Title

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Publication Date
1989-10-01

LBL-25674 Rev.
UC-400

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

APPLIED SCIENCE DIVISION

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October 1989

APPLIED SCIENCE DIVISION

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

LBL-25674

THE ROLE OF OIL IN ELECTRICITY GENERATION IN FIVE EUROPEAN COUNTRIES: PAST, PRESENT, AND POTENTIAL*

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* This work was sponsored by the U.S. Department of Energy, under contract No. DE-AC0 3-76SF00098. Opinions are those of the authors.

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Dianne V. Hawk and Lee Schipper

ABSTRACT

The annual primary oil demand of five European countries — France, Germany, Italy, England & Wales, and Sweden — declined by approximately 25% between 1973 and 1986. Nearly one-third of this decline is the result of the phasing-out of oil for use in electricity generation. In 1973, oil was the first- or second-most important energy source for electricity generation in all of these countries,—generating between 14% and 59% of electricity produced. By 1986, oil's share of electricity generation had declined to between 1.5% and 5.6% in all countries except Italy (39.4%), where oil is still being used for base-load generation. The oil-fired generation facilities existing in 1973 are still in place and operable (in various stages of reserve), however, and some oil-fired generation is used, primarily to meet peak load. Thus, the infrastructure that supports oil-based electricity generation remains in place, but the *intensity* with which oil is used has changed. This sector could trigger a large and sudden rise in the demand for oil. If the oil-using capacity in each of these countries were utilized at its highest feasible level (capacity factors between 60% and 79%), oil use by the power sector would increase by a factor of five. This increase translates to a 25% increase in the total oil demand of these five countries.

In England & Wales and Sweden, oil-based generation may soon increase above 1986 levels. In Sweden, oil-based generation will be used to bridge a supply gap that will result from the decommissioning of nuclear power plants in the absence of new generation capacity to replace them. In England & Wales, a competitive environment introduced through privatization, the relative youth of the oil capacity, and the current low oil prices may cause oil-based electricity generation to have a competitive advantage, even replacing some coal-fired generation. Continued delays in the nuclear program would encourage the use of oil to bridge supply gaps until the nuclear capacity comes online or a different generation source is selected. In Italy and Germany, oil-fired electricity generation will probably remain relatively constant. Unless German law changes, no additional oil-based generation will occur. Only in France will oil-based generation decline.

Although oil-fired electricity generation may increase above 1986 levels in the near future in some countries, the maximum potential levels of oil-based generation calculated in this report will not be attained in any of the countries *unless* a major electricity-generation resource or technology suffers a severe, unforeseen disruption. In the absence of such a disruption, institutional barriers against dependence on oil will preclude the realization of the existing potential. Nonetheless, the hidden potential for oil use in the power sector, represented by the existing oil-fired capacity, must not be forgotten. As institutions and political agendas evolve, so too might attitudes regarding oil use.

THE ROLE OF OIL IN ELECTRICITY GENERATION IN FIVE EUROPEAN COUNTRIES: PAST, PRESENT, AND POTENTIAL

Dianne V. Hawk and Lee Schipper

1. Introduction

The first oil crisis in 1973 caused most European members of the Organization for Economic Co-operation and Development (OECD) to curb their oil use. The OECD countries' acute awareness of their vulnerability to oil supply disruptions and the dramatic rise in the price of oil compelled them to assess the quantity of oil they used, as well as the tasks for which they used it. Since 1973, these countries have replaced oil with other energy resources and improved the efficiency with which oil is converted to useful work. Consequently, annual primary oil demand in OECD Europe declined by approximately 25% between 1973 and 1986. Nearly one-third of this decline is the result of phasing-out oil for electricity generation. Much of the oil-fired electricity generation of 1973 has been replaced by generation from nuclear, natural gas and solid fuels. Oil's contribution to electricity generation in OECD Europe dropped from 28% of electricity generated in 1973 to 9% in 1986.

In many countries, however, the oil generation capacity existing today is comparable to that in place in 1973. The oil capacity is operable (in various stages of reserve) and some oil-based electricity is generated, primarily to meet peak load. Thus, the infrastructure that supports oil-based electricity generation remains in place, but *the intensity with which oil is used* has changed. In light of this, we have set out to determine if governments and/or electric utilities of France, West Germany, Italy, Sweden and England & Wales can or will increase the amount of oil-fired electricity generation over today's levels, by how much and under what conditions. This sector could trigger a large and sudden rise in the demand for oil: a potential 25% increase in the total oil demand of these five countries. This translates to an increase of nearly 2 million barrels of oil per day. In this report, we explore how the role of oil in electricity generation has changed over the last 15 years, and contemplate the potential role(s) of oil in generation in both the immediate future and over the long-term planning horizon.

In the first section, we explain the role of oil in electricity generation in 1973. We describe the existing oil generation capacity and how that capacity was used, i.e., the amount of electricity actually produced with oil and the corresponding primary oil requirements. We calculate the capacity factors and discuss the types of load that oil-fired generation was used to meet.

Next we describe the trends in the use of oil for electricity generation since 1973, and explain the strategy behind the changes: Did oil use decline? If so, was this principally in response to the oil crises in the 1970's or had oil use in generation been decreasing prior to the 1970's as a result of energy or environmental policies? What resources have replaced oil?

Then we focus on the situation in 1986, identifying the role of oil in generation as we did for 1973. We explain how generation capacity, production, primary oil requirements and related indicators have changed since 1973.

As we contemplate the fuels that are alternatives to oil, we now find that they are also beset by security and environmental problems. Natural gas, seen by many as the "cleanest" of the fossil fuels, still has not significantly penetrated the power generation sector in Europe, in part because of continuing concerns over security of supply. A large share of Europe's gas is imported from the USSR and Algeria. The combustion of fossil fuel, especially coal, causes many severe environmental problems, including acid rain, air pollution, and the "greenhouse effect." In addition to the environmental and supply disruption that would be associated with "another Chernobyl," nuclear power poses significant environmental risks at the stages of fuel reprocessing, waste disposal and plant de-commissioning. Many people are also concerned with the security of reprocessing facilities in the face of terrorist threats. In addition to these fuel/resource specific problems and/or potential problems, which range from catastrophic to chronic, there are system problems, such as mechanical difficulties at power stations or with the transmission grid that cause temporary loss of load and thus affect the utilities' ability to supply electricity.

Any one of the above problems could cause a disruption in electricity generation. If such a disruption were to occur, would electricity supply systems be better equipped to respond and more resilient than they were in 1973? Today, oil-fired generation may come to the rescue as a back-up source of generation! In the next section, we explore the short term possibilities for increased oil use in generation based on the existing generation capacity and the maximum technically feasible capacity factor. How does this compare to actual oil-based generation in 1986 and how does the corresponding *potential* primary oil requirement compare with actual primary oil requirement for electricity generation in 1986? How would the *potential* increased oil requirements for electricity generation affect *potential* national oil requirements for the countries in 1986?

Then we ask if, and under what circumstances, the *potential* amount of oil-based generation would be realized, based on social, economic, legal, institutional, political, and environmental considerations. Considerations such as relative fuel prices, legal restrictions (associated with environmental and national security), public opinion, and contractual agreements are likely to determine whether or not oil-fired generation will increase. Circumstances under which oil-fired generation might be used as a backup source of generation are, for example: labor strikes that affect the supply of primary fuel inputs, accidents at generation facilities (unanticipated forced outages), and unexpected delays in new capacity coming on line.

Finally, from the long-term perspective of individual countries, we discuss the future prospects of oil use in this sector. In the mid-1990's, most existing oil-fired capacity will be over 25 years old. Thus, decisions must be made about whether oil will to have a permanent role in generation or whether today's role is only the result of electricity supply systems in transition. We investigate plans to refurbish or retire old oil capacity and/or replace it with new (more efficient) oil capacity or with a different fuel-based technology.

2. Context

In 1973, oil demand for France, Germany, Italy, England & Wales, and Sweden amounted to 514.3 MTOE, which accounted for 61% of these countries' total primary energy use.[1] In the aftermath of the crisis, these countries recognized the insecurity of their energy supply due to the potential for unpredictable disruptions of oil imports resulting from geo-political activity and the economic consequences of high oil prices. To minimize the negative impacts of this new situation, oil use would have to be reduced.

[1] Primary energy includes all energy resource requirements -- solid fuels, oil, gases, nuclear fuel and hydro resources (oil-equivalent energy content) -- before any transformation (or energy conversion) occurs.

Any and all contributions to this end, large and small, were important. Individuals, as well as commercial/service building managers, reduced their household use of oil for space and water heating; in the longer term, many replaced existing oil systems with other systems of a different energy base (Schipper *et al.,* 1985). Likewise, people reduced the number of miles driven and purchased more efficient vehicles (Schipper *et al.,* 1985). Efforts have also been initiated to make use of alternative fuels (Sathaye, 1988). Similarly, oil use for industrial processes has declined (IEA, 1987). For all of these oil uses, some immediate reduction was achieved, but much of the potential reductions required time to implement changes, changes that involved individual consumer or corporate decisions, economic opportunity and follow through.

In 1973, 12% of total oil demand for these five countries was for electricity generation. The share ranged from 6% in Germany to 20% in Italy. Electric power generation was one homogeneous task that accounted for a large portion of total oil demand, for which decision-making power was concentrated. Thus, targeting this use of oil for reductions could produce relatively quick and large results. Furthermore, the reduction of oil use for electricity generation was even more imperative because electricity was seen as one attractive alternative to oil for end-uses such as space and water heating. As end-users replace oil with electricity, the elimination of oil use for electricity generation was necessary so that reductions in oil for end-uses would not be counteracted by increased oil use for electricity generation.

The remainder of this paper will explain how oil use for electricity generation has changed since 1973 and what the future may hold. We now look at electricity supply in 1973, to understand how much electricity was being produced and with what energy resources.

Many of the terms used in this report have variable meanings and/or represent different concepts in different communities. In order to avoid misunderstandings, we present our definitions of selected terms in Appendix 1.

