Disclosure of Hidden Energy Demands: A New Challenge for NEPA

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DISCLOSURE OF HIDDEN ENERGY DEMANDS: A NEW CHALLENGE FOR NEPA

By Michael Gerrard*

INTRODUCTION

The specialization of the American economy obscures the identity of the ultimate users of energy, even from themselves. As a result consumers remain ignorant of the amount of energy which they use, and of the efficiency of that usage.¹ Direct personal use of energy in the United States, such as electricity and natural gas for home heating, cooking and lighting, and gasoline for private automobiles, accounts for only about one-third of national energy use.² Usage by industry and government to provide for the intermediate and final goods and services, for which we as individuals ultimately pay through our purchases and taxes, accounts for the remainder. To all but the most sophisticated consumers, this two-thirds portion of our actual energy demand is nearly invisible.

To illustrate the hidden dimension of energy use, take the simple example of this page. It appears to be inert, consuming no energy except for the light required to read the print. But the manufacture of this page involved various energy-consuming steps. First a tree had to be cut down by a mechanical saw, conveyed by land or water to a paper mill, and reduced to pulp by mechanical de-barkers, chippers and cookers. Once chemically or mechanically converted into paper, the sheet may have been transported to another city where ink was applied by an electrically-driven printing press and the pages were bound. The completed journal was then transported to its subscribers. To these energy expenditures must be added a share of the energy consumed in the manufacture of the saws, paper mills and trucks which would not have been built had there not been sufficient demand for reading material, plus a share of the energy required to mine the coal or extract the oil that ran the machines that produced the saws and the other devices, and so on. The com-
pounding of these and other remote effects shows that our seemingly innocent sheet of paper in fact has ultimately consumed an indeterminate but non-trivial amount of energy. Society is suffused with these hidden effects, whose sum has been enough not only to cause economic turmoil (through the unanticipated effects of fuel price hikes), but also to threaten environmental disaster, since roughly 80% of all air pollution, plus lesser amounts of other forms of pollution, is directly attributable to the use of energy by motor vehicles, boilers, furnaces, and electric power plants.

The indirect use of energy largely accounts for one of the most alarming—if least noticed—energy events of the past decade. Since the 1920's, the productivity of energy had been increasing as a result of more efficient technologies and the increasing importance of the low-energy service sector of the economy. In 1966, however, this trend suddenly reversed, and until 1970 energy use became dramatically less efficient. Since 1970, the trend has improved somewhat. The post-1966 reversal is mainly attributable to the use of fuels for non-energy purposes such as raw materials for synthetic products like fertilizer, detergents and plastics, and to the use of less efficient forms of energy, especially electricity. Changes in production and consumption patterns, such as the use of modern energy-consuming luxuries, e.g., air conditioning, and the absence of improvements in power plant efficiency, have exacerbated this effect.

Increased industrial energy consumption since World War II has also been due partly to the substitution of power for labor. In a time of scarce energy and high unemployment, it makes sense to try to reverse this process and partially to de-automate, particularly if energy costs continue to rise faster than labor costs. Should such a reversal take place, craftsmanship and durability might be valued more, and high labor productivity less, especially if declining productivity signifies a shift to a lower-energy economy.

Considerations of indirect energy have unfortunately been bypassed by the mainstream of environmental policy-making. Systematic energy accounting is a pre-requisite to achieving the oft-advocated low-consumption society. New techniques have been devised to calculate the use of indirect energy, but they have not yet found widespread application. Their use could have profound effects on a wide range of industrial and governmental practices. Simple dollar cost accounting does not always reflect differences in the energy cost of comparable products or undertakings. The different prices of different fuels, and of the same fuels in different regions and from different sources; government subsidies and price controls;
and other hidden factors mean, for instance, that two different buildings or building materials with the same selling price may have far different energy impacts in construction and operation. Furthermore, in projects where expense is not normally a major consideration, such as certain medical or national defense items, energy may still be conserved while preserving the goals of the projects.

The impact statement process of the National Environmental Policy Act of 1969 (NEPA), probably the nation's most powerful single tool for environmental protection, is a logical place to institutionalize the use of indirect energy analysis. This article seeks to show why such calculations are important, how they may be performed, what their implications are, and how they may be applied to NEPA. The article will begin with a discussion of the current lack of and need for energy analysis in environmental impact statements. Next is an explanation of new techniques which have been developed to analyze energy impact, followed by a detailed examination of how these techniques were applied to one major construction project (a proposed New York City highway). Finally some implications of such analysis to public policy will be shown.

I. INDIRECT ENERGY AND NEPA

Although an average of 1270 environmental impact statements (EIS's) have been filed annually under NEPA for the past three years, energy has been largely ignored. The Nixon administration considered exempting from NEPA projects which promised to increase energy supply for fear that the impact statement process would cause delays and exacerbate energy shortages, but apparently few realized that NEPA could save energy. Thus the government was left with very little control over the 40% of American energy which is consumed by manufacturing, even though the government itself is a major purchaser of the products of that industrial energy.

This failure occurred in spite of the rather clear statutory language in NEPA that environmental impact statements should describe the impact of the proposed action on "the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and any irreversible and irretreivable commitments of resources which would be involved in the proposed action should it be implemented." The Council on Environmental Quality (CEQ) guidelines for preparation of impact statements are even clearer. They specify that "secondary or indirect, as well as primary or direct, consequences for the
environment should be included in the analysis . . . Such secondary effects . . . may often be even more substantial than the primary effects of the original action itself. The same guidelines also mention "energy and natural resources conservation" as areas of environmental impact.

Furthermore, many NEPA commentators have advocated that close attention be paid to these secondary impacts. The courts have on several occasions ruled impact statements inadequate because of failure to analyze such secondary impacts as energy consumption, stream sedimentation, and irretrievably lost capital resources. But by all accounts these secondary effects, especially those relating to long-term productivity, have been largely ignored in the impact statement process. CEQ found in a poll of all federal agencies in November, 1974, that "in general, the problem [of energy impact] has been recognized but that little has been done to develop good methods or guidelines to assess energy demands." Among the plethora of handbooks which has been released on preparing impact statements, there is only glancing mention of energy impact. Even the Federal Energy Administration (FEA), did not mention indirect energy in its proposed guidelines for impact statements on FEA projects, and the General Services Administration (GSA), which constructs government buildings and hence is responsible for a great deal of energy use, did not even mention direct energy in its proposed EIS guidelines. The Environmental Protection Agency (EPA) has not rejected statements which did not analyze energy impact.

CEQ reports that 21 states have adopted some sort of NEPA-type impact statement requirement, most requiring the same types of impacts to be analyzed as NEPA itself does. As Table 1 shows, eight of the 21 states require in their laws or administrative rules that some aspects of the direct energy requirements of proposed projects be analyzed, but none explicitly calls for analysis of indirect energy impact. A number of the states report that new requirements are being formulated, and so it is possible that some states will soon mandate such indirect energy analysis.

One possible indication that the federal and state governments might be responsive to the need for indirect energy analysis is EPA's willingness (albeit under court pressure) to promulgate indirect source regulations under the Clean Air Act, by which such traffic-generating facilities as shopping centers can be banned because of their likely contribution to automobile pollution. Several of the state "little NEPA's" also require such analysis of the indirect im-
pact of new facilities on community growth.

For indirect energy analysis to be useful in evaluating environmental impact, uniform techniques must be adopted to perform the necessary calculations. Progress is rapidly being made in devising such techniques.

