evaluate for local conditions conservation measures, and set up local demonstration projects

to accelerate their acceptance. Such an approach of local technical education and demonstration projects was used successfully in modernizing the American agriculture, and could also help in increasing American energy efficiency.

4.4.2. Access to Capital

Capital is a scarce resource that society has to allocate among competing needs. As was shown in Section 3, it is a better use of capital to invest in fuel savings rather than in new fuel supplies development. But the energy producing sector of the economy seems to enjoy a better access to capital than the energy consuming sectors, and therefore some government intervention is desirable to channel some capital to the energy consuming sectors, so that a more optimal use is made of society's limited capital.

In order to enhance the availability of capital for energy conservation projects, the following government policy initiatives are recommended:

1. Encourage the energy supply sector to invest in "producing" energy by conservation. For example, allow gas and electric utilities to invest and earn a return in energy conservation projects in the residential, commercial and industrial sectors. The success of the Oregon Plan, of electric utility investment in residential energy conservation (see Section 3.9.4) indicates that such investment schemes by traditional energy suppliers can indeed be carried successfully. Oil and gas companies should also be encouraged to invest in improving the energy efficiency of the economy, possibly by giving them, some of the same tax incentives they receive for exploration and development, for producing oil and gas in homes and factories. The benefits of having energy producers invest in energy conservation are manifold:

   i) The energy producers can earn a return (often less risky) on their money;

   ii) The energy consumer with the conservation measure benefits from a reduced energy bill;

   iii) Other energy consumers benefit from a slower increase in energy prices, because the energy saved by conservation is cheaper than the next source of energy supply; and

   iv) The economy benefits from a reduced demand for capital, since the energy produced by conservation requires less initial capital than new energy supplies, therefore freeing some capital for use for other desired projects.

2. Use a windfall-profits tax to provide additional funds for conservation investments, especially for the needy. Removing price controls is necessary to provide the proper incentives for conservation and for development of new more expensive supplies of energy. Price controls on oil have been removed, and it is recommended that gas prices be decontroled too. Such a decontrol however stirs the social debate about whether the owners of old (and cheap) energy supplies deserve all the increase in income that they receive because of this decontrol, and whether it is fair to impose the hardships of increased energy prices on the rest of society, especially on the less fortunate members of that society. Such equity concerns are of course not new, progressive income taxes and transfer payments having been enacted time ago to provide a more level distribution of income. A similar redistribution of income is proposed here for energy, by taxing some of the windfall profits of energy producers, to provide conservation funds to energy consumers, in order to lessen the impact of increased energy prices.

3. Abolish Government subsidies and supports for the synthetic fuels program, and re-channel some of the money to energy conservation. For the same amount of money, more fuel would be produced by conservation than by synthetics production. The energy production sector is well organized and financed to undertake synthetics development on its own, if such developments is warranted, a point echoed by many corporations involved in such development.

4.4.3. Incentives Feedback

In areas where the incentives for conservation are lacking or are too small or too new and unfamiliar for energy consumers to act upon, government policy initiatives can replace or reinforce those incentives. Four such areas that can benefit from government intervention are:

1. Mandate energy efficient building code standards, and retrofit efficiency standards. This would strengthen the presently too-weak incentives for new building developers and landlords to provide energy efficient buildings, since they don't pay for fuel costs. The buildings energy efficiency programs should be well coordinated with the educational and financial assistance programs proposed before. For example, the Energy Extension Service can provide training for the construction trades, on how to achieve the new energy standards in old and new buildings, and utilities could provide some of the retrofit financing. A well informed developer or landlord, receiving technical and financial assistance, would accept more easily new efficiency standards.
2. Mandate energy efficiency standards for appliances (the Appliances Standards program of DOE was terminated in FY82). Life-cycle costing is new to most consumers, and many would still be heavily influenced by first cost considerations in choosing an appliance. Energy costs may also be too small for one individual consumer to care about, but since there is a large number of consumers, the influence of appliances energy use on the national level may be considerable. The setting of appliances standards should be well coordinated with the information dissemination and education programs, where for example the merits of life-cycle costing methods are emphasized and the new achievable energy efficiencies are publicized. If the information program is successful, consumers will demand better energy performance of appliances, and the efficiency standards regulations may never need enforcement (for example, the automobile efficiency standards for 1985 will probably be met before that date because of consumer demand, a demand that was undoubtedly helped by the EPA reporting of mileage figures). The setting of efficiency standards would also help in heightening the public awareness about the importance of and the national commitment to increased energy efficiency.
3. Marginal pricing is necessary in order to reflect to energy users the true national cost of new energy supplies. The equity problems of income redistribution, raised by marginal pricing, can be resolved with a taxation policy, that taxes excess profits and provides funds for conservation in order to ease the impact of increased energy prices, as explained previously. Keeping energy prices low by regulations does not provide the proper, nationally beneficial, incentives for energy conservation. Two good steps already undertaken towards proper price incentives are the decontrol of oil prices, and the PURPA regulation requiring utilities to purchase cogenerated electricity at their marginal production cost. Further needed steps in that direction are the decontrol of gas pricing, in a measured way that would avoid sudden large economic disruptions, and possibly raising the price of electricity above the average "rolled-in" cost, to reflect the rapidly rising cost of new power plants (the excess revenue need not all go to utilities, some can be taxed and redistributed to consumers).
4. To provide incentives for small business to increase their energy efficiency rather than pass their fuel costs unto customers, stimulate competition among them. This competition would follow naturally from a successful program of offering technical and financial help to increase energy efficiency, and to emphasize the competitive advantage of reduced energy costs.