3. Electricity Generation in 1973: The Role of Oil

Electricity demand was growing rapidly by the early 1970's. In 1973, electricity demand comprised 9% of total final energy demand[2] in France, 11% in West Germany, 10% in Italy, 13% in England & Wales, and 17% in Sweden. Inexpensive oil supplies, in part, enabled electricity supply to keep up with growing demand. In 1973, these five countries had total oil requirements that amounted to 514 MT. Of this amount, 13% or 64 MT were used to generate electricity. Thus, oil use for power generation comprised a sizeable portion of total oil requirements. In 1973, over 60% of these countries' total oil supplies were imported from OPEC countries. Hence, electricity supply systems were vulnerable to disruptions of oil supplies. Table 1 displays the amount of electricity produced in 1973, disaggregated by generation resources, for each of our five countries.

[2] Final energy demand includes demand of solid fuels, oil gas and electricity. It excludes transfer and transformation losses from refineries, electricity generation, and use by transformation industries.

TABLE 1:
1973 Electricity Generation By Fuel[1,2]

	France	Germany	Italy	E&W	Sweden	TOTAL
(TWh)	174.5	299.0	145.5	201.8	78.1	898.9
Oil	67.6	42.8	85.8	41.1	12.9	250.7
Natural Gas	9.3	35.6	4.5	0.0	0.0	49.4
Other Gases	*	11.5	6.3	1.1	0.2	19.1
Coal	28.2	178.7	3.1	139.7	*	349.7
Nuclear	14.0	11.7	3.1	19.3	2.1	50.2
Hydro	47.5	15.5	39.1	0.6	59.9	162.6
Geothermal	0.0	0.0	2.5	0.0	0.0	2.5
Other	7.8	3.2	0.6	0.0	3.0	14.6
(%)	100.0	100.0	100.0	100.0	100.0	100.0
Oil	38.7	14.3	59.0	20.4	16.5	27.9
Natural Gas	5.3	12.0	3.1	0.0	0.0	5.5
Other Gases	*	3.8	4.3	0.5	0.3	2.1
Coal	16.2	59.8	2.1	69.2	*	38.9
Nuclear	8.0	3.9	2.1	9.6	2.7	5.6
Hydro	27.2	5.2	26.9	0.3	76.7	18.1
Geothermal	0.0	0.0	1.7	0.0	0.0	0.3
Other	0.0	4.9	0.8	0.0	3.8	1.6

(1) Net generation for France and E&W; Gross generation for Germany, Italy and Sweden.
(2) Refer to Appendix 3 for breakdown of energy resources included in each fuel category for each country. Refer to References for data sources.
(*) - included in another category, see Appendix 3.

For France and Italy, the single largest share of electricity was generated with oil: 38.7% and 59.0%, respectively. In Germany and England & Wales, coal generated 59.8% and 69.2% respectively but oil came in second, contributing 14.3% and 20.4% of total electricity supply. Sweden, with its abundant water resources, generated 76.7% of its electricity with hydropower and oil, in second place, generated 16.5% of total electricity. Nuclear programs were under way in all these countries, with a particularly aggressive program in France, although nuclear power contributed less than 10% of total electricity generation in any country.

In 1973, oil-using capacity (both monovalent oil plants and polyvalent plants that use oil as one of their fuels) in these countries was substantial, comprising 21% of installed capacity. New oil-using capacity was either planned or under construction.

TABLE 2:
1973 Installed Generation Capacity by Fuel[1,2]

	France	W.Germany	Italy	E&W	Sweden
(GW_e)	43.3	61.9	37.6	58.9	19.5
Oil	10.2	7.9	12.5	9.3	7.0
Natural Gas	*	5.9	0.3	0.0	^
Other Gases	*	*	0.1	1.9	^
Coal	10.2	26.4	0.1	38.7	^
Mixed	^	13.9	9.1	5.1	^
Nuclear	2.9	2.4	0.6	3.4	0.5
Hydro	16.2	4.7	14.6	0.5	12.0
Geothermal	0.0	0.0	0.4	0.0	0.0
Other	3.8	0.4	0.0	0.0	0.0

1) Net capacity for France, E&W, and Sweden; Gross capacity for Germany, and Italy.
2) Refer to Appendix 3 for breakdown of energy resources included in each fuel category for each country. Refer to References for data sources.
* - included in another category, see Appendix 3.
^ - included in above category.

As one might expect, this oil capacity was used to fill base load in all countries except Sweden where the oil capacity was used to meet intermediate load and as back-up baseload capacity in years with low hydropower production. The capacity factors presented in Table 3[3] confirm that the oil capacity typically fulfilled this duty cycle.[4]

TABLE 3:
1973 Oil Capacity Factors

	France	Germany	Italy	E&W	Sweden
1973 mono-oil	0.76	0.61	0.78	0.50	0.21

Following is a synopsis of the role of oil in electricity generation in 1973, for each of the five countries. Figures 1-5 show electricity production by fuel, 1973-1986, for France W. Germany, E&W, and Sweden, respectively.

[3] These capacity factors were calculated using the monovalent oil capacity only and thus slightly overestimate the intensity of use of the monovalent capacity, because some electricity generated with oil was generated in polyvalent plants. For discussion of capacity factor calculation and usage, see Appendix 2.

[4] For the purposes of this analysis, capacity factors of 65% indicate that the capacity was used for meeting baseload, 30% for intermediate load and 10% for peaking capacity. These are lifetime levelized nominal annual capacity factors used by the Electric Power Research Institute (EPRI) as general guidelines. Actual plant capacity factors for plants in a given category vary widely, depending on actual outage rates, individual system load characteristics and economic dispatch patterns (Electric Power Research Institute, 1986).

FRANCE. France's electricity generation was based primarily on three resources: oil (39%), hydro (27%), and coal (16%). Clearly, electricity production depended heavily on the availability of oil. Primary oil requirements for oil-fired generation amounted to 14 MTOE in 1973, approximately 11% of national total oil demand. At this time, having only small domestic reserves, France imported 99% of its oil requirements, nearly 80% of these requirements from the Middle East. Thus, with 39% of its electricity supply dependent on middle Eastern oil imports, France was hit hard by the 1973 oil crisis.

All this oil-based electricity was generated by 10.2 GW of monovalent oil capacity and ~8 GW of mixed-fired (oil + other) capacity. Another couple of GW had been ordered and were under construction in 1973. The oil capacity factor was 76% (Table 2). In France too, oil-based generation filled base load. (Some hydro-power, generated from run-of-river facilities that amounted to approximately half of the hydro capacity, and the little nuclear power available also contributed to base load generation.)

WEST GERMANY. In 1973, electricity generation in West Germany was heavily weighted on one fuel base: 60% of the electricity produced was generated with lignite and bituminous coal . The remainder of the electricity was generated with oil (14%) and gas (12%). Of the five countries, West Germany was the least reliant on oil. Still, the 8.8 MTOE of oil required for electricity generation represented 6% of the national total oil demand, 96% of which was imported from OPEC countries. With over one tenth of its electricity supply dependent on OPEC oil imports, West Germany's electricity supply system was affected by the 1973 crisis (although by no means devastated or without readily available alternatives — coal) and had an incentive to minimize oil-based generation.

At this time, West Germany maintained 8 GW of monovalent oil capacity and ~7 GW of polyvalent oil-using capacity. Like Italy, Germany valued immediate, short-term fuel switching capability, -- the polyvalent oil capacity represented 11% of its generation capacity (all polyvalent capacity accounting for 22% of capacity). -- as partial compensation for its oil import dependence. The capacity factor for the monovalent and bivalent oil plants was 61%. Oil generation was used to meet base/intermediate load.

ITALY. Italy's electricity was produced primarily with oil (59%) and hydro-power (27%) in 1973. This share of oil-based generation gave Italy the most oil-dependent electricity supply of all five countries. As Italy imported 98% of its national total oil demand, over 60%[5] from the Middle East, the electricity supply was exceedingly vulnerable to disruptions in the oil market.

Monovalent oil plants comprising 12.5 GW of capacity and polyvalent oil plants comprising 9.1 GW produced the 86.3 TWh of oil-based electricity. With 24% of their generation capacity able to use more than one type of fuel, it appears that prior to 1973, Italy appreciated the importance of immediate, short-term fuel switching in response to relative fuel price fluctuations, and the availability of fuel supplies. Italy had few indigenous energy resources, and had for some time imported (net) over 90% of its total energy demand. With a capacity factor of 78%, oil-based generation filled base load. Hydro-power, generated from run-of-river facilities also contributed to base load generation.

ENGLAND AND WALES.[6] England and Wales's (E&W) electricity generation was based

[5] Estimated, based on import share of 55% in 1970, and 76% in 1975.

[6] England and Wales (E&W) is analyzed in this report, instead of Great Britain or the United Kingdom, because one electricity system, including generation, distribution and transmission facili-

primarily on two resources: coal (69%) and oil (20%). Primary oil requirements for oil-fired generation amounted to 17 MTOE in 1973, approximately 15% of national total oil demand. At this time, having only small domestic reserves, the United Kingdom imported 99% of its oil requirements.

All this oil-based electricity was generated by 9.3 GW of monovalent oil capacity and 5.1 GW of polyvalent, oil using, capacity. In 1973, ~8 GW of oil-fired capacity was under construction. The oil capacity factor was 50%. In E&W, oil-based generation filled intermediate in 1973.

SWEDEN. In 1973, hydro-power was the principal energy source for electricity generation in Sweden: 77% of electricity produced was generated with hydro-power. The remainder of the electricity was generated primarily with oil (20%). Still, the 2.8 MTOE of oil required for electricity generation represented over 10% of the national total oil demand, virtually all of which was imported. With over 39%[7] of its oil supply dependent on OPEC oil imports, Sweden's electricity supply system was affected by the 1973 crisis, and would have an incentive to minimize oil-based generation.