<table>
<thead>
<tr>
<th>State</th>
<th>Authority</th>
<th>Energy Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arizona</td>
<td>Administrative memoranda</td>
<td>None</td>
</tr>
<tr>
<td>California</td>
<td>Cal. Env. Quality Act—Amendément</td>
<td>Asks about measures to reduce wasteful or inefficient energy use</td>
</tr>
<tr>
<td>Connecticut</td>
<td>Conn. Env. Policy Act</td>
<td>None</td>
</tr>
<tr>
<td>Delaware</td>
<td>Coastal Zone Act</td>
<td>Some industrial applicants are asked direct energy requirements and sources</td>
</tr>
<tr>
<td>Georgia</td>
<td>State Tollway Authority Act manual</td>
<td>None</td>
</tr>
<tr>
<td>Hawaii</td>
<td>Hawaii Revised Statutes</td>
<td>None</td>
</tr>
<tr>
<td>Indiana</td>
<td>Env. Management Board draft guidelines</td>
<td></td>
</tr>
<tr>
<td>Maryland</td>
<td>Md. Env. Policy Act—Revised Guidelines</td>
<td></td>
</tr>
<tr>
<td>Massachusetts</td>
<td>Guidelines under Mass. Env. Policy Act</td>
<td></td>
</tr>
<tr>
<td>Michigan</td>
<td>Guidelines under Governor’s Exec. Order</td>
<td></td>
</tr>
<tr>
<td>Minnesota</td>
<td>Regs. under Minn. Env. Policy Act</td>
<td>None</td>
</tr>
<tr>
<td>Montana</td>
<td>Guidelines under Mont. Env. Policy Act</td>
<td></td>
</tr>
<tr>
<td>Nebraska</td>
<td>Dept. of Roads Action Plan</td>
<td>None</td>
</tr>
<tr>
<td>New Jersey</td>
<td>Env. Impact Statement Guidelines</td>
<td>Asks about “energy consumption of the project during both the construction and operational phases”</td>
</tr>
<tr>
<td>Nevada</td>
<td>Laws of 1971</td>
<td>None</td>
</tr>
<tr>
<td>North Carolina</td>
<td>N.C. Env. Policy Act Guidelines</td>
<td>None</td>
</tr>
<tr>
<td>South Dakota</td>
<td>S.D. Env. Policy Act</td>
<td>None</td>
</tr>
<tr>
<td>State</td>
<td>Env. Policy Guidelines</td>
<td>Notes</td>
</tr>
<tr>
<td>-----------</td>
<td>------------------------------------------------------------</td>
<td>--------------------------------------------</td>
</tr>
<tr>
<td>Texas</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Virginia</td>
<td>Guidelines under Va. Env. Policy Act</td>
<td>None</td>
</tr>
<tr>
<td>Washington</td>
<td>Guidelines under Wash. Env. Policy Act</td>
<td>None</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>Guidelines under Wisc. Env. Policy Act</td>
<td>Asks impact on energy resources</td>
</tr>
</tbody>
</table>

**NOTE:** These states are all those listed by the U.S. Council on Environmental Quality as having impact statement requirements as of August 1, 1974. The information in this table is derived from a poll conducted in February, 1975, by the Council on the Environment of New York City. In mid-1975, New York State also adopted an environmental impact bill requiring assessment of "effects of the proposed action on the use and conservation of energy resources."

### II. NEW ANALYSIS TECHNIQUES

The most accurate way to examine the indirect energy requirements of products or projects is systematically to trace all steps leading to the manufacture of each component. To do this one would have to learn, for instance, where a highway contractor purchased his concrete, and then go to the supplier and study his processes and his suppliers, and so on. This enormously expensive and time-consuming task is beyond the means of most public agencies which must prepare impact statements. It is possible to obtain a close approximation of indirect energy demand, however, through a shortcut known as input-output (I/O) analysis.

A technique first developed before World War II by Wassily Leontief for use in economic planning, I/O analysis details the flow of goods and services in the economy. It is based on tables which show the dollar amount of business transacted between different commercial and industrial sectors. Although I/O analysis requires a formidable amount of data collection, once the tables are compiled they can be used for many different purposes, and each user does not have to repeat the compilation. At the Center for Advanced Computation of the University of Illinois at Urbana-Champaign, a team of researchers led by Dr. Bruce Hannon has constructed I/O tables tying energy flows to dollar flows. One result has been a set of coefficients relating the direct and indirect energy input of various goods and services to final dollar demand. This method has shown, for instance, that one dollar's worth of asphalt takes about 456,000 British thermal units of energy to produce, while one dollar's worth of a doctor's or dentist's services averages only about 15,000
Serious problems limit the utility of I/O analysis. The basic data, collected by the Bureau of Economic Analysis of the U.S. Department of Commerce, are so voluminous that they take several years to compile and process. The latest official I/O tables, released in 1974, cover the economy of 1967. The data, much of which comes initially from the U.S. Censuses of Manufacturers, Transportation, Mineral Industries, and Agriculture, sometimes neglect feedstocks or certain purchased fuels, can be incomplete because of restrictions on corporate information, and do not include the energy expended in making the tools used by an industry in that industry’s energy consumption. The overall effect can be an understatement of the energy used by some economic sector. This caution is worth rephrasing: “We are, quite frankly, left with an attitude that any energy analysis must be treated with considerable skepticism and care if it does not have a component of direct contact with individuals involved in the system under analysis.”

The I/O analysis is also incompatible with fluctuating prices, though at least one variant claims to have overcome this problem.

Most importantly, I/O tables are national or regional aggregates, and in fact they were first devised for analysis of national and regional economies. Since no particular project is likely to fit the national average for such projects precisely, errors will always arise as average figures are applied to specific situations. This may not be a great problem when calculating the energy consumption of materials—there are a limited number of ways to make Portland cement (though admittedly the distance the materials must be transported varies widely)—but a comparison of highways in Manhattan with highways in rural Iowa can prove bothersome. Yet rough figures, or at least orders of magnitude, can still be obtained.

Other complications for environmental analysis, with or without I/O techniques, arise because the environmental impact of one B.t.u. is not always the same as that of another. The following criteria are suggested for comparing the impact of different forms of energy:

1) Place utilized. Coal burned in a densely populated city, for instance, does greater damage to health and property than coal burned in a remote region.

2) Control techniques used. Whether an electric power plant has sulfur dioxide scrubbers, for example, helps determine its emissions levels.

3) Method of extraction and transport. Strip-mined coal vs.
deep-mined coal, offshore oil vs. onshore oil, oil moved by ship vs. oil moved by pipeline can all have different environmental impacts.

4) Pollution characteristics of the fuel. Natural gas is by far the cleanest fossil fuel; coal, the dirtiest. Since a much higher portion of the chemical industry’s energy consumption than of the primary metals industry’s is gas (and much of it is used as a raw material rather than burned), a B.t.u. used by the chemical industry has less environmental impact than one used for primary metals. However, this gas would most likely have been used elsewhere had the chemical industry not consumed it; so, when one considers the opportunity cost of the natural gas, one finds that the chemical industry should not receive credit for low pollution because it uses gas. In calculating the environmental impact of future energy demands, one must project the incremental sources of that energy. The Department of the Interior reports that although about 31% of the nation’s energy demands in 1975 are met with natural gas, only about 11% of the increased energy demands between 1975 and 1980 are expected to be. Thus the current pollution profile of an energy demand sector does not necessarily inform us about that sector’s future pollution profile.

5) Recovered vs. extracted resources. Although paper and paperboard manufacture is relatively energy intensive, 38.3% of the required energy is provided by paper waste products, which would probably not be available for other energy uses; thus the resource—though not necessarily the pollution—impact of each B.t.u. is lower than it would be if fossil fuel were used exclusively.

6) The amount of energy required to transform the fuel into a usable form, a factor discussed in Section IV, infra.

Despite its drawbacks, I/O analysis offers many possibilities for filling environmental and energy research needs. Some of the areas of inquiry where I/O and related techniques have recently been employed are as follows:

1) The economic impact of pollution control on the national and regional economies.

2) The employment and manpower impact of alternate uses of the Highway Trust Fund, of various fuel allocation systems, of federal pollution control and abatement expenditures, of future energy projects, and of energy conservation.

3) The management of coastal zone resources.

4) The environmental impact of consumption patterns of different income groups.

5) The flow of water, both directly and embodied in goods, be-
between California and Arizona.\textsuperscript{56}

6) The energy requirements of various services provided by the State of Oregon.\textsuperscript{57}

7) The generation and flow of pollutants and other residuals in the economy.\textsuperscript{58} Related work is underway to assign coefficients to the pollution and solid waste generated by various economic sectors, especially to determine the environmental impact of materials substitutions.\textsuperscript{59}

8) The effect of various taxes on energy consumption.\textsuperscript{60}

9) The economic impact of new energy technologies.\textsuperscript{61}

10) The amount of energy consumed and pollution generated by the manufacture of products traded internationally.\textsuperscript{62}

Energy consumption is still the best single indicator of environmental impact, and saving energy usually reduces pollution.\textsuperscript{63} Further refinements in analytical techniques, however, should be used whenever possible. Several systems approaches to the calculation of environmental impact have been devised. These approaches tend to be more precise than most energy I/O analyses because they rely less on aggregated data. Most, however, are also more cumbersome and expensive.\textsuperscript{64}

The next logical development would be a system that would predict the environmental and energy impact of any economic or technological shift, and quantify externalities to a greater extent than previously possible.\textsuperscript{65} A methodology which accounted for all dollar, energy, resource, and pollutant flows would be the ideal system, but there is little hope that we will see such a model in the next decade. A completely satisfactory model of the nation's economy alone has eluded researchers. Otherwise, the goal of "fine-tuning" the economy could be easily achieved. To expect soon a model which will also trace the flow of energy and materials is hopelessly ambitious. The fragmented techniques which already exist to predict such flows nevertheless offer useful guidance to policy-makers, and are as sufficient as most other methods of environmental impact analysis.