5. Summary and Conclusions

We have analyzed the fuel uses in the U.S. for heating applications, and established a large potential for cost-effective fuel savings in these applications. With presently known technologies and under present economic conditions, about 6.6 Quads of fuel per year out of about 27.6 can be cost-effectively saved in heating applications. The technologies considered were weatherstriping and thermal insulation in the residential sector, and cogeneration in the industrial sector.

The capital cost of these fuel savings is estimated at about $160 billion, which is much less than the $260 billion that would have to be invested in developing equivalent new energy supplies of about 4 million bbl/day oil production capacity plus 17.6 GWe installed electric capacity. The equivalent cost of the energy saved compares favorably with present energy prices, and would undoubtedly fare favorably also when compared to future energy prices from new supplies. Thus the cost of saving energy in homes is equivalent to 3.4 $\$/10^6$ Btu for oil and gas, and 3.6 cents/kWh for electricity, compared to presently paid average prices of $\$5/10^6$ Btu for oil and gas and 5.4 cents/kWh for electricity. The cost of cogenerated electricity is 3 to 4 cents/kWh, whereas the utilities marginal electricity costs are between 5 and 7 cents/kWh. Implementing the fuel savings outlined in Section 3 would save $19 billion per year from the society's bill for energy (net, after paying for the conservation projects). Considering the positive effects on the economy of such annual savings plus the initial capital cost savings, the pursuit of energy conservation should be one of the high priority items of U.S. energy policy.

The initial capital investment required to realize these fuel savings is a large additional demand for capital when compared to the levels of investments normally present in the residential or industrial sectors. However, the energy production sector has in the past handled investments of this magnitude and it is suggested that the energy production sector be allowed and encouraged to invest in fuel-savings opportunities. By channeling some of the capital to which traditional energy producers have access into the energy consuming sectors, many benefits accrue: (1) to energy consumers that have their energy bills reduced; (2) to energy producers that earn returns on their money in what seems *a priori* a less risky venture that new supply developments; and (3) to society that would see a reduced demand for capital for energy production, and a slower increase in future energy prices.

The realities of the market fail to foster investments in energy conservation in the way an ideal market would. The market imperfections identified are the lack of information, limited access to capital, and inadequate incentives feedback. Since it would be economically beneficial to society to undertake energy conservation investments, government interventions are justified to correct for market imperfections by providing information and education programs about increased energy efficiency, promoting some movement of capital from the energy production sector to the energy consuming sectors, and correcting for weak incentives with efficiency standards. Thus the government intervention recommended is not designed to force the market in uneconomical directions, but rather to remove the barriers that prevent real markets from fulfilling the promise of ideal ones, thereby improving the general state of the economy.