At this time, Sweden maintained ~7 GW of monovalent oil capacity. In Sweden, oil generation had, for some time, been used to meet intermediate load in years with lower levels of precipitation and thus, less hydro power. In 1973, thermal production fell in the historical average range of 15-16 TWh. Thus, oil generation was used primarily at peak and and to follow load in 1973.

In summary, oil was an established and fundamental resource for electricity generation in 1973. Italy and France, the countries that generated the largest share of their electricity with oil and had the highest capacity factors for the oil capacity, used oil to generate electricity to satisfy base load. In West Germany and England & Wales, oil-fired generation met intermediate load and in Sweden, oil's role in generation fluctuated between intermediate/peak and load following depending on the hydro power available. Of these five countries, only Italy and Germany maintained significant bivalent oil capacity, demonstrating an appreciation of short-term fuel switching ability. This capability would prove valuable in the coming years.

4. Changes in Electricity Generation Policy and Operation Since 1973

The period since 1973 has been one of exploration and transition in which energy policy, and in particular, policy regarding electricity generation and use has been formulated or reformulated. As policy has been translated to action, many changes have occurred in the electricity supply systems of the five countries under study.

Since the early 1970's, energy demand growth has slowed. In particular, electricity demand growth has slowed due to increasing electricity prices that were driven up by rising

ties and regulatory bodies, plans for demand by and supplies this region. Scotland has its own system, as does Northern Ireland, although, power exchanges do occur between Scotland and E&W. We refer to Great Britain or the United Kingdom only when decisions/actions constitute national policy and are not limited to the E&W supply region of the Central Electricity Generation Board (CEGB), the national electric utility.

[7] Value for 1970 imports, (Industridepartementet, 1974).

primary energy costs, energy conservation policies and programs (Wilson *et al.*, 1989) more stringent emission standards, and high interest rates. The price increase has particularly affected electricity growth in the industrial sectors as the average annual growth rate (AAGR) in this sector slowed most dramatically, dropping to a rate one quarter of that seen prior to 1973. Electricity demand growth also declined because of structural shifts within the industrial sectors toward less electricity-intensive industries and because the market for some electricity-using devices became saturated, especially for enduses in the residential sector (Schipper *et al.*, 1987). Extensive growth in the use of electric space heating explains the relatively higher growth rates in France and Sweden. Table 4 displays average annual growth rates for electricity demand during the periods 1960-1973 and 1973-1986.

TABLE 4:
Electricity Demand
Average Annual Growth Rates

	1960-1973	1973-1986
(Percent)		
France	7.2	4.5
West Germany	7.8	2.5
Italy	7.7	2.9
E&W	5.4	1.1
Sweden	6.8	4.0

Source: OECD Energy Balances, 1987, 1988.

Although growth in electricity demand slowed during the period 1973-1986 relative to the previous 13 year period, electricity demand grew faster than total energy demand. Thus, electricity comprised a larger share of total energy demand in 1986 than it did in 1973 (Table 5).

TABLE 5:
Electricity Demand
as a Share
of Total Final Energy Demand

	1973	1986
(Percent)		
France	9.0	16.6
West Germany	11.2	16.6
Italy	10.3	14.4
Sweden	16.7	28.9
E&W	13.1	14.9

Source: OECD Energy Balances, 1987, 1988.

As countries turned their efforts toward decreasing the use of oil, electricity generation, a sector using between 6% and 20% of the countries' total oil demand, emerged as a politically attractive source for reductions. And, as electricity was becoming an increasingly important energy source, both as a substitute for oil and in meeting new energy demand, it was critical that oil use in electricity generation be eliminated so that over time, oil use would not actually increase.

Since 1973, profound changes have been made in the mix of fuels used for electricity generation, the import dependence of the corresponding primary resources, and the policies governing electricity supply, and visions of the future of electricity systems. In all five countries, oil use for electricity generation has been curtailed, as revealed by Figures 1 through 5. In large part, the rate, as well as the total quantity, of reduction of oil use in this sector was in direct response to the 1973 oil crisis and the subsequent oil price rise in 1979. Reductions were encouraged through different means: taxes on oil, regulatory restrictions on the use of oil for generation and the construction of new oil capacity and taxes on electricity. The means by which reduction was achieved, and the rate, varied from country to country, depending on the ratio of public/private ownership and the degree of regulatory control. In France and E&W, with completely nationalized supply systems, decisions can be made and immediately acted upon. Italy also has a nationalized electricity supply system, but the political environment and government institutional relationships cause decision-making and follow-through to be slow and conflicted. In Germany, electricity is supplied by primarily joint private/public ownership.[8] Hence, much of the reduction was motivated by oil price signals to companies and by Federal government voluntary "off-oil" incentive programs. The Swedish system is characterized by a number of companies of mixed ownership, but the largest company, Statens Vattenfallsverk (or Vattenfall), is state-owned and has long generated the majority of electricity produced in Sweden. In this system, national policy is often carried out through informal agreements among the various suppliers and the national government. As price leader, Vattenfall plays a key role. Government policies are often first implemented by Vattenfall. Other private suppliers follow Vattenfall's lead voluntarily to avoid more explicit government action against them (Lucas, 1985). This dynamic indicates the potential to expediently implement change.

However, the decreasing reliance on oil and the diversification to other resources was not exclusively induced by the crisis in every country: The momentum of change had already begun prior to 1973. Following is a qualitative, country-by-country discussion of how the fuel mix of electricity generation has changed since 1973, the impetus for this change, how governments responded to the oil crisis on an immediate, short-term basis and how long-term policy and planning was influenced.

FRANCE. Oil-based electricity production had increased constantly since its introduction in the late 1940's through to 1973, when it peaked. With 40% of its electricity generated with oil, France had to respond quickly to the 1973 oil crisis to restore a reliable electricity supply system and to reduce the excessive costs of imported oil. The French national electric utility, Electricité de France (EDF), responded by burning more coal and natural gas and less oil.

In 1970/71, France committed itself to a nuclear program based on PWRs, development proceeding at a rate of one reactor order per year. (Geraud, 1983) This move was the culmination of several reactor research programs that had sprung from the French military nuclear program and increasing political awareness of the persistent French sensitivity to oil dependence. In the 1950's and '60's, a number of events occurred to emphasize their vulnerability and the need to attend to energy supply security issues: the supply cut and rationing of oil and oil products that resulted from the Suez Canal crisis in 1956, bombings of the Middle East pipelines, disagreements amoung Middle East states, the embargo following the Six-Day War

[8] Public ownership is not at the federal level, but at Länder, municipal and city levels. Joint ownership is defined as less than 95% public and less than 75% private.

in 1967, and the nationalization in 1968 of fourteen French oil companies by Algeria. These events were omens of things to come.

After the crisis in 1973, the nuclear program took on new dimensions. The anticipated role of nuclear power grew to a grand scale and with the prevailing sense of urgency, the pace of nuclearization sped up. EDF ordered PWRs from Framatome, *the* French nuclear supply system manufacturer, on the following schedule: 13 GW in 1974 with 1975/76 construction start-up dates; 12 GW in 1976/77; 5 GW each year from 1978 to 1981; approximately 11 GW in 1982/83; and an average of 3 GW per year since 1983.

Due to reactor standardization and the absence of delays caused by debate and litigation over plant siting, the French were able to bring the first reactors in this series on line within 6.5 years and the remainder, in less than 6 years (EDF, private communication).[9] In 1977, two 900 MW PWR that had been ordered in 1970 came on line. Between 1979 and 1981, the 13 GW order of 1974 came on line.

The displacement of oil in every sector became, and still is, the cornerstone of French energy policy. In 1985, taxes on heavy fuel oil for power generation comprised approximately 30% of the unit price of the oil. Among the countries studied, this is the largest percentage tax on fuel oil. In France, oil-based electricity generation is in the past.

WEST GERMANY. By 1973, West Germany had embraced oil, to the detriment of the coal industry. Oil was increasingly being used in industry, the residential and commercial sectors as well as for power generation. Domestic coal, traditionally twice as expensive as foreign coal, could not compete with cheap abundant flows of oil. Domestic coal production had peaked in 1956 at 157 Mt and declined rapidly to 112 Mt in 1967. The Federal and State governments tried to offset this decline through voluntary agreements with electric utilities to burn coal and with oil companies to restrict sales (Lucas, 1985), by providing direct goverment subsidies to the coal industry, and by taxing heating oil.

These efforts were relatively ineffective in reviving the domestic coal industry. Thus, before the oil crisis in 1973, there was little or no movement to reduce oil use for generation, for which the absolute amount, as well as the share, had been increasing since the early 1960's. The increasing reliance on oil was contemplated warily by government bodies and electric utilities concerned with the public electricity supply. But, the decisions for investment were in the hands of individual utilities (which comprised over 300 electric generating utilities of public, mixed, and private ownership and industrial enterprises), and much importance was (and still is) placed on letting the market determine the appropriate, economic resources (Röhling and Mohnfeld, 1985). Although this governing philosophy is maintained today, government responses to the events of the 1970's have contradicted this philosophical position.

Immediately after the crisis in 1974, the federal government issued the third version of the Verstromungsgesetz (the law that articulates government policies regarding electricity generation). This version was modified to restrict the use of oil in power generation. The modification with the most immediate effect specifies that the amount of heavy fuel oil used for power generation could not rise to a level above that achieved in 1973 (Röhling and Mohnfeld, 1985). Another provision of the Verstromungsgesetz extends government funds to electricity producers to cover a portion of the cost of converting existing oil or oil/gas generating stations to coal-fired generation facilities. Another provision requires that special permission be obtained from the Energy Ministry before an oil- or oil/gas- based generation facility

[9] Compared with average lead times of 13.4 years in the US (International Energy Agency, 1985).

may be constructed. Permission is only granted if the construction of such a facility promotes national German energy and economic policy goals. Since the late 1960's, German energy policy has been aimed at minimizing the threat of energy supply disruptions by diversifying the types of energy resources, reducing the import share of those energy resources, and geographically diversifying the sources of imported energy resources. This explains why no new oil plants have been approved since 1975.