It is not suggested that a detailed energy analysis is a necessary part of every environmental impact statement. Instead, the cost of the project could be multiplied by the energy intensity of the relevant input-output sector; if the product exceeded some predetermined threshold for energy impact—say, 500 billion B.t.u.'s—then a detailed energy analysis would be called for.\textsuperscript{66}
III. Detailed Application: The West Side Highway

To illustrate how indirect energy can be computed using input-output analysis, the example of the West Side Highway (WSH) in Manhattan has been chosen. The Miller Highway to the south and its northern extension, the Henry Hudson Parkway, together known as the WSH, run along the Hudson River from the Battery, at the southern tip of the island, to the George Washington Bridge, some 12 miles to the north, and beyond to link up with the Saw Mill River Parkway. Built in the 1920’s and 1930’s by the now-controversial Robert Moses and less-celebrated city officials, the road, elevated for much of its length, had fallen into such disrepair that on December 5, 1973, a trailer truck plunged through the pavement. The future of the highway had already been under active discussion, and this incident, which led to the closing of large parts of the road and the diversion of traffic to once-quiet residential streets, sparked increased activity. In 1974 a joint city-state planning group called the West Side Highway Project (WSHP) presented five alternatives for the future of the roadway, ranging from simple maintenance and repair at a cost of $86 million to construction of a massive interstate highway through a tunnel in landfill created in the Hudson River, at a cost of $1150 million. The latter alternative, called the “outboard”, with its promise of revitalizing a depressed construction industry, slowing the exodus of employers from Manhattan’s Central Business District, and bringing 90/10 federal Highway Trust Fund matching money into the city, was favored by many economic and political sectors in New York. It was opposed by many leaders in the communities along the route, who feared increased traffic congestion and possible destruction of their cherished Riverside Park, as well as by most environmental groups in New York City, who predicted that a new interstate highway would bring in more cars and hence more air pollution.

WSHP prepared an environmental impact statement for the five alternatives, and late in this process, almost as an afterthought, decided to mention energy impact. The resulting 311-page draft EIS included only two pages on energy. These two pages presented an extremely rough discussion of the energy consumption rates of various travel modes, seriously underestimating the energy advantages of mass transit over automobiles in Manhattan, while ignoring both the indirect energy consumption of the vehicles operated on the highway, and the amount of energy required to build the highway. In preparation for a public hearing of the draft EIS held Sept.
12, 1974, the Council on the Environment of New York City conducted a more detailed energy analysis of the project. A summary of that analysis is presented here.

First, the average cost of building each alternative (minus right-of-way) was multiplied by the I/O coefficient for highway construction, 112,200 B.t.u.'s per dollar. This was adjusted for inflation, and for that portion of the construction expenditures which go to engineering, planning, services, and other "soft" functions not included in the 112,200 coefficient. Different coefficients were then applied for these functions, and for the right-of-way costs, reflecting the lower energy intensity of administration as compared to construction. Adjustments were made for the different rates of inflation for these two different types of activities.

The results of the calculations are compiled in Table 2.

**Table 2**

<table>
<thead>
<tr>
<th>Alternative*</th>
<th>Without Transitway Per Year</th>
<th>With Transitway Per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
<td>2,893</td>
<td>638</td>
</tr>
<tr>
<td>Reconstruction</td>
<td>7,659</td>
<td>20,434**</td>
</tr>
<tr>
<td>Arterial</td>
<td>2,325</td>
<td>387</td>
</tr>
<tr>
<td>Inboard I</td>
<td>47,993</td>
<td>56,376</td>
</tr>
<tr>
<td>Inboard II</td>
<td>49,211</td>
<td>57,693</td>
</tr>
<tr>
<td>Inboard III</td>
<td>48,373</td>
<td>56,906</td>
</tr>
<tr>
<td>Outboard O</td>
<td>61,680</td>
<td>73,194</td>
</tr>
<tr>
<td>Outboard Q</td>
<td>63,585</td>
<td>75,099</td>
</tr>
<tr>
<td>Outboard O</td>
<td>61,562</td>
<td>72,741</td>
</tr>
<tr>
<td>Outboard Q</td>
<td>63,056</td>
<td>74,295</td>
</tr>
</tbody>
</table>

*See note 68, supra, for a description of the alternatives.
**Rail transitway. All others are express busways.

Construction periods ranged from six years for the arterial without transitway to 12 years for reconstruction. The four variations for both the inboard and the outboard plans are due to different interchange alignments and other small variations.

To put these figures in perspective, the 74 trillion B.t.u.'s required for the outboard with transitway roughly equals 13 million barrels of crude oil or 600 million gallons of gasoline; spread over the estimated 10 years the construction would require, it would annually equal half the gasoline directly consumed by all the passenger cars in Manhattan in a year.
A more exact method of computation would take each material component of the highway and multiply it by its own coefficient, and then compute the fuel requirements of the construction equipment at the site. This was not possible here because coefficients were not available for many of the most important construction materials in the highway, such as stone fill, sand drains, and riprap. An exact analysis would also require consideration of energy at every stage during the design process. The engineer planning an excavation, for instance, would calculate the fuel used by the equipment as well as the other factors normally considered. The analytical job becomes difficult and expensive after the design is complete. However, calculations were made for two materials, concrete and steel, for which coefficients were available. The raw materials for the concrete, for instance, must be mined, shipped, crushed, ground, blended, and put through other operations, all of which consume energy. By the time this was done, the millions of tons of concrete alone which would go into the outboard highway had consumed several times the amount of energy consumed by the entire maintenance alternative.

This energy would be consumed in places other than New York. The exporting of energy demands is usually ignored as an impact of new projects. Since indirect energy often exceeds 75% of a construction project’s total energy demands, the actual high-consumption regions of the country are often quite different than appearances would indicate. Not only does the project export energy demands, it also exports a classic good—jobs, and a classic evil—pollution. The steel consumed by the West Side Highway in New York creates jobs, pollution, and energy demands in Pittsburgh. Which city benefits more from this exchange is a question for economists and physicians; whether the government of New York City should (since it probably won’t) consider this imposition on Pittsburgh in its decision-making is a question for political philosophers. But such commerce of dollars and materials is the essence of an advanced economy with specialized division of labor.

In addition to the energy required to build the highway, the indirect energy consumed by the vehicles which travel it (or which travel because of it) is also important. A project consultant performed a computer analysis of projected traffic volume in 1995 for all of Manhattan, broken down between automobiles and trucks, and adjusted for the different speeds experienced by different kinds of vehicles on various types of roadways and at different times of the day. The result was the projected 1995 direct energy consumption
of all motor vehicles in Manhattan (except buses, for which no figures were available) based on the consultant's projections. (It did not reflect the additional energy consumed in earlier years by vehicles forced to drive at slower speeds around construction sites.) To calculate the indirect energy consumption of the vehicles on the highway, the number of gallons of gasoline for autos for each alternative was converted into B.t.u.'s. Based on work by Eric Hirst of Oak Ridge National Laboratory, this figure was then multiplied by 1.2626 to account for the added energy consumption in refining, transporting, and selling gasoline and motor oil. Hirst also calculated that an additional 3400 B.t.u.'s are consumed per vehicle mile travelled for other indirect energy demands of urban vehicles—manufacture, transport and sale of the autos, repairs, maintenance, parts, insurance, parking, garaging, and tolls.

A number of critics have questioned the validity of allocating these additional non-gasoline-related energy costs of cars to the roads the vehicles will travel. These are the components of this 3400 B.t.u. figure:

700 is for repairs, maintenance, parts, and parking. This allocation is relatively straightforward, since the amount of such services a car requires is closely related to its mileage; if the differences between one WSH alternative and another are such that one will induce much more traffic than the other, then the additional maintenance, etc. caused by that traffic should be attributed to the WSH.

1600 is for the manufacture, transport and sale of the cars. The relationship between the demand for cars and the availability of highways is very difficult to assess. Some families will own cars no matter what, so long as some roadways are available; so perhaps the portion of the vehicle miles traveled (VMT) by people whose car ownership is not affected by the WSH should not be attributed to the WSH. On the other hand, the size of many government and commercial vehicle fleets may well be affected by the WSH, because it could alter their freight movement patterns.

600 is for insurance. Insurance rates (which are related to the administrative costs, and therefore the energy consumption, of the insurance companies and their investments) are not very closely related to the marginal VMT; they are related to the safety of the roadways. So if an interstate highway is indeed safer, then that might mean somewhat lower insurance rates. This would be a minor energy conservation factor which would slightly diminish the energy disadvantages of a large highway (as would the fact that a few new cars would not have to be manufactured, because a few old ones might not crash).

500 is for parking, tolls, and garaging. These are most closely related to
the number of trips made. This analysis has concerned itself with VMT, and not the number of trips; some trips would likely be generated by an interstate WSH but the exact number cannot be determined.

If we use a smaller coefficient of 1700 rather than 3400 to account for these questions of attribution, then the final calculations for total direct and energy consumption differences for operation among the alternatives come to about 8% less than those derived from the 3400 coefficient, well within the margin of error of these calculations.