6. References

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Use	Electricity Used 10^{12} Btu	Energy Efficiency η (%)	Quality of Required Energy C_2	Effectiveness ϵ (%)	Availability Required 10^{12} Btu	Primary Fuels Used 10^{12} Btu	Effectiveness of Using Primary Fuels (%)
Space Heating	281	100	.09	9	24	876	3
Water Heating	337	85	.07	6	21	1,050	2
Cooking	195	45	.13	6	11	608	2
Clothes Drying	102	50	.11	6	6	318	2
Crop Drying	3	85	.11	10	.3	11	3
Direct Heat 1500°F	36	85	.52	44	16	112	14
Direct Heat 2000°F	11	85	.58	49	6	35	16
Direct Heat 3000°F	58	85	.66	56	32	180	18
All Uses	1,023	78	.15	11	116	3,190	4

Table 1 Effectiveness of electricity use for heating functions in the US for 1974

Use		Fuels Used 10^{12} Btu	Energy Efficiency η (%)	Quality of Required Energy C_2	Effectiveness ε (%)	Availability Required 10^{12} Btu
Space Heating		9,600	80	.15	12	1,156
Water Heating		2,035	80	.07	6	122
Cooking		664	24	.13	3	21
Clothes Drying		67	50	.11	6	4
Crop Drying		119	85	.11	10	12
Process Steam		4,615	85	.30	26	1,190
Direct Heating	600°F	1,145	85	.31	26	302
	1000°F	1,404	70	.42	29	413
	1500°F	1,126	50	.52	26	293
	2000°F	298	50	.58	29	86
	3000°F	1,763	50	.66	33	582
All Uses		22,836	75	.24	18	4,181

Table 2 Effectiveness of fossil fuel use for heating functions in the US for 1974

	Single-Family Houses			Multiple-Family Low-Rise Buildings		
U.S. Census Region	Oil	Gas	Electricity	Oil	Gas	Electricity
Northeast	203	175	66	81	72	24
North Central	221	194	75	95	84	27
South	96	82	36	34	30	12
West	125	108	48	42	37	16

Table 3 Average fuel use for space heating in typical housing units in the four U.S. census regions (10^6 Btu per heating season)

U.S. Census Region	Single-Family Houses: Oil Heating	Single-Family Houses: Gas Heating	Single-Family Houses: Elec. Heating	Multiple-Family Low-Rise Buildings: Oil Heating	Multiple-Family Low-Rise Buildings: Gas Heating	Multiple-Family Low-Rise Buildings: Elec. Heating
Northeast	3500	3140	3500	1400	1340	1400
North Central	3500	3500	3500	1400	1400	1400
South	3020	840	2100	930	300	600
West	3500	1260	3500	1400	400	1040

Table 4 Estimate of cost-effective retrofit investment in residential structures in the four U.S. census regions (1980-$ per housing unit)

	Single Family Houses			Multiple-Family Low-Rise Buildings		
U.S. Census Regions	Oil Savings (%)	Gas Savings (%)	Elec. Savings (%)	Oil Savings (%)	Gas Savings (%)	Elec. Savings (%)
Northeast	58	54	58	58	56	58
North Central	58	58	58	58	58	58
South	53	31	44	46	30	38
West	58	35	58	58	33	49

Table 5 Estimated percentage of fuel savings in residential heating in the four U.S. census regions (savings are expressed as percentage of fuel use before retrofit)

	Single Family Houses			Multiple-Family Low-Rise Buildings		
U.S. Census Regions	Oil Heating	Gas Heating	Elec. Heating	Oil Heating	Gas Heating	Elec. Heating
Northeast	4610	3700	450	1720	1480	130
North Central	2030	10280	940	220	2060	170
South	2160	9810	3660	180	950	430
West	520	6300	1380	40	990	290

Table 6 Estimate of number of housing units by type of space-heating fuel used, in the four U.S. census regions, for 1974 (in 1,000 units)

	Oil Savings		Gas Savings		Electricity Savings	
	Oil Saved 10^{12} Btu/yr	First-cost Investment 10^9 \$	Gas Saved 10^{12} Btu/yr	First-cost Investment 10^9 \$	Electricity Saved 10^{12} Btu/yr	First-cost Investment 10^9 \$
Northeast	618	18.6	409	13.6	19	1.8
North Central	270	7.4	1246	38.9	43	3.5
South	112	6.7	257	8.5	59	7.9
West	38	1.9	251	8.3	40	5.1
All U.S.	1038	34.6	2163	69.3	161	18.3

Table 7 Retrofit investment and fuel savings potential in residential heating in the U.S.