Prior to 1973, government programs were in place to stimulate the domestic coal industry. A "voluntary" arrangement existed between the federal government and utilities where the revenue from a general tax was paid to electricity producers in proportion to the domestic coal that they burned. After the 1973 oil crisis, this arrangement took on additional importance as a means to discourage the use of oil for electricity generation.

This strategy to promote domestic coal use was formalized in 1977 with a contract between the Federal government, the coal industry, and electricity producers, called Jahrhundertvertrag (literally, the Hundred-Year Treaty). Under this contract, electricity producers agreed to purchase an average of 33 MT of domestic hard coal per year over a ten year period (1978 to 1987) in exchange for a government subsidy to compensate for the difference in the producers' cost of purchasing domestic coal rather than imported coal or oil. In 1981, the contract was extended to 1995 and the purchase quantities were increased to 40 MT in 1985, 45 MT in 1990 and 47.5 MT in 1995 (Lucas, 1985). For the first 11 MT of domestic coal used, the industry is compensated for the difference between the cost of domestic and imported coal. For the next 22 MT, it is compensated for the difference between the cost of domestic coal and imported oil, as long as the price of domestic coal exceeds the cost of imported oil. Domestic coal use above those quotas is not compensated (Lucas, 1985). Under this contract, electricity producers are allowed to burn imported coal. Through 1987, they could burn an amount of imported coal equivalent to no more than half the domestic coal burned. After 1987, the permitted portion is one to one (Lucas, 1985).

To finance this subsidy to the coal industry, the government taxes electricity use, amounting to an additional 4-5% of the consumers' electricity bill.[10] The revenues from this tax, called the Kohlepfennig, are paid into a fund called the Power Generation Fund (or literally, the Fund to Guarantee Coal Use) from which the subsidies are paid.

To meet electricity demand immediately following the 1973 crisis, natural gas was used to displace most of the oil-fired generation. Oil-based generation fell to less than one-quarter of its 1973 level by 1975, only to return to the 1973 level in 1976. Since 1976, oil-fired generation has declined steadily, being replaced by nuclear and coal-fired generation. The Federal government had extensive, long term plans for nuclear power to accommodate new growth in electricity demand. In the 1973 energy program, the federal government anticipated that installed nuclear capacity would amount to 45 GW or more in the 1980's. The public opposed this proposition and due, in large part, to the efforts of a powerful, broad-based anti-nuclear movement, nuclear capacity had reached less than half this magnitude by 1986. Since 1977, no nuclear construction permits have been granted. With the nuclear program on hold, and electricity demand growing, other resources were required for electricity generation; but the Federal government has maintained that the "other resources" should not be oil. As the government has held to this position by honoring the Jahrhundertvertrag, the German economy has been adversely affected. Prior to 1986, oil was more expensive and foreign coal was cheaper than domestic coal. Thus, the government was only required to compensate the utilities for using domestic coal rather than foreign coal. Since the oil price collapse in 1986

[10] This cost is entered on consumers' bill separately from the electricity charges, in order to to "disguise this government inspired distortion of free market costs within their tariffs." (Lucas, 1985)

however, oil has been less expensive than domestic coal and the government has also had to compensate the utilities for this difference in cost as well.

ITALY. Of the five countries under study, Italy is the only one in which the amount of electricity generated with oil has remained at nearly the same level since 1973. This is due largely because Italy has no indigenous resources to replace oil-fired generation. Secondarily, over 1/3 of Italian generation capacity was relatively new oil capacity and thus represented a large capital investment.

Italy did not only rely on oil as an energy source. Because Italy posessed one-third of European oil refining capacity in 1973 (G. Pireddu, personal communication), they also depended on flows of oil for industrial revenue. Actually, Ente Nazionale per l'Energia Elettrica (ENEL), the national electric utility, relied so heavily on oil because the large Italian oil refining industry made cheap heavy fuel oil readily available. This politically powerful refining industry was partially responsible for inhibiting the adoption of nuclear power.

The Italian nuclear power program began in the 1950's, and has led to the construction of 4 nuclear power stations, three of which are prototypes from the 1960's. In the 1960's and early 1970's, pressure from the refining industry prohibited the expansion of the program (G. Pireddu, personal communication). Since the oil crisis in 1973, Italian national energy plans have included large increases in nuclear and coal-fired electricity generation. However, increasing popular opposition has prevented these plans from being realized. In 1987, a referendum was passed that put a moratorium on nuclear power construction. The 1988 Italian National Energy Plan is the first this decade that excludes nuclear power from electricity resource generation plans.

Thus, oil has continued to be a dominant fuel for electricity generation. Since 1973, new growth in electricity demand has been met through increased coal-fired generation in polyvalent stations. In order to decrease dependence on oil, and thus increase stability of power supply, a law was passed in the mid-1970's that required all new conventional thermal power stations to be constructed to burn at least two fuels.

ENGLAND & WALES. Nearly since its formation, the national electric utility, the Central Electricity Generating Board (CEGB), has been required to purchase British coal for generation. The rationale is two-fold: Coal is E&W's largest indigenous energy resource (a secure, reliable energy supply, not subject to international politics) and the industry that has emerged around it requires a vast amount of labor. However, problems arise because E&W's hard coal has always been expensive (over twice the world coal price, on average). This high fuel cost translates to high electricity prices, which in turn, have restricted the growth of industry relative to their international counterparts who have benefited from cheap electricity. In order to ameliorate this problem, the CEGB announced the beginning of a nuclear program. The plan was to substitute nuclear power for coal-based electricity generation, anticipating that low nuclear generation costs would decrease the average cost of electricity.

After the oil crisis in 1973, the nuclear program assumed a greater importance. Throughout the 1970's, nuclear generation replaced oil instead of the coal based generation it had been intended to displace. Also, much of the oil-fired generation was replaced by increasing the load on existing coal plants. However, in February of 1974, just after the curtailment of oil supplies and the corresponding price rise, the E&W was hit by two more crises: the Electrical Power Engineers' Association banned out-of-hours working, and the National Union of Mineworders banned overtime (Evans and Dowlatabadi, 1982). The latter crisis escalated into a strike lasting for several weeks. With coal supplies unavailable, the CEGB was forced to increase oil use in generation in spite of the recent price escalation. Although this episode only lasted a few weeks, the value of the oil-based generation capacity was not forgotten, as articulated by the Electricity Council in their 1984 Development Plan:

> Although oil fired plant is expensive to operate, the large modern units are being retained to meet a probable longer term capacity need, to maintain primary fuel diversity, and to cover unexpected increased in demand, coal price escalations or oil price reductions (Electricity Council, 1984).

Between 1970 and 1975, 8 GW of nuclear capacity, all Advanced Gas-cooled Reactors (AGRs), were commissioned, but only 2 GW were actually constructed. After much oscillating, the AGR program was aborted by the late 1970's due to design and construction problems. A new nuclear program was not eagerly pursued because electricity demand in the 1970's slowed dramatically and E&W found themselves with excess capacity. Electricity demand declined due to increased energy costs, particularly coal prices, which were steadily rising as labor costs increased. New, cheap natural gas became an attractive alternative to increasingly expensive electricity in industry and the residential sector.

By the 1980's, coal and new nuclear generation had displaced oil-based electricity generation. Depressed electricity demand and the failure of the AGR program left CEGB with still no substitute for expensive coal-based generation. This situation was dramatized by the coal miners strike in 1984 that severely curtailed domestic coal supply. In response, E&W imported coal to substitue for domestic coal and fired up idle oil capacity to replace coal-fired generation. The details and implications of this return to oil-fired electricity generation will be discussed thoroughly in the next two sections of this report.

The goal of a strong nuclear power program was not abandoned, and in 1983/4 E&W embarked on a new program based on Pressurized Water Reactors (PWRs). In January 1983, a Public inquiry was initiated to consider the construction of a PWR at Sizewell B. In 1987, the decision to commence was made. The CEGB hoped to follow this plant up with "a minimum of four or five near-identical stations" (Electricity Council, 1984/5).

SWEDEN. The Swedish government initiated its nuclear power program in the mid-1950's. Since then, the government has supported the program to reduce dependence on imported oil-based generation (Lucas, 1985) which was increasingly being used to meet new demand (hydro-power resources could not be harnessed fast enough to accomplish this, nor were there ultimately enough to meet projected electricity demand.) Industry and the electric utilities (both public and private) supported the nuclear program for commercial reasons. Due to the problems with, and the ultimate failure of, the domestically developed Boiling Water Reactor (BWR) design, and private and public ambivalance over using American light water designs, the first Swedish nuclear power plants did not come on line until the early 1970's.

Unlike other industrialized countries in the same predicament — no indigenous conventional fossil fuel resources — Sweden did not pursue a coal policy. The reason for this seems to be its vested interest in protecting the purity of expansive inland waters, thus maintaining ecological stability.[11] The lakes and rivers are poorly buffered and can be acidified by sulfur emitted through coal combustion. In addition, nuclear power, thought to be a clean and relatively inexpensive resource, appeared to be an attractive alternative to coal use.

Oil-fired electricity generation had been increasing since the early 1960's, even more rapidly since 1967, to accommodate the rapidly expanding electricity demand by the

[11] Refer to Lucas, 1985 for a discussion of the historical roots of Swedish concern for the environment.

industrial and residential sectors, and to fill in for nuclear capacity that was under construction. In addition to having 20% of its electricity generated with oil in 1973, Sweden's electricity imports from Denmark and Norway were severely curtailed due to those countries' own problems arising from the crisis. With hydro-power at normal low levels (the crisis occurring in October, the fall during which water flows are lightest), and only minimal alternative generation sources, Sweden's first response was to initiate an energy savings campaign and establish restriction on electricity use (Wilson *et al.*, 1989).

The long term policy regarding oil generation remained the same: existing oil capacity would continue to be used, but progressively less intensively. Oil-based generation would be replaced with, and new electricity demand would be met by, nuclear power and cogeneration (mostly coal based, in industry and the district heating sector).