A similar procedure was followed to calculate the indirect energy consumption of trucks on the highway.8

When all the figures were added up, this table was prepared, giving the total direct and indirect energy costs attributable to operation (as opposed to construction) of the highway.

**Table 3**

**TOTAL MANHATTAN DIRECT AND INDIRECT VEHICLE CONSUMPTION (MILLION B.T.U.'S)**

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Consumption</th>
<th>Differences Among Alternatives (Null Plan = 0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Null Plan (No Action)</td>
<td>126,700</td>
<td>0</td>
</tr>
<tr>
<td>Maintenance</td>
<td>134,800</td>
<td>8,100</td>
</tr>
<tr>
<td>Reconstruction</td>
<td>133,700</td>
<td>7,000</td>
</tr>
<tr>
<td>Arterial</td>
<td>160,700</td>
<td>24,000</td>
</tr>
<tr>
<td>Inboard</td>
<td>137,000</td>
<td>10,300</td>
</tr>
<tr>
<td>Outboard</td>
<td>133,800</td>
<td>7,100</td>
</tr>
</tbody>
</table>

These results were quite surprising. The figures revealed that vehicles would consume *twice* the energy that the impact statement said they would. They showed that one of the least energy-consuming alternatives was the grandest—the outboard—while the alternative with the greatest operating energy consumption was the modest “arterial” plan, which would involve demolishing the present elevated structure and replacing it merely with an at-grade road.

There are two major complications with these findings:

1) No one knows what sort of engine will be predominant in urban automobile design (or if indeed there will be such a thing as an urban automobile) in 1995, so it is impossible to predict the fuel economy of these future vehicles. Thus current fuel economy was calculated, with adjustments for vehicle weight and emission control devices.
2) Traffic forecasting, though rapidly improving, is still a primitive art. One of the recurring debates among highway engineers in the controversy over the WSH was whether the presence of the interstate road would induce new traffic. EPA and the highway opponents thought it would, citing the experience that for decades virtually every new highway in New York City became congested with new traffic within a few months of its opening. The WSH consultants and the interstate supporters asserted the highway would not induce new traffic, largely because they claimed traffic to be more a function of economic activity than of highways, and because they felt that new parking restrictions would curtail auto use and that no new traffic could enter Manhattan anyway because the bridges and tunnels into the island are already used to capacity.

The findings are primarily a function of the WSH consultants’ assumption—whether or not that is tenable—that the WSH would not induce new traffic, and therefore would not become congested. Since a car travelling at 10 m.p.h. consumes far more fuel per mile than one going at 40 m.p.h., if the interstate does indeed allow higher speeds, energy will be saved. This illustrates the vulnerability of energy analysis of transporation systems to the often tenuous assumptions of highway planners.

If the planners' assumptions are correct, then these findings present a policy quandary, since the roadway which consumed the most energy in construction consumed close to the least for operation, and vice versa. A vital question then becomes whether fuel shortages will be short-term or long-term. If only short-term shortages are foreseen, then one might opt for the design with the lowest construction energy use but higher operation energy use. If the shortages are thought to be chronic, then the alternative with the lowest total energy cost over its entire useful life should be chosen. (This is a problem similar to that faced by financial planners who must predict future interest rates to make investment decisions.)

A complete policy analysis, of course, must also calculate the energy impact of mass transit alternatives to the interstate highway. New York City was not faced with a choice between building a highway or building a mass transit system; the city already has an extensive subway and bus system, so funds for transit along the West Side would probably have gone largely into station and train upgrading and maintenance, with perhaps some money spent on improving the regional rail freight network. Since no official array of transit alternatives had been released, no energy calculations were performed.
However, a number of useful studies demonstrate the energy impact of mass transit projects. An examination of the energy impact of the new BART system in San Francisco found that BART is more energy efficient per passenger mile than automobiles, but not necessarily than buses, when the energy to build and operate all the relevant vehicles, roads, and tracks is considered. The construction energy for BART was a significantly greater portion of the system's total energy costs than is the construction energy for autos and highways. For all modes, the average vehicle occupancy was a key determinant of energy efficiency per passenger mile. A similar study, nationally aggregated, produced these results for the amount of energy consumed per passenger mile, measured in kilowatt-hours, (kWh) including all construction (averaged over the life expectancy of the facility) and operation energy:

<table>
<thead>
<tr>
<th>Mode</th>
<th>Energy (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Automobile</strong></td>
<td></td>
</tr>
<tr>
<td>3600 pound</td>
<td>1.90</td>
</tr>
<tr>
<td>2000 pound</td>
<td>0.98</td>
</tr>
<tr>
<td><strong>City Bus</strong></td>
<td>0.66</td>
</tr>
<tr>
<td><strong>Rapid Rail</strong></td>
<td>0.71</td>
</tr>
<tr>
<td><strong>Personal Rapid Transit</strong></td>
<td></td>
</tr>
<tr>
<td>Small car</td>
<td>2.34</td>
</tr>
<tr>
<td>Large car</td>
<td>2.88</td>
</tr>
<tr>
<td><strong>Dial-a-Ride</strong></td>
<td></td>
</tr>
<tr>
<td>Gasoline</td>
<td>2.91</td>
</tr>
<tr>
<td>Diesel</td>
<td>1.79</td>
</tr>
<tr>
<td><strong>Motorcycle</strong></td>
<td>0.62</td>
</tr>
</tbody>
</table>

This table indicates the enormous energy advantages of buses and rapid rail over automobiles. The data also suggest that such oft-heralded new technologies as Personal Rapid Transit may not be as idyllic as often supposed. The same applies for hydrofoils and short take-off and landing aircraft. Making autos smaller and more efficient, and diverting as much auto traffic as possible to buses and subways, hold greater potentials for energy savings.

Energy would also be saved by prolonging the lifespan of individual cars, given the large energy cost of building them; in fact a reduction in obsolescence makes energy sense for almost all prod-
ucts. Perhaps in addition to the fuel consumption stickers on new cars and the energy efficiency labels on new appliances, the total manufacturing energy consumption of the product divided by the number of years of its life expectancy should be shown, to give consumers a better idea of the impact of their purchases.

The energy advantages of mass transit over automobiles also indicate that if electric rates are allowed to rise to discourage demand, special arrangements might have to be made for transit systems so that the increased financial pressures do not force curtailed service or higher fares, counterproductively forcing people back to the auto.

Mass transit is so energy efficient that large cities may consume less energy per inhabitant than small ones. In fact, New York City energy consumption per dollar of money income is 54% below the national average. Although much of this difference results from a lack of heavy industry within the city borders, another major factor is the large portion of the population that rides subways and buses. It may well be that dense housing developments save energy in various ways—they encourage mass transit use; a smaller portion of their walls face outside, so they lose less heat; and they permit total energy systems with heat recovery, solid waste use, and minimum transmission losses.

Another intriguing issue is the influence of highway safety on energy consumption. Roughly one-fifth of the total production of the automobile industry is required to replace or repair damaged vehicles, consuming an enormous amount of energy. Thus safety programs, besides their other obvious benefits, may be viewed as an energy conservation measure.

Finally, the less energy-intensive modes of travel such as mass transit and bicycles, tend to cost the traveller less than do more energy-intensive modes, such as automobiles and airplanes. Unless a massive modal shift saves enough money for wage rates to be reduced, travellers will have more disposable income; but more energy, rather than less, could ultimately be consumed if they spend this money on items such as housing, which require more energy than was saved by their modal shift. The same result occurs if the individuals invest their money with financial institutions or corporations that then use it in energy-intensive ways. An activity that consumes a large amount of energy per dollar also usually creates few jobs per dollar, because it is capital—rather than labor—intensive, so energy conservation tends to spur employment.

Despite all the uncertainties involved, indirect energy analysis
has major policy implications which are not foreseen in any other way.

IV. OTHER IMPLICATIONS OF ENERGY ANALYSIS

Although scattered, enough indirect energy analysis has been performed to date to have important implications for a variety of public policies in addition to transportation.101

1. Agriculture

An act such as eating meat or fruit seems innocent from an energy perspective, but it is not. Increasing amounts of energy are used on American farms, not only to power tractors and other equipment, but also to serve as the raw material for fertilizer, and to process, transport and store food. An indirect energy analysis reveals that the foods which consume the most energy per calorie and protein yield are meat and poultry, fruit, and processed vegetables; the least energy consuming are fresh vegetables, flour, and cereals.102 When all of the energy used in growing, processing, transporting and otherwise preparing the food is considered, one glass of milk requires the energy equivalent of one-half glass of diesel fuel; one pound of hamburger demands about three pounds of coal.103 Hence, food is grown as much from fossil fuels as from live plants.104 According to one estimate, the labor-intensive wet-rice agriculture of China produces 250 times as much food energy for each unit of fossil energy expended as does American agriculture105—though of course it produces far less food per man-hour.