	1974 Fuel Use For Heating Applications 10^{12} Btu (10^{9} kwh)	Cost-Effective Fuel Savings 10^{12} Btu/yr	Electricity Saved or Cogenerated 10^{9} kwh/yr	Initial Capital Cost of Fuel-Saving Measures 10^{9} \$	Price of Energy Supply \$/10^{6} Btu (¢/kwh)	Cost of Conservation-Produced Energy \$/10^{6} Btu (¢/kwh)
Space Heating						
- Electric	256[a] (82)	147[a]	47	18.3	(5.4)	(4.5)
- Oil & Gas	9,600	3,201		103.9	4.9	3.8
Water Heating						
- Electric	309[a] (99)	44[a]	14	0.9	(5.4)	(0.7)
- Oil & Gas	2,035	492		3.3	4.6	0.8
Total Residential	12,200	3,884	61	126.4	4.9 (5.4)	3.4 (3.6)
Process Steam	4,615	1,340	242	16.0	(5.1-7.4)	c (3.0-4.1)
Heating T < 1000°F	2,549	1,020	196	8.1	(5.1-7.4)	c (2.6-3.4)
Heating T > 1000°F	3,187	396	37	8.1	(5.1-7.4)	c (3.6-5.1)
Total Industrial	10,351	2,756	475	32.2	(5.1-7.4)	c (2.9-3.9)
Total Residential and Industrial	22,550[b]	6,640	536	158.6	4.9 (5.1-7.4)	3.4 (3.0-3.9)

[a] Primary fuels used in electricity production

[b] If we include fuels used by utilities for electricity that is later displaced by cogeneration, the total fuel use becomes 27,630 x 10^{12} Btu--see text.

[c] Cogeneration-produced electricity is cheaper than utility-produced electricity. Hence there is a profit rather than a cost associated with oil and gas savings by cogeneration.

Table 8 Cost-Effective Fuel Savings in Heating Appliances and Their Capital Requirements