Nuclear power generation dramatically expanded in 1975, exceeding conventional thermal (mainly oil) generation for the first time. This trend continued, and by 1980, oil-fired generation had nearly been eliminated.

In 1980, a public referendum was passed that mandated the complete phasing out of nuclear power generation by 2010. Between 1980 and 1986, however, no concrete plans were made for phasing out nuclear plants. Nor has the government decided what energy sources will replace nuclear power. Electricity generation proceeded normally. Then, after the accident at Chernobyl in Spring of 1986, studies were commenced and passionate public and private debate emerged. Still, the role of oil-fired generation remained minimal.

In the period since 1973, policy changes with regard to oil-based electricity generation have been made in all five countries and notable changes in the amount of electricity generated with oil have occured in all countries except Italy. For France and Sweden, the trend away from oil-based generation began prior to 1973, but the rate of change was increased in response to the oil crisis in 1973. In Germany, England & Wales, and to some extent Italy, the shift away from oil appears to have begun in direct response to the 1973 oil crisis. By 1986, the amount of electricity generated with oil had declined by over 65% in all countries but Italy.

The next section describes the state of electricity supply, particularly the role of oil-based generation, in 1986 and contrasts this situation to that of 1973.

5. Electricity Generation in 1986: The Role of Oil

Electricity demand growth slowed during the 1970's. After 1973 however, electricity use grew faster than total energy demand. As a result, electricity's share of total energy demand has increased: Between 1973 and 1986, electricity demand had grown from 9% to 16% of total final energy demand in France, 11 to 15% in West Germany, 10 to 14% in Italy, 13 to 15% in England & Wales, and 17 to 30% in Sweden. Growth of electricity demand in each country has been largely driven by increased use in the residential sectors for space heating and miscellaneous electric appliances.

With electricity's increasing significance in energy supply, the reliability of electricity supply, and thus the availability of the primary fuel inputs, is more important than ever. To this end, oil's role in electricity generation has been greatly diminished except in Italy, where it has been slowly reduced. By 1986, oil use for electricity generation amounted to only 7% of these five countries' oil requirements, down from 13% in 1973. The total oil requirements of these five countries declined from 514 MT to 381 MT between 1973 and 1986: thirty percent of this decline was due to the reduction of oil use for electricity generation.

In addition to decreasing their reliance on oil, these countries diversified their oil import sources and proportionately decreased their import reliance on OPEC member countries. Since 1983, the North Sea has succeeded the Middle East as the single largest source of Europe's oil supply (Pohl, 1988). Table 6 contains data on the amount and fuel mix of electricity generation in 1986.

Since 1973, oil-based electricity production has declined by 92% in France, 74% in England & Wales, 68% in Sweden, 64% in Germany, and now contributes less than 5% of these countries' electricity supply. In Italy, the amount of electricity generated with oil has declined by only 14%, and oil is still the largest single energy source for power generation. In the other countries, the bulk of generation is based on coal and nuclear power. Hydro power production has increased in France and remains important in Sweden.

TABLE 6:
1986 Electricity Generation By Fuel[1,2]

	France	Germany	Italy	E&W	Sweden	Total
(TWh)	346.3	408.3	192.4	229.5	133.6	1292.5
Oil	5.3	12.5	75.3	12.8	3.9	109.8
Natural Gas	3.0	25.4	26.9	0.0	0.0	55.3
Other Gases	*	9.0	4.3	0.2	1.0	13.5
Coal	26.6	218.9	27.9	178.5	*	463.4
Nuclear	241.4	119.6	8.8	37.5	67.0	446.2
Hydro	64.4	18.6	44.5	0.5	59.8	186.8
Geothermal	0.0	0.0	2.8	0.0	0.0	2.8
Other	5.6	4.3	1.9	0.0	1.9	13.7
(%)	100.0	100.0	100.0	100.0	100.0	100.0
Oil	1.5	3.1	39.1	5.6	3.7	8.5
Natural Gas	0.9	6.2	14.0	0.0	0.0	4.3
Other Gases	*	2.2	2.2	0.1	0.0	1.0
Coal	7.7	53.6	14.5	77.8	*	35.9
Nuclear	69.7	29.3	4.6	16.3	50.1	34.5
Hydro	18.6	4.6	23.1	0.2	44.8	14.5
Geothermal	0.0	0.0	1.5	0.0	0.0	0.2
Other	1.6	1.2	1.0	0.0	1.4	1.1

1) Net generation for France and E&W; Gross generation for Germany, Italy and Sweden.
2) Refer to Appendix 3 for breakdown of energy resources included in each fuel category for each country. Refer to References for data sources.
* - included in another category, see Appendix 3.

This decline in oil-based electricity generation is not due to the retirement of oil-using capacity. To the contrary, oil-using capacity has increased slightly over 1973 levels. Table 7 contains a breakdown of generation capacity by fuel.

TABLE 7:
1986 Installed Generation Capacity by Fuel[1,2]

	France	Germany	Italy	E&W	Sweden
(GW_e)	92.5	100.6	67.3	56.5	33.0
Oil	6.7	12.2	18.3	10.3	3.7
Natural Gas	0.8	13.8	0.4	0.0	0.0
Other Gases	^	*	0.1	3.0	1.7
Coal	7.9	33.9	9.0	31.1	*
Mixed	8.4	12.9	19.7	4.9	0.0
Coal/Oil	4.4	9.3	5.5	4.5	0.0
Coal/Gas	1.0	3.6	0.0	0.4	0.0
Oil/Other	3.0	*	14.2	0.0	0.0
Nuclear	44.7	19.9	1.3	5.0	9.6
Hydro	23.1	6.7	18.0	2.2	15.8
Geothermal	0.0	0.0	0.5	0.0	0.0
Other	0.9	1.2	0.0	0.0	2.2

1) Net capacity for France, E&W and Sweden; Gross capacity for Germany and Italy.
2) Refer to Appendix 3 for breakdown of energy resources included in each fuel category for each country. Refer to References for data sources.
* - included in another category, see Appendix 3.

Oil-based electricity generation has declined because oil-using capacity is now utilized much less intensively than it was in 1973. Table 8 contains oil capacity factors[12] for all five countries for 1973 and 1986.

TABLE 8:
Oil Capacity Factors 1973 & 1986

	France	Germany	Italy	E&W	Sweden
1973 mono-oil	0.76	0.61	0.79	0.50	0.21
1986 mono-oil	0.09	0.12	0.47	0.14	0.12

The capacity factors in Table 8 relate the dramatic decline in the intensity with which the oil capacity is utilized. By 1986, oil capacity factors had fallen dramatically. With capacity factors of between 0.07 and 0.14 for all countries except Italy, oil capacity is no longer filling base load but is being utilized to meet peak demand.

[12] These capacity factors were calculated using the monovalent oil capacity only and thus, slightly overestimate the intensity of use of the monovalent oil capacity because some electricity generated with oil was generated in polyvalent plants. For discussion of capacity factor calculation and usage, see Appendix 2.

The following is a synopsis of the role oil in electricity generation in 1986, for each of the five countries.

FRANCE. By 1986, France's electricity generation was based primarily on three resources: nuclear (70%), hydro (19%), and coal (8%). Oil-based electricity contributed less than 2% of electricity generated. Primary oil requirements for oil-fired generation amounted to 1.3 MT in 1986, approximately 1.5% of total national oil demand. By 1985, France still imported most (96%) of its oil demand, of which the OPEC share was 52%, (versus 80% in 1973). Thus, the electricity supply was no longer nearly as vulnerable to oil supply disruptions as it was in 1973.

All this oil based electricity was generated by 6.7 GW of monovalent oil capacity and 8.4 GW of mixed-fired (oil + other) capacity (Table 7). The monovalent oil capacity declined by 50% from the 1973. Half of the missing capacity was reconverted to coal-fired capacity, and the rest was retired. The oil capacity factor was 9% (Table 8). Producing only 5.3 TWh, or less than 2% of electricity generated in 1986, oil-based generation was used very infrequently, only when absolutely necessary to help meet peak demand.

ITALY. In 1986, Italy's electricity was still produced largely with oil (39%) and hydro-power (23%). Gas and solids have significantly increased their roles in generation, replacing oil. As was the case in 1973, Italy has the most oil-dependent electricity supply of all five countries. Italy now imports 97% of its national total oil demand, 59% from the Middle East (nearly unchanged since 1973); thus, electricity supply is still quite vulnerable to disruptions of oil.

Italy has 18.3 GW of monovalent oil plants and 20.3 of polyvalent oil plants. The monovalent oil capacity is larger than it was in 1973 by about 6 GW, because plants under construction in 1973 have since come on line. With 34% of its generation capacity able to use more than one type of fuel (polyvalent capacity more than doubled since 1973), Italy now places even more importance than in 1973 on immediate, short-term fuel-switching capability. From Table 8, we see that the oil capacity factor is now 47%, so oil plants are still being used to meet base/intermediate load, although they have been pushed farther back in the order of dispatch, and so are not used as intensively.

ENGLAND AND WALES. England and Wales' (E&W) electricity generation is based primarily on two resources: coal (79%) and nuclear (16%). Oil-based electricity comprised 12.8 TWh or 5.6% of the total electricity supply. Primary oil requirements for oil-fired generation amounted to 5 MT in 1986, approximately 6% of national total oil demand. Since 1973 however, the United Kingdom has gone from importing nearly all its oil to becoming a net exporter of crude oil in 1986. Thus, currently the electricity supply is not very vulnerable to oil supply disruptions.

This oil based electricity was generated by 10.3 GW of monovalent oil capacity and 4.5 GW of mixed-fired (oil + other) capacity. The monovalent capacity has grown by 1 GW since 1973. However, actually 7.6 GW of the monovalent capacity existing in 1986 had come on line since 1976, and old capacity was retired, eliciting a net increase of 1 GW. The oil capacity factor was 14%. In E&W, oil-based generation filled peak load in 1986.