Meat is particularly energy consuming. Livestock are an intermediate processing step, which return only about one-fifth of the food value of what they eat. Thus the energy required to produce five tons of corn will only produce about one ton of beef.106 To compound matters, cattle increasingly are being herded into enormous feedlots, where instead of grass, they are fed grain which people might otherwise eat. If strip mining in the West reduces available grazing land and forces still more cattle into feedlots, the effect will be exacerbated.107

An energy analysis of an agricultural project was conducted for the Environmental Impact Assessment Project in Washington, D.C. In analyzing the EIS for a major irrigation project in North Dakota, the researchers independently devised and used almost exactly the same methodology as was used in studying the West Side Highway.108 They discovered that the Bureau of Reclamation, which pre-
pared the EIS, failed to account for the energy consumption of the materials (sprinklers, pipes, etc.) that would go into the project, and for the construction energy. Though the EIS had mentioned the power which would be lost because water now serving a hydroelectric generating plant would be diverted to irrigation, it did not mention that the hydroelectric generators might have to be replaced by fossil fuel stations at only one-third the efficiency. These indirect effects, when distributed over the 25-year construction period, are far greater than the direct energy cost of operating the irrigation project acknowledged by the impact statement. The conclusion was reached that the net food yield would be much larger if the energy that would be consumed by this project were used to manufacture fertilizer which was then shipped to an underdeveloped country like India, where great incremental increases in farm productivity would result from additional fertilizer applications.

2. Architecture

Considerable discussion of late has centered around the energy costs of operating buildings, and the need for windows that open, efficient heating and cooling systems, better insulation, and the like. The government is finally accepting the idea that the cost of a building must be calculated, over its entire life, to include fuel and power. Less discussion has centered on saving energy during construction itself. However, many authorities now agree that some building standards are too rigid and allow unnecessarily high safety margins, resulting in far greater amounts of energy-consuming materials than are necessary for structural integrity. Greater attention to detail in design could save large amounts of building material and therefore energy—possibly as much as half.

One relevant factor is the choice of material. Since the energy requirements to process different substances vary widely, from 21 kWh per ton for sand and gravel to 207,000 kWh per ton for certain kinds of titanium, substitution has great promise. The one measure with the greatest potential seems to be replacing aluminum with steel, because the electrolytic process by which aluminum is extracted from bauxite consumes great quantities of power. It has been estimated that if the four million pounds of aluminum used for exterior covering in the new Sears Tower in Chicago had been replaced by 5.75 million pounds of weathering steel like Cor-Ten, with the same structural characteristics, the energy cost would have been cut by two-thirds and 1.3 million kWh would have been saved. There are other areas as well where steel or other materials
can replace aluminum, just as there are places where cotton, wool, or wood could substitute for plastics and synthetics. Some decorative building materials, like white cement, consume excessive amounts of energy in comparison with their substitutes. Still more energy can be saved, particularly in small buildings, by using handmade materials. A conventional brick, for instance, takes about four times as much energy to manufacture as a soil cement brick, which possesses even greater strength and is produced by hand with a block-making ram.

Another energy consideration in materials is whether they have been or can be recycled. The energy required to produce raw steel from scrap is about 25% of the energy required to make steel from virgin ores. For aluminum, the figure is less than 5%; for paper, 60-70%. Not all materials can be recycled, however. About 75% of the copper produced is recyclable, but less than 10% of the titanium, because it is usually dissipated in use.

There are two final points regarding indirect energy and construction. First, a seldom-mentioned indirect energy cost of space cooling is the heat which air conditioners generate outdoors. The average temperature in cities is at least one degree above that of the countryside, and the difference is partly due to heat from these and other machines. Second, though home fireplaces are frequently suggested as a way to save fuel, most of the heat from the fire and some of the air warmed by the heating system can be lost up the chimney, so it is doubtful there is a net gain from fireplaces.

3. Alternate Energy Sources

Just as it takes energy to produce aluminum, it takes energy to produce energy. Ten million tons of coal may be buried in a seam, but if it takes three tons worth of energy to extract the ten tons, the seam contains only seven tons of effective energy. The usable resource is the net energy, “what is left after the processing, concentrating and transporting of energy to consumers is subtracted from the gross energy of the resources in the ground.” A vast array of rigging, piping, heating, shipping, and other equipment is required for most energy production. Since the most easily accessible domestic reserves of coal, oil and gas have already been depleted, more and more energy is needed to extract fuel and the net gain is less. Domestic natural gas is still the most efficient energy delivery system, but it, too, is getting more difficult to produce. At least one researcher, perhaps only slightly overstating the matter, has called
the diminishing return on energy investment "the principal force driving world inflation."\textsuperscript{125}

Indirect energy analysis has already cast doubts on two new energy sources—oil shale and the fission nuclear reactor. It has been calculated—and disputed—that it actually takes more energy to mine oil shale, extract the oil from it, and convert it into electricity, than is derived from the shale; so every kilowatt of electricity from shale actually \textit{loses} energy.\textsuperscript{126} There may be an energy profit in non-electric uses of shale oil, however. And even if shale oil turns out to have no net energy gain, it might be used to convert the coal used in its production into more versatile oil—so shale could then be viewed as an energy storage and conversion technique, not as a new energy source.\textsuperscript{127}

With nuclear power, more energy is required to process—"enrich"—uranium to be used as a reactor fuel, than it takes to process any of the three major fossil fuels.\textsuperscript{128} In fact, uranium enrichment is one of the nation’s major consumers of energy. There is considerable disagreement over just how much, if any, net energy is gained by nuclear power. Some commentators have written that the energy invested in enriching uranium is very quickly paid back once the nuclear power plant begins operation; others have calculated that this energy investment is not repaid for many years, conceivably not until all economically recoverable uranium reserves are exhausted.\textsuperscript{129}

The role of electricity itself is another point of controversy. Electric power plants are at best 40\% efficient and usually closer to 30\%.\textsuperscript{130} As mentioned earlier, the increased use of electricity has led to lowered overall energy efficiencies in the United States. Three factors tend to encourage increased electrification: electricity’s great convenience, its cleanliness at the point of use (though not at the power plant),\textsuperscript{131} and the possibility that one day nuclear and other new power sources will provide electricity without further depleting fossil fuel reserves. In one application of these factors, the planners of a new housing project in New York City decided to use electric rather than oil heat. Though this method would consume 23\% more fuel, they found it would become more efficient if and when Consolidated Edison’s long-delayed nuclear power plants reached full capacity.\textsuperscript{132} Another factor was that much electric heating is required during the hours of the day when overall electricity demand is low. During the peak hours, Con Edison must employ relatively inefficient gas turbine generators to meet its load; but during the off hours the company can get by on its large baseload
plants, which are more efficient. Finally, the developers used a Con Edison air pollution diffusion model to determine the impact of electric heating vs. oil heating on ground level pollution levels, and they computed that the electric heat would be better because the power plants would release their emissions from tall stacks higher in the atmosphere. The New York City Dep't of Air Resources disputes the Con Edison air quality models, claiming that Con Edison power plants have a far greater impact on pollution levels than the utility admits.

Indirect energy analysis has implications for solar energy as well. Though sunlight is an inexhaustible resource, it is so diffuse that a great deal of fossil fuel energy is required to build and operate the equipment used to capture it and will continue to do so until solar plants have largely displaced fossil fuel plants. Until that time, solar power will pollute, via the fossil fuels needed to capture it—though much less than if fossil fuels were used directly. The estimated upper limits of the net efficiency of various schemes for using solar power range from 3% for energy plantations, in which crops would be grown, dried, and burned for power, and 6% for a large satellite with photovoltaic cells beaming energy to earth, to 55% for a large thermal plant which generates electricity from the heat. Solar energy, however, has the advantage of adding no additional heat load to the atmosphere (an advantage not realized with the satellite system). Furthermore, the manufacture of silicon solar cells is much more labor-intensive than refining petroleum.

A final point regarding energy sources is that some of the energy inputs can be used again, while others are lost forever. Energy cannot be destroyed, merely converted, but some means of conversion—such as simple burning—turn it into a form which we can never recapture. In energy production, the steel casings in oil drilling, the roof bolts in coal mining, and the oil left in some pumped-out wells, not to mention the fuel burned in producing the fuel, will probably never be usable again. But the steel in an oil refinery, and “the vast materials demands of solar energy collectors are ‘deposits in a materials bank’ that could possibly be withdrawn later for reuse.” Energy systems should be designed so that a maximum portion of the energy invested in them can be recovered.