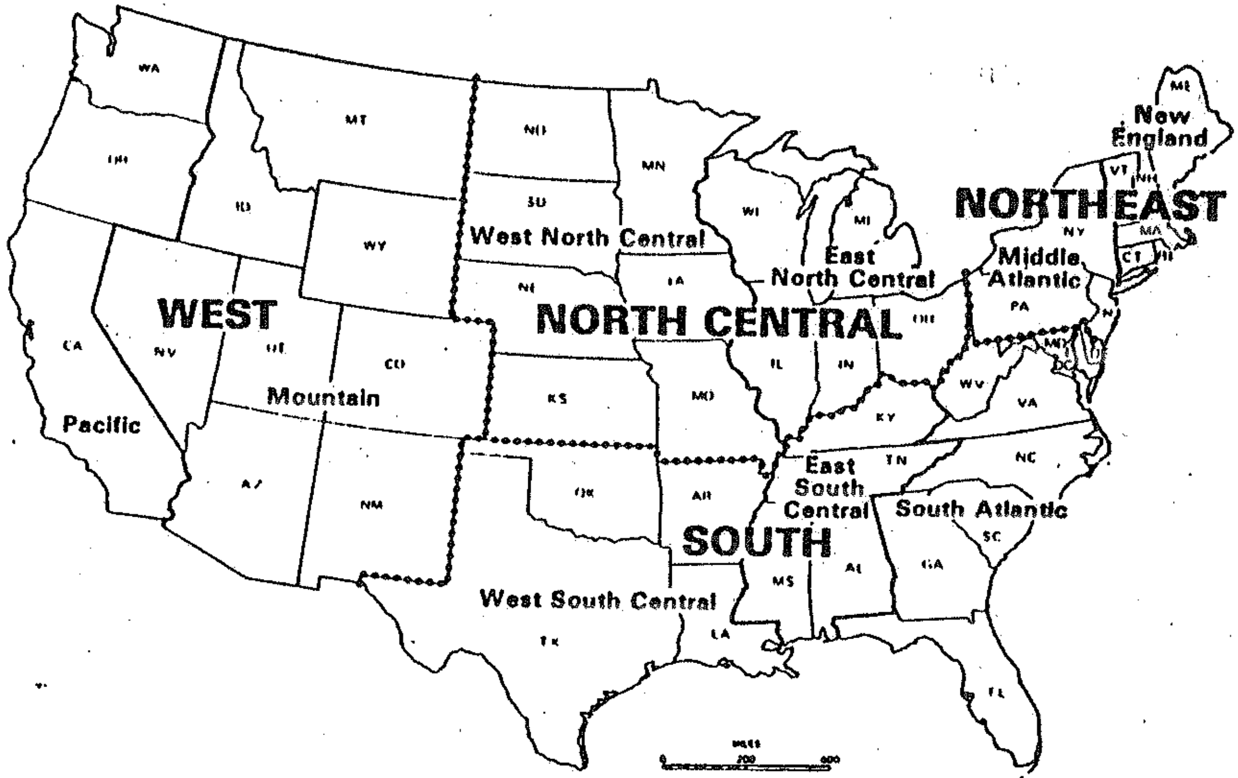

Figure 1 The Four Regions of the US Bureau of the Census

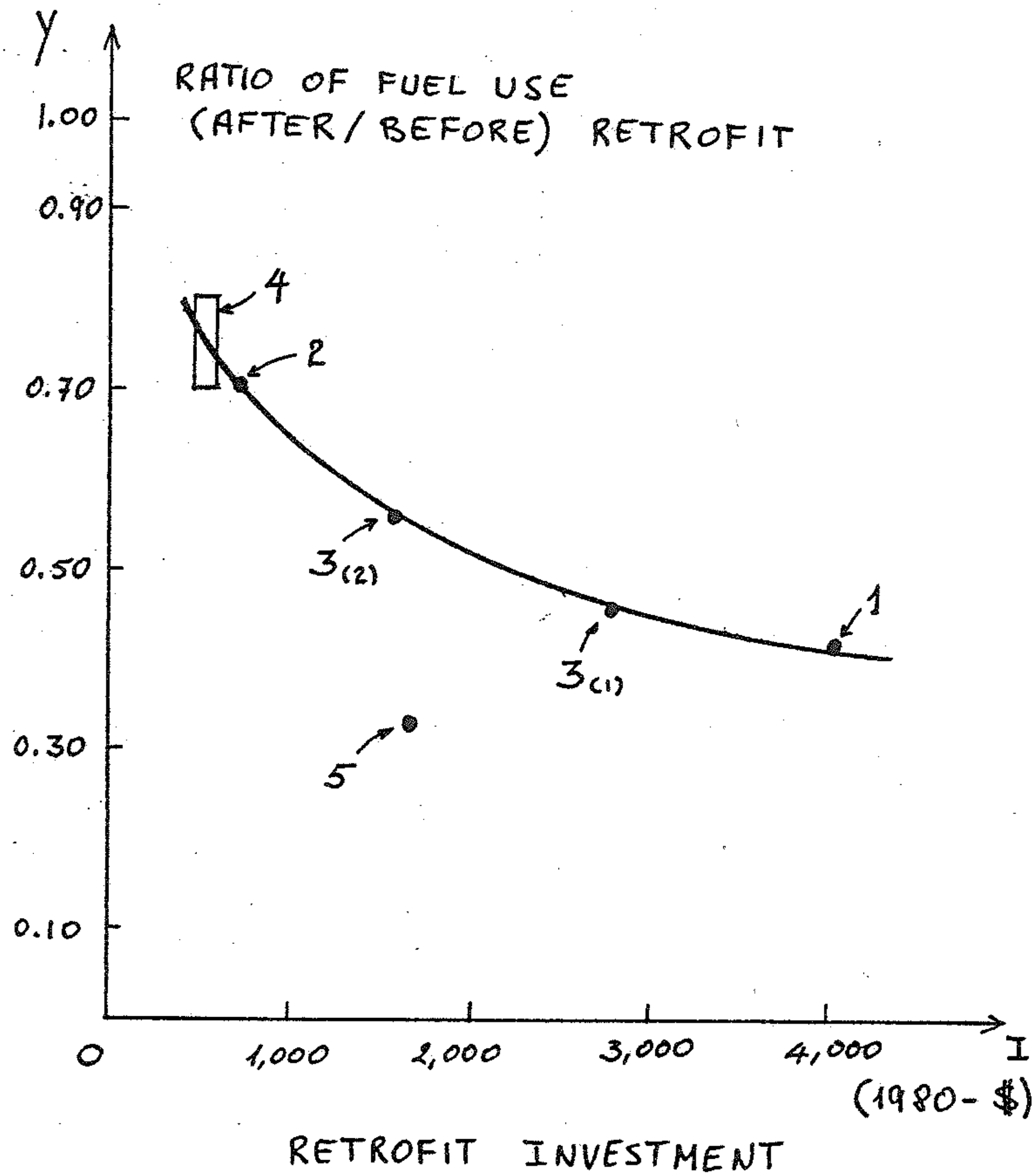

Figure 2 Ratio of Fuel Use -- After/Before -- Retrofit versus Retrofit Investment