WEST GERMANY. By 1986, electricity generation in West Germany was still heavily weighted on one fuel base: 55% of the electricity produced was generated with lignite and bituminous coal. However, the remainder of the electricity was generated primarily with nuclear power (29%) instead of the oil used in 1973. For the 12.5 TWh of oil-based electricity produced, 2.7 MT of oil were required, representing only 2.3% of the total national oil demand. In 1986, West Germany's oil supply was comprised of 95% net imports, over 56% of which comes from OPEC. Thus, West Germany has significantly reduced the vulnerability of its electricity supply to disruptions due to changes in the availability of foreign oil.

Now, West Germany maintains 12.2 GW of monovalent oil capacity and 9.3 GW of bivalent oil-using capacity. This is 4.6 GW more monovalent oil capacity than existed in 1973. This oil capacity was under construction pre-1973. The capacity factor for the monovalent oil capacity declined from 61% in 1973 to 12% in 1986. Instead of filling base load, oil generation was used to meet peak load.

SWEDEN. The resource base of electricity generation in Sweden is now split between two fuels: 50% of the electricity produced is generated with nuclear power and 45% is generated with hydro power. Oil-based generation accounts for less than 4% of electricity generation. The 0.4 MT of oil required for electricity generation represents about 2% of the national total oil demand. Sweden has no indigenous oil resources and thus imports all of its oil supply. In 1986 however, only 18% of Sweden's oil came from OPEC, down from 40% in 1973. Currently, Sweden's electricity supply would not be greatly affected by a disruption of oil supplies.

Sweden has 3.7 GW of monovalent oil capacity, remaining constant or declining slightly since 1973.[13] With a capacity factor of 12%, down from 21% in 1973, oil capacity has been pushed back in the order of dispatch, and is now used primarily to generate electricity during peak demand, to follow load, and to compensate for fluctuations in the amount of hydropower available as precipitation levels vary from year to year).

In France, West Germany and England & Wales, the role of oil changed from base to peak between 1973 and 1986, and consequently, oil-based production decreased dramatically. In Sweden, the role of oil-based generation stayed the same, used at peak and to follow load, but it was not used as often or as intensively. Oil capacity was pushed back in the dispatch order and thus the amount of oil-based production declined by 50%. In Italy, oil's role in electricity generation stayed the same -- to fill base load -- but was pushed back in the dispatch order, so actual oil-based production decreased only slightly.

What did stay the same over the years? In all the countries except France and Sweden, the monovalent oil capacity remained in place and even increased slightly over the 1973 value. The additional oil capacity is the result of oil capacity coming on line in the mid to late 1970's that had already been under construction in 1973. Polyvalent oil capacity remained constant also, with the exception of Italy, where all new capacity must be polyvalent by law (enacted in the 1970's). Most of this capacity is operating at some level or is in various stages of reserve: spinning, stand-by, or standing. With 1986 capacity factors between 3-22%, this capacity is not used nearly as intensively as it *could* be. In the next section we explore how much electricity this oil-based (including polyvalent plants) capacity *could* generate.

[13] Conventional fossil fuel capacity for Sweden can not be broken down by fuel but, knowledgeable sources indicate that no additional oil capacity was constructed.

6. Potential Levels of Oil-based Electricity Generation

By using other energy resources, supply security problems associated with oil have been averted. Nuclear energy and coal have replaced oil in base-load electricity generation since 1973. In addition, the range of resources used for electricity generation has expanded, as more gases and miscellaneous solids have augmented the basic generation fuels. Unfortunately though, these resources bring with them the same problems and in some cases, new and different ones.

In addition to the fuel/resource-specific problems and/or potential problems (which range from catastrophic to chronic) that are associated with current generation fuels (noted in the introduction), typical mechanical difficulties that periodically plague stations cause temporary loss of load and thus affect the countries'/utilities' ability to supply electricity. In the event of a disruption of electricity supply, the existing and relatively idle oil-using capacity could be used more intensely to generate a back-up supply of electricity. In this section, we quantify the maximum amount of electricity that *could* be generated with this capacity, and the corresponding *potential* oil demand. We find that the electricity generation sector, with the necessary infrastructure in place, could indeed trigger an immediate, sharp rise in oil demand.

As discussed in the previous section, oil capacity is still operable in all of the countries. Although operable, the intensity with which it can be used is limited by the wear that has come with age. The "first life" of an oil-fired plant is approximately 30-40 years (Gorzelnik, 1987). At the end of that period, the plants can be refurbished (which includes replacing boiler piping components and overhaul of turbine and generator, for example) thereby extending the working life of the plant by 10-15 years (Gorzelnik, 1987). E&W has the newest oil-fired capacity of all the countries under study. Much of this oil-fired capacity was under construction in 1973: 72% of oil-fired capacity came into operation since 1976 and the remaining capacity was built prior to 1965. Indeed, the oil-fired capacity is E&W's newest capacity. Over 54% of France's oil-fired capacity first came into operation between 1970 and 1973. Approximately 35% of Germany's oil-fired capacity came into operation since 1973, with most of the remaining oil-fired capacity having been built between 1966 and 1973. Most (68%) of Sweden's oil-fired capacity became operable between 1966 and 1973. The rest is older. Well over half Italy's oil-fired capacity came on line between 1970 and 1973. Except for E&W, the oil-fired generation capacity in these countries is around 15 years old (in mid-life), and thus has 15-20 years of service before refurbishment or retirement. This conclusion is supported by the fact that this capacity has been maintained but has not been used in base load for the last 10 years and thus is not subject to heavy wear.

The vintage and use history of the oil-fired capacity indicates that in the short term -- several months to several years -- this capacity could be used more intensely and produce more electricity. Furthermore, these countries' resource plans indicate that only minimal conversions or decommissioning of oil capacity will occur before 2000 and thus most of the oil capacity will remain in place and available in the short-term.

In this section, we calculate the maximum *potential* amount of oil-based electricity that could be produced by the oil-using capacity. In England & Wales, the maximum level of power production by oil-using capacity has been recently demonstrated and in Sweden, it has been estimated by governments/utilities who anticipate making use of it in the future. In France, Germany and Italy, we derive an estimate from both general and country-specific characteristics of the capacity. We calculate this potential in two ways, in order to reflect two different scenarios in which oil-using capacity might be used. In the first case, we apply the relevant capacity factors to the monovalent oil-using capacity only. In this instance we want to see how much electricity this back-up monovalent oil capacity could produce if back-up generation capacity was needed to replace current base-load capacity. Such will be the situation in Sweden when nuclear power is phased out and would be the situation if nuclear capacity in any of these countries became disabled. In the second case, we apply the relevant capacity factors to all the oil-using capacity -- the monovalent oil capacity and the polyvalent capacity that uses oil. This calculation elicits a maximum use of oil for power generation. If another fuel became unavailable, or if the price of oil remained low enough to attain a competitive advantage over other fuels, oil could be used in the polyvalent plants (replacing the scarce fuel) and monovalent oil capacity could be used instead of monovalent capacity using the scarce fuel. This was the situation in which E&W found itself during the 1984 coal labor strike.

Table 9 contains the principle elements of our calculations of maximum *potential* oil-based electricity generation.

TABLE 9:
Potential Oil Demand
for Electricity Generation

	France	W. Germany	Italy	E&W	Sweden	Total
1986 Capacity Factor	0.04	0.07	0.23	0.08	0.15	
Highest Feasible Capacity Factor	0.60	0.60	0.60	0.79	0.62	
1986 Oil-using Capacity (GW)	14.1	21.5	38.0	15.2	3.7	92.5
monovalent	6.7	12.2	18.3	10.3	3.7	51.2
polyvalent	7.4	9.3	19.7	4.9	0.0	41.3
Potential Oil-fired Electricity Generation (TWh)						
CASE 1: Monovalent Oil Only	35.2	64.1	96.2	71.3	20.1	286.9
CASE 2: All Oil-using	74.1	113.0	199.7	105.2	20.1	512.1
Compared to Actual 1986 Generation (*Potential*/Actual Production, %)						
CASE 1: Monovalent Oil Only	6.6	5.1	1.3	5.6	5.2	2.6
CASE 2: All Oil-using	14.0	9.0	2.6	8.2	5.2	4.6
1986 National Oil Demand (MT)	86.0	116.7	81.9	77.0 (UK)	18.8	380.6
Potential Additional Oil Demand (over 1986 actual) (MT)						
CASE 1: Monovalent Oil Only	7.2	11.1	4.9	21.6	1.7	46.5
CASE 2: All Oil-using	16.9	21.6	26.1	33.8	1.7	100.1

Sources: For national oil demand — OECD Energy Balances, 1987, 1988.

We have calculated the annual *potential* generation by multiplying the 1986 monovalent oil capacity in Case 1, and the sum of all oil-using capacity in Case 2, by the highest feasible capacity factors and then multiplied by 8760 hours per year.[14] From this calculation, we can see that maximum *potential* oil-based electricity generation exceeds actual 1986 oil-based electricity generation by a factor of 1.3 to 6.6 in Case 1 and 2.6 to 14.0 in Case 2 (see Figure 6). The five-country *potential* oil generation is greater than the actual 1986 oil-based electricity production by a factor of almost 3 in Case 1 and by nearly 5 times in Case 2 (see Figure 7). This translates to an oil demand increase of 46.5 MT (11%) over actual 1986 national oil demand in Case 1, and in Case 2, an additional 94.1 MT (25%).

ENGLAND & WALES. In 1984, coal miners went on strike in England & Wales. This strike lasted for nearly a year, during which domestic coal supplies dwindled to half the normal level. The CEGB was in need of alternative generation resources because they had been using coal to generate nearly 82% of the electricity that they produced. The principal alternative was oil, augmented by more electricity imports from the South of Scotland Electricity Board. Between 1983 to the end of the labor strike in early 1985, oil based electricity generation leaped from 6.6 to 80.9 TWh, or 3.1% to 37.9% of total production. This increase in oil-based generation was possible simply by increasing the load on all oil-using capacity. The capacity factor increased from 0.08 to 0.79.