4. Pollution Control

Critics of the environmental movement frequently claim that ecologists drive up energy demands by their insistence on new
HIDDEN ENERGY DEMANDS

pollution-control equipment.\textsuperscript{133} This argument neglects the finding that the energy costs of such pollution control devices as power plant scrubbers, automobile catalytic converters, and wastewater treatment plants are almost equalled by the energy \textit{savings} from such environmental measures as greater use of mass transit, redesign of automobiles, incineration of solid wastes to generate electricity, and more recycling.\textsuperscript{140} One favorite claim is that a ban on the gasoline additive tetraethyl lead (which has severe adverse health effects) consumes extra gasoline and should be opposed. One petrochemist, however, has calculated that the energy consumed by manufacturing the additive exceeds the energy that is saved by using it.\textsuperscript{141}

Some pollution control measures may still be counter-productive. Consider, for example, particulate control from coal-burning boilers. Such control is conventionally achieved by electrostatic precipitators, large energy-consuming devices which usually achieve 85-95\% abatement. If one wants to achieve continuous 99\% abatement, however, two precipitators may be needed, and to achieve 99.9\% abatement, three may be required.\textsuperscript{142} That last precipitator may cause more pollution than it removes, because of the pollution from the power plant which runs the precipitator. Reaching the last percentage point required to achieve near-zero emissions may therefore be shortsighted, not only economically but also in terms of energy and pollution. For economic reasons, 99.9\% abatement has rarely been required.

One pollution control measure which could save energy is the removal of poisonous sulfur from smokestack emissions. The sulfur thus removed could then be used as a substitute for a portion of the petroleum-based asphalt used in road building and repair. The Federal Highway Administration estimates that such substitution could save up to 26 million barrels of petroleum a year.\textsuperscript{143}

Most current air pollution regulations merely prescribe that a stationary source of pollution must reduce its emissions by a certain date, but do not specify how this reduction is to be achieved. Installing a control device that removes 25\% of the pollutants from a power plant has the same impact on the plant’s emissions as not installing a control device but instead increasing the conversion efficiency of the plant from 30\% to 40\%.\textsuperscript{144} The former course is likely to be chosen because it is easier and cheaper. However, the latter course is far superior environmentally because it will save a great deal of fuel, which thus will not have to be extracted, transported, and processed—all operations that consume energy and generate pollu-
tion. A more systematic national strategy of air pollution control might ultimately achieve greater benefits at lower cost than a fragmented local strategy.

The conversion efficiency of power plants—the portion of their fuel input which they return as electricity—is a key consideration. Only a tiny fraction of energy research and development expenditures over the past decade was devoted to improving the efficiency of the combustion process, though it is in that process where most energy losses occur. Federal research priorities must give greater emphasis to improving fuel use efficiency, a policy that the Federal Energy Administration is beginning to recognize. The efficiency of power plants has not significantly improved in more than ten years, but more research might change that. Conventional power plants, however, are limited by the theoretical Carnot efficiency of about 40%, unless waste heat is recovered and reused.

Indirect energy consumption, which is tied to capital investment, is more sensitive to fluctuations in the national economy than is direct energy consumption, which reflects current operations. Therefore certain trends in air quality may be caused more by the state of the economy than by the direct successes or failures of environmental protection.

Solid waste disposal is another environmental measure with great energy potential. Some 46% of all municipal solid waste is paper, much of which can be recovered and used as a supplemental electric utility fuel just as much waste crankcase and other oil could be reclaimed. The energy costs of collection and separation would probably be far below the energy recaptured. In fact, environmental impact statements for projects where solid waste is a byproduct should mention the lost energy potential in that waste.

Indirect energy analysis of packaging reveals the energy lost by throwaway cans and bottles. Calculating all of the costs of manufacture and distribution, along with the average life cycle of a returnable bottle, it was discovered that a throwaway bottle uses three times as much energy and a throwaway can uses four times as much energy as a returnable bottle. Surprisingly, a polyethylene bag costs less energy to make than a paper bag. And the common container which takes the least energy to make of any its size is the wooden berry basket.

Each missed opportunity for energy conservation is a short-term environmental threat, not only because of the pollution created by the needless energy generation, but also because today's squandering of fuel contributes to tomorrow's energy emergency, in which
bans on high-sulfur fuel, offshore oil drilling and strip mining may be swept aside in the immediate clamor for energy.

**Conclusion**

This article has demonstrated that indirect energy analysis can have surprising and profound implications for environmental policy. It does not advocate, as others have, the substitution of energy analysis for all other environmental impact measurements, nor does it suggest opening the Pandora’s box of separate energy impact statements. But the federal, state and local governments should not forgo this opportunity for new forms of environmental analysis and new vistas of energy conservation. The conservation pleas of the winter of 1973-74 emphasized austerity and postponement. They might have also focused on substitution, but they did not, partly because little indirect energy analysis apparently came to the attention of policy makers. If those responsible for implementing NEPA, the nation’s premier environmental law, continue to ignore the implications of indirect energy, the trauma Americans experienced following the Arab oil embargo of 1973 could be visited upon the United States many times to come.

**Footnotes**

*Policy Analyst, Council on the Environment of New York City. I would like to thank these persons for their help with my net energy work, though I alone am responsible for any errors in this article: Malcolm Baldwin, U.S. Council on Environmental Quality; George Bugliarello, Polytechnic Institute of New York; Clark Bullard and Robert Herendeen, University of Illinois; Ruben Brown and William Crowell, Council on the Environment of New York City; Joel Darmstadter, Resources for the Future; Edward Ferrand, New York City Dep’t of Air Resources; Harold Gershinowitz, Rockefeller University; William Hoppen, Ardsley-on-Hudson, New York; H.G. Mike Jones, Brookhaven National Laboratory; Charles Komanoff, Council on Economic Priorities; Lewis Kwis, New York City Planning Commission; Gerald Leach, International Institute for Environment and Development; Michael Miernik, West Side Highway Project; Thomas Moss, office of U.S. Representative George Brown; Dick Netzer, New York University; Robert Rickles, Institute for Public Transportation; and Diane Serber, Richard Stein & Associates.
The word "consumers" is used colloquially, because, of course, energy can be neither created nor destroyed, merely converted. Many conversion processes—most importantly, combustion—transform energy into a state of entropy from which it cannot be retrieved.


An interesting, but insignificant, implication is that manual razors ultimately consume more operating energy than electric razors, because the energy needed to heat the water most men use in shaving manually exceeds by several times the power needed to drive an electric shaver. H. GERSHINOWITZ & M. GERRARD, ENERGY AND THE NEW YORK CITY ENVIRONMENT (Council on the Environment of New York City, 1974) [hereinafter cited as GERSHINOWITZ]. Cf. advertisement, Continental Oil Co., Wall Street J., Dec. 10, 1974, at 11.

The theory of the energy basis of economics and society has been thoroughly explored in H.T. ODUM, ENVIRONMENT, POWER, AND SOCIETY (Wiley-Interscience 1971). For a summary of Odum's views by one of his colleagues, see T.A. Robertson, Systems of Energy and the Energy of Systems, 60 SIERRA CLUB Bull. 21-23 (March 1975).

COUNCIL ON ENVIRONMENTAL QUALITY, ENVIRONMENTAL QUALITY—1973, at 266 (Annual) [hereinafter cited as ENV. QUALITY].

In other words, energy use has been declining in relation to the Gross National Product. Whether energy productivity has been declining as a percentage of that portion of the GNP which represents production of real goods and services, rather than that which reflects negative externalities, is open to question.


ENV. QUALITY—1974, supra note 5, at 389.

Administration Split by Proposal to Waive NEPA on Energy
Projects, 4 BNA Env. Rep. 1839 (March 8, 1974); Peterson Says Administration Will Not Recommend Changes in NEPA This Session, 4 BNA Env. Rep. 2024 (April 5, 1974).


12 STANFORD RESEARCH INSTITUTE, PATTERNS OF ENERGY CONSUMPTION IN THE UNITED STATES 152 (Office of Science and Technology, Executive Office of the President, 1972) [hereinafter cited as PATTERNS OF ENERGY CONSUMPTION].


24 See Proposed FEA Reg. § 208, 40 Fed. Reg. 26279 (1975). Though FEA’s massive plan for “Project Independence” contains a good discussion of conservation options for industry, it does not integrate indirect energy into its discussions of other economic sectors. See, Project Independence infra note 41, especially Appx. AIII.


26 House Committee Staff Issues Report on EPA, CEQ Impact Statement Efforts, 5 BNA Env. Rep. 265 (June 28, 1974).

27 Env. Quality—1974, supra note 5, at 401.

28 Id. at 402; T.C. TRZYNA, ENVIRONMENTAL IMPACT REQUIREMENTS OF THE STATES: NEPA’S OFFSPRING 19022 (EPA-600/5-73-006 Office of Research and Development, Environmental Protection Agency, April 1974).

29 Also to be watched with interest is a suit filed in U.S. District Court for the Southern District of New York in December 1974, in which a number of environmental groups and individuals in New York City sued the city, state, and federal governments for filing an inadequate environmental impact statement for the West Side Highway Project, partly on the grounds that the statement failed to discuss energy impact. Action for Rational Transit v. West Side Highway Project, Case No. 74 Civ. 5572 (S.D.N.Y., filed Dec. 1974).