In 1984, E&W demonstrated the ability to dramatically increase the amount of oil-based electricity that can be generated, and sustain the increased power level for nearly a year. Thus, it is highly probable that this same performance could be achieved 3-4 years later. Calculations in Table 9 indicate that if the 1986 oil-using capacity were used at a 0.79 capacity factor, the amount of oil-based electricity generation could be increased to a factor of 8.2 times 1986 actual oil-based electricity generation. This would increase the United Kingdom's 1986 oil demand (77 MT) by 33.8 MT, shifting oil demand for electricity generation from the actual 9.6% of the United Kingdom's 1986 total oil demand to 53.5%.

SWEDEN. Since 1985, the Swedes have been following through on their 1980 declaration to phase-out nuclear power by year 2010. The government is researching energy resources that Sweden could use in the long term to replace nuclear power and provide a basis for future electricity supply. Public pressure has spurred debate over whether this phase-out should be accomplished as as early as 1997. As a consequence, the government is evaluating the ability of the existing generation resources to displace nuclear power as it is gradually phased-out, thereby acting as a bridge until the country decides on the long-term replacement strategy. Here lies a new role for oil in Swedish power generation. The existing oil-using capacity could be utilized more intensively to displace some nuclear power. In the government report, "After Chernobyl" (Statens Energiverk, 1987), the Expert Group established by the Swedish Government to analyze the safety of nuclear reactors, estimates that 20 TWh of electricity could be produced using existing oil capacity,. This amount of oil-based production requires that the oil-using capacity be operated at a 0.62 capacity factor. The *potential* level of oil-based production is over 5 times the actual 1986 production, and translates to an additional 1.7 MT of oil. If this increased oil-based generation occurred, oil use for electric power generation would then account for 9% of Sweden's 1986 total oil demand (18.8 MT), up from the 1986 actual share of 2.1%.

[14] NOTE: The capacity factors in Table 9 are calculated using both mono- and polyvalent oil capacity and thus, do not correspond with the oil capacity factors presented in Table 8 which are calculated using monovalent oil capacity only. See Appendix 2 for further explanation.

For France, W. Germany, and Italy, we have selected a capacity factor of 0.6 to represent the maximum intensity at which the oil-fired capacity could be run. This is an estimate based on several considerations. First, the Electric Power Research Institute uses 0.65 as a lifetime levelized capacity factor for base-load oil-fired plants (Electric Power Research Institute, 1985). We use this average as a conservative estimate of mid-life utilization capability, since most of the capacity involved is mid-life (or younger) and has not been used in base-load for much of its existance. Second, the values of 0.62 for Sweden and 0.79 for the England & Wales serve as a guide to what is possible. The Swedish oil capacity being the oldest, on average, and England and Wales' capacity the youngest, it is probable that the oil capacity of France, W. Germany, and Italy, with average vintages in between these endpoints, could be used at a capacity factor somewhere in the range of 0.62 and 0.79. Although this capacity factor of 0.6 does not reflect the individual characteristics of the plants involved (such as plant technology[15], peculiarities with specific stations, etc.), we believe it is a reasonable, even conservative, approximation of the maximum possible level of utilization.

FRANCE. With its relatively young and under-utilized oil-using capacity, France has an enormous oil-fired power generation *potential.* Using 0.6 capacity factor, oil-based electricity production, and hence oil requirements, could increase by a factor of 14 times the actual 1986 oil-based electricity production. An additional 7.2 MT of oil would be required to generate this amount of electricity, raising the *potential* share of oil use for power generation to 21% from the actual 1986 portion of 1.5%. This additional amount of oil would increase the share of oil use in power generation from the actual 1.5% of 1986 national oil demand (86 MT) to 25.3%.

WEST GERMANY. Second only to France in both the amount of oil-using capacity in place and the low intensity of use, West Germany could increase its oil-based electricity production by a factor of 9 over actual 1986 annual production values if the capacity were run at 0.6 capacity factor. The 21.6 MT of oil necessary to generate this amount of of additional electricity represents an 18.5% increase over West Germany's actual 1986 total national oil demand of 116.7 MT.

ITALY. Despite the large amount of oil-based electricity generated in 1986 (75.8 TWh or 39.4% of total electricity generation), a tremendous potential for more oil-based generation still exists. At a 0.6 capacity factor, oil-using capacity could generate 2.6 times more oil-based electricity than was actually generated by this capacity in 1986. The 26.1 MT of oil that would be required above the actual 1986 demand, translates to an 31.9% increase over 1986 national oil demand.

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[15] While the monovalent oil capacity consists of base-load steam plants using heavy fuel oil, the polyvalent oil capacity includes some peaking gas-turbine units, especially in France and Italy. The data does not allow a breakdown by technology. However, we estimate than not more that two-thirds of the polyvalent capacity in Italy and less than half of the polyvalent capacity in France is comprised of peaking plants. The inclusion of peaking capacity in the calculation of potential oil generation will cause the 0.6 capacity factor be excessive. However, we believe that 0.6 for the base-load units is conservative and that these two effects will counteract one another.

7. Potential Oil-based Generation: Will it be Realized?

In the previous section, we demonstrated that the oil-using infrastructure currently in place in the power generation sectors of these countries could allow a huge increase in oil demand: 94.1 MT or 1.9 MBDOE. This increase in the oil demand of only five OECD countries would raise the total 1986 OECD oil demand by nearly 6%. Since generation plans for the five countries indicate that only about 10% of existing monovalent oil capacity will be converted or retired by the turn of the century, this potential oil demand will be relevant for at least the next decade. We anticipate that similar calculations for all OECD countries would yield a potential increase in oil demand that could indeed affect world oil markets.

However, it is highly improbable that each of these countries would concurrently achieve their own maximum potential oil use in power generation. Even though the capacity exists and could be utilized much more intensely, economic considerations such as relative fuel prices and individual plant generation costs, legal restrictions, and political pressure could limit each of these countries' achievement of their maximum potential level of oil-based electricity generation. Based on these considerations, we have determined that in at least one of these countries, the maximum amount of oil-based electricity generation will actually be realized, in others, oil-based generation is likely to increase over 1986 levels, and in still others, oil use for power generation is being eliminated entirely. In this section, we discuss the circumstances under which this increased oil use might occur.

FRANCE. According to EDF, oil use in power generation is a thing of the past. The reason is two-fold: Still dependent on imports for 55% of its energy needs (Chapuis, 1988) power generation is one sector where energy, especially oil, independence can be achieved. Second, nuclear power, having moved in during the 1970's to replace oil-based electricity generation in base-load, is now an industrial venture for the French. The industry, including all phases of the nuclear fuel cycle and power plant manufacturing, construction and operation, is an integral part of the French economy, a major domestic employer as well as source of revenue for the French government. With this large economic and political investment in nuclear power, and the current state of excess base-load nuclear capacity, increased use of oil for electricity generation cannot be justified.

Oil-fired generation is expected to continue to decline, in spite of declining oil prices. Nicole Jestin Fleury (Fleury, 1986) discusses the competitive position of oil-fired generation compared to coal and nuclear power in the face of declining crude oil prices. She concludes that at a price of $19-$24 per barrel of crude oil, base-load electricity could be generated less expensively by using existing oil capacity than by building new coal capacity. The price of crude would have to fall to $12-$17/barrel for existing oil capacity to beat out new nuclear capacity. Thus, with oil prices at between $14 and $17 per barrel today, it appears that oil-based generation could be justified based on generation costs. Political values (energy independence) and the larger economic considerations regarding the role of the nuclear industry in the French economy remain the dominant forces limiting the potential for oil-based electricity generation.

As of December 1987, EDF has 13 GW of nuclear capacity under construction (Electricite´de France, 1987). It is expected that there will be few commitments to new nuclear installations in the years to come (Chapuis, 1988) In addition, gas turbines using natural gas will be brought on to meet the rapidly increasing seasonal peak demand, growth which is largely due to increases in electric space heating. No significant expansion of coal-fired capacity is planned.

Several GWs of existing oil capacity have been scrapped since 1984 and ~2 GW more have been mothballed (Fleury, 1986). No new oil capacity will be built. In the future, oil capacity will be used solely as a back-up, dispatched after coal capacity. Realization of the potential 9.1 - 16.5 TWh of oil-based electricity generation is unlikely. Only the abrupt disablement of nuclear capacity could provoke the return of oil for power generation in France.

WEST GERMANY. Under existing law, increased oil use will not occur. Currently, government permission, which is required to build new oil capacity or to increase oil use for generation, will not be granted. Electricity producers, compensated for burning domestic coal under the Jahrhundertvertrag, have no incentive to burn oil regardless how low the price may fall. However, the Power Generation Fund, from which the electricity producers are paid, is seriously low, because decreasing oil prices mean that the government must pay the producers both the difference in the cost of domestic and foreign coal, and the difference between domestic coal and imported oil. If this situation persists, government policy may have to be modified, thereby opening the door for increased oil use. In the longer term, the growing opposition to nuclear power may favor increased oil use. When nuclear plants under construction are completed at the end of 1989, total nuclear capacity will be 24 GW. One project is now in the planning stages but its application for a license has been rejected by the state government of Hesse. "Further nuclear expansion does not look probable for the foreseeable future," (Hansen, 1988). The nuclear program has been held back due to stagnating electricity demand and strong public opposition. A possible source for replacing nuclear power (either for phasing out existing capacity or to accomodate new demand expected at the turn of the century) is imported coal. But environmental concerns -- effects of acid rain on forests, air quality and climate change -- arising in part from SO_2, particulates, and CO_2 emitted in power generation, cause many to question the wisdom of increasing West Germany's reliance on coal. In the light of this conflict, the relatively young oil-using capacity may find a larger role in electricity generation. It may be used to accomodate incremental increases in demand in the next decade or so, until the larger question is answered: what generation resource base will be adopted for the long term?