37 A relevant thermodynamic issue is the varied amount of work available from different forms of energy, a factor which must be included in detailed energy calculations. Much net energy discussion is muddled by confusion over this point. See Office of the Chief Engineer, Federal Power Commission, Staff Report: A Technical Basis for Energy Conservation 14, (FPC/OCE/2, April, 1974) [hereinafter cited as A Technical Basis for Energy Conservation]; W.D. Metz, Energy Conservation: Better Living Through Thermodynamics, 188 Science, 820-21 (May 1975).
38 For an alternative set of criteria with somewhat different aims, see Federal Energy Ad., Project Independence Report Appx. IV., at 202-82 (November 1974) [hereinafter cited as Project Independence].
39 A national allocation program of clean fuels would help resolve this problem. See Gershnowitz, supra note 3 at 3.
40 For an attempt at quantification of the different social costs of deep-mined and strip-mined coal, see G.E. Dials & E.C. Moore, The Cost of Coal, 8 Appalachia 1-29 (Appalachian Regional Commission, Oct.-Nov. 1974).
42 The proportion of industrial energy use that came from gas increased from 22.7% in 1947 to 46.5% in 1971, so though total
industrial energy consumption increased 69.4% in that period the environmental impact did not increase proportionately. Subcommittee on Energy of the House Committee on Science and Astronautics, Energy Facts, 93rd Cong., 1st Sess., ser. H at 50 (1973) [hereinafter cited as Energy Facts].

This idea was proposed to the author by Charles Komanoff of the Council on Economic Priorities.

Statistical Abstract of the U.S., supra note 7, at 515.

This figure relates to a percentage of total energy consumption for 1971. See Energy Consumption in Manufacturing, supra note 41, at 590-91.


51 Bureau of Labor Statistics, Dep’t of Labor, Bull. No. 1836
Impact of Federal Pollution Control and Abatement Expenditures on Manpower Requirements (1975).


63 "The evidence is abundant (but disorganized and dispersed) that the path of least energy consumption is also the path of least disruption and insult to the environment," in E.E. Hughes, E.M. Dickson, & R.A. Schmidt, Control of Environmental Impacts from Advanced Energy Sources 84 (EPA-600/2-74-002 Office of Research and Development, Environmental Protection Agency, 1974) [hereinafter cited as Hughes, Dickson & Schmidt].


Some of the non-I/O methods are:


—The Strategic Environmental Assessment System (SEAS) of the Environmental Protection Agency. See Env. Quality—1974, supra note 5, at 290-304.

—The Resource and Environmental Profile Analysis (REPA) methodology of Midwest Research Institute (MRI). MRI is a private consulting firm in Kansas City, Missouri, and several of its reports are kept confidential at the request of MRI’s clients. Among those reports that clients have released to the public, however, are R.G. Hunt & R.O. Welch, Resource & Environmental Profile Analysis of Plastics & Non-Plastics Containers, prepared for the Society of the Plastics Industry (Nov. 1974); Resource and Environmental Profile Analysis of Ten Beverage Container Systems, prepared for Film Dept., E.I. duPont de Nemours and Co., (Sept. 24, 1974); R.G. Hunt, et al., Resource and Environmental Profile Analysis of Nine Beverage Container Alternatives: Final Report, prepared for the Office of Solid Waste Management Programs, Environmental Protection Agency (EPA/530/Sw-91c, 1974); and R.O. Welch, The Energy Requirements of Meal Preparation: A Comparison of Restaurant vs. Home, prepared for the National Restaurant Ass’n, (July 12, 1974).

An example of the sorts of results which might be expected can be found in M.R. DOHAN AND P.F. PALMEDO, THE EFFECT OF SPECIFIC ENERGY USES ON AIR POLLUTANT EMISSIONS IN NEW YORK CITY: 1970-1985 (BNL 19064, Energy Systems Analysis Group, Brookhaven National Laboratory, 1974). This report, though not an I/O analysis, contains an extremely useful “reference energy system,” tracing the flow of energy in the New York City area, but it does not include indirect energy inputs from outside the region. COUNCIL ON ENVIRON-

The idea was proposed to the author in a private letter written by Professor Clark Bullard of the University of Illinois (March 31, 1975).

This has particular relevance because the largest portion of impact statements are filed for transportation projects. Env. Quality—1974, supra note 5, at 389.

The five alternatives were: (1) maintenance—extensive repair of roadway and replacement of some structural components, $86 million; (2) reconstruction—demolition of old roadway and construction of a new one with approximately the same configuration, $227 million; (3) arterial—demolition of old roadway and replacement with at-grade road, $76 million; (4) inboard—demolition of old roadway and replacement with partially below-grade interstate highway, with supplemental service roads, $900 million; and (5) outboard—demolition of old roadway and replacement with supplemental service roads, and new park or other land created on top, $1150 million.

Though a state statute known as the Blumenthal amendment, N.Y. Highway Law § 340-a (McKinney, Supp. 1974-75) outlawed any construction through the park, the author observed at public hearings and private meetings that residents feared that the law might not stand, and even if it did, that construction adjacent to the park would disrupt the park itself. See, Ted Wolner, Riverside Park: Now You See It, Soon You Won't, Village Voice, Oct. 17, 1974, at 42. New York Times, April 24, 1974, at 43, col. 1.

Fed. Highway Ad., Dep't of Transportation, and N.Y.S. Dep't of Transportation, West Side Highway Project Environmental Impact Statement 220-221 (1974) [hereinafter cited as West Side Highway Project EIS].

The EIS stated that subways are about twice as energy efficient as automobiles. Id. at 220. The total energy intensity in the 31-county New York metropolitan region (1970) was 3,124 B.t.u. per passenger mile (B.t.u./PMT) for subways, with an average occupancy of 23.5 persons per vehicle, and 6,508 B.t.u./PMT for automobiles, with an average occupancy of 1.5. Regional Plan Ass'n & Resources for the Future, Regional Energy Consumption 15 (Regional Plan Ass'n, 1974) [hereinafter cited as Regional Energy Consumption]. Lower average auto speeds, however, predominate
in the West Side compared with the rest of the region. See, Creighton, Hamburg, Inc., West Side Highway Transportation Analysis, prepared for Parsons, Brinckerhoff, Quade and Douglass (March 15, 1974) [hereinafter cited as West Side Highway Transportation Analysis]. This suggests an auto energy intensity of closer to 13,000 B.t.u./PMT. When peak hours are included in the calculation for West Side subway efficiency, an occupancy rate of 70 seems reasonable, reducing subway energy intensity to 1,049 B.t.u./PMT, or approximately one/twelfth the auto energy intensity. The uncertainties mean that the figure might be as high as one/fifth, but certainly not as high as the West Side Highway Project's (WSHP) one/half estimate.


73 West Side Highway Project EIS, supra, note 70, at 304.

74 Bezdek and Hannon, supra, note 49 (1963 coefficients were used).

75 A deflator of 0.565, from the Dep't of Commerce cost index for construction, was used to convert the 1963 dollars in the I/O tables into the 1973 cost estimates of the WSHP. Telephone conversation with Dep't of Commerce Regional Librarian, New York (Sept. 1974). Other useful indices may be found in the FEDERAL HIGHWAY AD., DEP'T OF TRANSPORTATION, PRICE TRENDS FOR FEDERAL-AID HIGHWAY CONSTRUCTION, 1967 BASE, FIRST QUARTER 1975. A further refinement would involve accounting for the differences in labor and material costs between New York and the United States as a whole.

76 The figures used were 0.80 for inboard and outboard, and 0.75 for arterial, maintenance, and reconstruction, computed from data contained in West Side Highway Project EIS, supra, note 70, at 304.

77 A coefficient of 26,500 was used, which is applicable to administrative functions. See Bullard & Herendeen, supra, note 34.

78 Regional Energy Consumption, supra, note 71, at 35.

79 The WSHP estimates that the inboard alternative, for example, required 1.7 million cubic yards of concrete. West Side Highway Project Design Report 7-9 (West Side Highway Project, 1974). The August, 1974 average price of concrete was $22.76/cubic yard. ENGINEERING NEWS-RECORD (Aug. 7, 1974). The most recent Bureau of Labor Statistics Wholesale Price Index for concrete was 146.2 (1967 = 100), and in 1963 was approximately 96.8. With this information, the 1963 value of concrete required for the inboard (I,) alter-
native was calculated. The primary energy intensity of cement is 433,124 B.t.u./dollar (in 1963 dollars). Bullard & Herendeen, supra, note 34. From this the energy cost of the concrete for the inboard was calculated to be 10,840,144 million B.t.u. A similar calculation was made for steel, using a WSHP estimate of 119 million pounds of structural steel for the inboard, an Iron Age (trade magazine) cost average for 1963 of $5.50/pound for structural steel shapes, and an energy intensity index of 262,460 for steel. The result was 1,717,800 million B.t.u. Telephone conversation with Iron Age (Sept. 1974).


A number of writers have also tried to roughly quantify the environmental as well as the energy impact of materials consumption. See, C.W. Dane, The Hidden Environmental Costs of Alternative

80 Bullard & Herendeen, supra, note 34.

81 This factor is ignored by many geographers. See D.B. Luten, The Economic Geography of Energy, 224 SCIENTIFIC AMERICAN 164, (Sept. 1971).

82 West Side Highway Transportation Analysis supra, note 71.


84 E. Hirst, Direct and Indirect Energy Requirements for
To avoid double counting, the 3400 figure excludes energy consumption in highway construction.


86 It was necessary to calculate the B.t.u. content of truck fuel. In the New York region, at least 90% of the trucks have gasoline engines. John C. Cosby, Wilbur Smith & Associates, Heavy Duty Vehicle Driving Pattern And Use Survey, Final Report, Part I, New York City 20, prepared for Environmental Protection Agency and Coordinating Research Council, Inc. (APT.D-1523, May 1973). Since diesel fuel has an energy content of 140,800 B.t.u./gallon and gasoline has a content of 124,900 B.t.u./gallon, a weighted average of 126,000 B.t.u./gallon was obtained. This is not an exact method of calculating the B.t.u. content, but it appears to yield reasonably reliable numbers. Then the same procedure was followed as for autos to calculate direct and indirect fuel consumption by trucks. Based on the average automobile fuel mileage of 2.4 times that of trucks, 8160 was used as the multiplier for other indirect energy demands for trucks (for manufacture, etc.). A detailed examination of truck indirect energy consumption, such as that which Hirst performed for automobiles, was not available to determine a more exact multiplier. Some of the same objections to the 3400 automobile coefficient may be raised against the 8160 truck coefficient. The same answers would apply, except that the number of trucks in service is probably more closely related to the available highway facilities than is the number of cars in service, due to the impact of highways on business location decisions.
88 See note 83, supra.
89 T.J. Healy & D.T. Dick, Total Energy Requirements of the Bay Area Rapid Transit (BART) System (Univ. of Santa Clara, July 1, 1974).
90 M.F. Fels, Comparative Energy Costs of Urban Transportation Systems (74-TR-2, Transportation Program, Princeton University, 1974).
92 R.A. Rice, supra, note 83. For a discussion of the energy impact of the electric car, see D.P. Grimmer & K. Luszczyniski, Lost Power, 14 Environment, April 1972, at 20.
95 One source of data for individuals who wish to calculate their...
own energy consumption is contained in A.J. Fritsch, The Contras-
sumers: A Citizen's Guide to Resource Conservation 159-79 (Praeger, 1974). Somewhat more detail may be found in A.J. Fritsch &
B.I. Castleman, Lifestyle Index (Washington, Center for Science in
the Public Interest, 1974).

For an interesting theoretical discussion of achieving no-
growth, steady-state cities, see H.T. Odum & L.L. Peterson, Rela-
tionship of Energy and Complexity in Planning, 42 Archi-

Regional Energy Consumption, supra, note 71, at 6, 7. Bruce
Hannon of the Center for Advanced Computation maintains, how-
ever, that when all indirect energy inputs are considered, New York-
ers consume approximately 23% more per capita than the national
31, 1973; and B. Hannon, Energy Conservation and the Consumer
10 (Center for Advanced Computation, Oct. 1974). More data on the
impact of density on transportation energy consumption may be
found in J.M. Lutin, Comparison of Energy Savings for Work
Trips, An Analysis of Alternative Commuting Patterns for New
1974).

B.C. Netschert & R. Weinstein, The Impact of Urbanization
on the Demand for Energy, in Urban Demands on Natural
Resources 137, proceedings of Western Resources Conference, Den-
ver, Colo., (July 8-10, 1970). See also Real Estate Research Corp.,
The Costs of Sprawl: Detailed Cost Analysis, prepared for Council
on Environmental Quality, Dep't of Housing and Urban Develop-
ment and Environmental Protection Agency (April 1974).

D.P. Moynihan, Traffic Safety and the Health of the Body
Politic 6, Monday Evening Papers, No. 10 (Center for Advanced
Studies, Wesleyan Univ., undated).

B. Hannon, Energy Conservation and the Consumer, 189
Science 99 (1975).

For a general theoretical discussion, see H.T. Odum, supra,
note 4.

One consideration worth noting, although beyond the scope of
this article, is that the wealthier an individual becomes, the larger
a share of his energy budget goes into indirect energy, in the form
of airplane trips, larger houses, more clothing, more financial
investment, etc. Therefore, attempts to conserve energy solely
through more efficient residential or auto use (e.g., better insula-
tion, more car-pooling) will have proportionally less impact on the
rich. Equity, then, as well as the need to conserve fuel, dictates the need for controls over both indirect and direct energy demands.


103 E. Hirst, Today's Oil Shortage is Tomorrow's Food Crisis, ENVIRONMENTAL ACTION, Dec. 8, 1973.

104 W. Clark, U.S. Agriculture is Growing Trouble as Well as Crops, 5 SMITHSONIAN, Jan. 1975, at 60.


107 Energy analysis has shown that cheese represents a far more efficient way of supplying protein than does meat, although it is less efficient than grain. B. Hannon, Options for Energy Conservation, TECHNOLOGY REV., Feb. 1974, at 29.

108 In fact, the researchers for the Environmental Impact Assessment Project and for the Council on the Environment of New York City were totally unaware of each others' work until both analyses had been completed.

109 A Scientific and Policy Review of the Final Environmental Statement for the Initial State, Garrison Diversion Unit (North Dakota) 21, Environmental Impact Assessment Project (Gary L.

110 NAT'L BUREAU OF STANDARDS, DEP'T OF COMMERCE, TECHNICAL OPTIONS FOR ENERGY CONSERVATION IN BUILDINGS 118, NBS Technical Note No. 789 (1973); GENERAL ACCOUNTING OFFICE, HOW FEDERAL AGENCIES CAN CONSERVE UTILITIES AND REDUCE THEIR COST: GENERAL SERVICES ADMINISTRATION, DEPARTMENT OF DEFENSE 15-16 (B-178205, 1974).


112 ENERGY FACTS, supra, note 42, at 79-83.


114 Whether this is the case for cars is in question, because of the greater weight that would result from the substitution. The aluminum industry, in fact, maintains that aluminum is an overall energy saver. See statement of E.A. Walker in the Hearings Before The Subcomm. of the House Comm. on Government Operations and House Comm. on Science and Astronautics, 93rd Cong., 1st sess., pt. 4, at 1556-94 (1973).


117 E. Hirst, The Energy Cost of Pollution Control, 15 ENVIRONMENT 41 (Oct. 1973) [hereinafter cited as Energy Cost]. This calculation does not include collection, separation and transportation of the material.

118 BRAVARD, FLORA & PORTAL, supra, note 79, at 1.
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121 W. Clark, It Takes Energy to Get Energy; the Law of Diminishing Returns is in Effect, 5 Smithsonian 84 (Dec. 1974).

122 Hughes, Dickson & Schmidt, supra, note 63, at 82.


124 Two estimates of the relative total efficiencies of natural gas and other fuels are, Energy and the Environment: Electric Power, supra, note 65, especially the appendices; Office of Energy Research and Planning, Office of the Governor, State of Oregon, Energy Study: Interim Report (July 26, 1974) [hereinafter cited as Energy Study: Interim Report]. These two studies employ different definitions of energy efficiencies, and should be used with caution.


126 Energy Study: Interim Report, supra, note 124, at iii. It has been reported in the press that Texaco decided in 1974 not to bid on oil shale leases in Colorado, largely because of net energy calculations. However, Texaco says these reports are inaccurate, and that it is continuing work on oil shale. Letter from Gordon C. Hamilton, Texaco Inc. to the author (July 23, 1975).

127 This idea was proposed to the author in a private letter from Dr. Thomas Moss, in the Office of U.S. Rep. George E. Brown, Jr. (Dec. 3, 1974).


133 Mencher, HAKKI & Rolinski, supra, note 132.


135 Hughes, Dickson & Schmidt, supra, note 63, at 83.

136 Id. at 79.

137 Id. at 81.

See, e.g., A Technical Basis for Energy Conservation, supra, note 37, at 3.


A.B. Lovins, On Total Energy Costs, 5 Eco, July 8, 1974 at 5.


A Technical Basis for Energy Conservation, supra, note 37, at 14.


Berry, Fels & Makino, supra, note 35, at 513.


Devising new subjects for impact statements seems to have become a major exercise in recent years. Among the new varieties that have been proposed are:


4. **“Reverse Impact Statements,”** showing what will happen to prospective tenants of low-income housing, for example, if a project is not built. See P. Marcuse, *Conservation for Whom?* in *Environmental Quality and Social Justice in Urban America* 19 (J.N. Smith ed., Conservation Foundation, 1974).