ITALY. The 1987 nuclear referendum put an end to the existing Italian nuclear power program. Thus, nuclear power will not displace oil generation (at least until the turn of the century, even if a new program using new technology were initiated in the near future). The proposed 1988 Italian National Energy Plan (Comitato Technico per l'Energia, 1988) indicates that coal will not displace oil either, as was previously proposed by other electricity generation resource plans of the 1980's. New environmental emission standards have discouraged the use of coal for power generation. According to the 1988 plan, natural gas will move in to meet the anticipated growth in electricity demand. By 2000, natural gas-fired generation is expected to triple. Oil generation is expected to remain constant over the next 5 years and then decline by 15-50%, depending on the rate at which electricity demand increases. Prior to 1995, Italy's electricity demand growth is anticipated to temporarily exceed supply capabilities. Thus, during this period, oil-based generation from monovalent oil plants may even increase. Continued oil use in power generation will enable ENEL and other producers to benefit from relatively low oil prices. Oil generation will constitute a fundamental part of the Italian electricity supply for the forseeable future. However, due to political concerns over heavy reliance on a single fuel and the fuel flexibility allowed by the large capacity of polyvalent plants, it is unlikely that the maximum potential oil-fired generation calculated in the previous section will be reached.

ENGLAND & WALES. The electricity supply system in England and Wales is now in the process of being privatized. In a government White Paper released in March 1988 (Secretary of State for Energy, 1988), the government's proposal for the future structure of the electric power industry was outlined. The CEGB will be split into two privately-owned generating companies. One company will consist of approximately 30% of CEGB's existing capacity, all of which will be non-nuclear. The second company will hold the remaining CEGB generating capacity. Under this scenario, electricity generation would be competitive and not regulated while distribution would be effected by 12 regulated but privately-owned distribution companies. This proposal stipulates that some portion of the electricity supplies procured by the distribution companies must be generated by nuclear power. The existing oil capacity would take on even more importance in the hands of private companies that will need to minimize generation costs in order to compete. Over half the CEGB's generation capacity is more than 30 years old. The oil capacity is newest of all the capacity: 72% is less than 15 years old and can produce relatively inexpensive electricity. Thus, in the face of privatization and competition in electricity generation, the existing oil capacity may be used more intensively than it is today.

The fate of the new nuclear program is still unknown. Although the go-ahead to commence construction of the first (Sizewell B) of up to six PWRs has been given, the public is ambivalent (political parties split: Conservatives for, Labor against) and some problems around fuel reprocessing and waste disposal programs have arisen (Bupp, 1987). If the nuclear program does not proceed as scheduled or is cancelled, and in light of the upturn in electricity demand in the United Kingdom, existing oil capacity may be used in the interim until a new strategy is devised.

SWEDEN. The 1980 referendum called for the phasing-out of nuclear capacity by 2010. The 1986 nuclear accident at Chernobyl acted as a catalyst, inducing the public to demand even an earlier date for the phase-out to be completed. In a study commissioned by the government, titled "After Chernobyl," released in 1987, three scenarios were considered in which the completion date for the phase-out varied from between 1989 to 2005. In the first two scenarios, the maximum potential oil-fired generation calculated in section 6 was required. In their third scenario, a level of oil-based electricity generation above actual 1986 levels was expected.[16] Today's lower oil prices (not accounted for in the "After Chernobyl" analysis) would decrease the economic strain associated with this relatively large anticipated amount of oil use. Thus, over the next 20 years, oil-fired electricity generation will most likely increase to 20 TWh, replacing nuclear power and acting as a bridge until a new, major electricity generation resource is selected.

8. Conclusion

In 1973, oil was the first or second most important energy source for electricity generation in the five countries analyzed in this report. By 1986, oil use for power generation had diminished by more than 50% (except in Italy). However, in all five countries, oil-using capacity has been preserved and will continue to be maintained. In all of the countries, oil-using

[16] We assume that these estimates for oil use have accounted for the need to have some generation capacity available to compensate for annual fluctuations in hydo-power, the role oil capacity has historically played.

capacity is maintained as a back-up generation source in the event of unexpected disruptions that prevent the use of principle base-load capacity. In all countries except France, oil may (will, in the case of Sweden) be used to meet new demand for an interim period if nuclear programs are delayed or cancelled.

In some countries, oil-based generation may soon increase above 1986 levels. In Sweden, oil-based generation will be used to bridge a supply gap that will result from the decommissioning of nuclear power plants in the absence of new generation capacity to replace it. Oil-fired generation could increase in England & Wales, due to privatization and delays in the nuclear program. In a competitive environment introduced through privatization, the relative youth of the oil capacity in conjunction with the current low oil prices, oil-based electricity generation may be seen to have a competitive atvantage, even replacing some coal-fired generation. Continued delays in the nuclear program would encourage the use of oil to bridge supply gaps until the nuclear capacity comes on line or a different generation source is selected. In Italy and Germany, oil-fired electricity generation will likely remain relatively constant. Unless German law changes, no additional oil-gased generation will occur. Only in France will oil-based generation decline.

Although oil-fired electricity generation may increase above 1986 levels in the near future in some countries, the maximum potential levels of oil-based generation calculated in this report will not be attained in any of countries *unless* a major electricity generation resource or technology suffers a severe, unforseen disruption. In the absence of such a disruption, institutional barriers against dependence on oil will preclude the realization of the existing potential. Nonetheless, the "hidden" potential for oil use in the power sector, represented by the existing oil-fired capacity, must not be forgotten. As institutions and political agendas evolve, so too might attitudes regarding oil use: world oil markets would follow.

9. Acknowledgements

We would like to thank the reviewers of earlier drafts of this report who provided helpful comments: Jon Koomey (LBL), Andrea Ketoff (LBL), Chris Marnay (LBL) and Didier Borderon (Shell International Petroleum Company); France — Michel Benard (EDF) and Christine Chapuis (EDF); W. Germany — Ebernard Jochem (ISI), Eckhard Schultz (VDEW), and Paul Suding (ENERWA); Italy — Giancarlo Pireddu (ENI); England & Wales — Nick Baldwin (CEGB) and David Newbery; Sweden — Jan Randers (KRAFTSAM) and Asa Sohlmann (Statens Energiverk). Special thanks to Jon Koomey for his diligent critiques and editing.

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APPENDIX I:

GLOSSARY

Available Capacity: See net installed capacity.

Back-pressure: A generator set driven by steam which, when discharged from the turbine, is applied for a purpose irrelevant to power production (such as district heating, process steam).

Capability, Gross & Net: Installed capacity excluding stations in "Reserve Category." Used by CEGB. Prior to 1982, capability = capacity; 1982 and after, capacity = capability + reserve. (E&W term)

Capacity Factor: Ratio of amount of electricity produced by a generating unit (or group of units, ie all units fired with a common fuel base) to the amount of electricity that the unit could have produced if it were operating at its maximum installed rating (or other specified measure of capacity, such as available capacity).

Electricity Generation, Gross & Net:
Gross - electricity generated minus electricity used by generating station.
Net - gross electricity supplied minus electricity used in pumping at pumped storage stations.

Electricity Supplied, Gross & Net: Same as Electricity Generation.

Excess Capacity: An ambiguous term. It is defined as the difference between an 'average reserve margin' and the actual reserve margin of a specific utility. This 'average' carries more meaning if it is a regional average than a national average.

Installed Capacity , Gross & Net:
Gross - the maximum continuous rating of the generating sets in the stations including auxiliary and stand-by sets, which are connected to the prime movers and to the busbars and are capable of use. Scrapped plants and any other plant that has been disconnected is excluded.
Net - Gross installed capacity minus generating station's own power consumption.

Load Factor: Ratio of consumption (production) within a given period of time (usually 1 year) to the consumption (production) that would result from continuous use of the maximum demand (peak) occurring within that period. Calculated for a specific class of users: industrial, residential, etc.

Monovalent Capacity: Generating plants that can utilize only one energy source.

Output Capacity: Net installed capacity minus any limitations of prime movers. (E&W term)

Plants in Reserve: Same as Standing Reserve. (E&W term)

Polyvalent Capacity: Generating plants that can utilize more than one energy source.

Rated Capacity, Gross & Net: Same as installed capacity.

Reserve margin: Available capacity beyond what is demanded at peak. Reported as a percent of peak demand.

Rotational Reserve: Same as Stand-by Reserve. (E&W term)

Spinning Reserve: Stations available for immediate (within minutes) dispatch.

Stand-by Reserve: Stations not in operation, but that can be brought into full operation in less than one month.

Standing Reserve: Stations not in operation, but that can be brought into full operation in several months to one year.

Transmission Capacity: The rated capacity in MW of a power line, accounting for limits imposed by transformers connected to it.

APPENDIX II:

Calculation and Usage of Capacity Factors

In this appendix, we explain the meaning/significance of the capacity factors, as calculated and used in this report. The capacity factor was calculated as follows:

$$Capacity\ Factor = \frac{TWh\ of\ oil\text{-}based\ electricity\ produced}{TW\ oil\text{-}using\ Capacity \times 8760\ hours\ per\ year}$$

The question arises whether to use the monovalent oil capacity in the denominator or all oil-using capacity (the sum of monovalent and polyvalent oil capacity). Using the monovalent only would tend to over-estimate the intensity with which the monovalent oil capacity was used because some portion of the oil-based electricity produced was likely generated by polyvalent capacity. The error is probably larger in 1986 than in 1973, because fewer polyvalent plants were burning less oil than in 1973. On the other hand, using the sum of mono- and poly-valent capacity seriously underestimates the intensity with which the monovalent oil capacity was used. Table A2 below, contains both calculations for 1973 and 1986.

Table A2:
Comparison of Capacity Factors

	France	Germany	Italy	E&W	Sweden
1973 mono-oil	0.76	0.61	0.79	0.50	0.21
1973 mono- & poly- oil	..	0.33	0.46	0.33	0.21
1986 mono-oil	0.07	0.12	0.47	0.14	0.12
1986 mono- & poly- oil	0.04	0.07	0.23	0.10	0.12

For Sweden, the capacity factor is the same for both methods of calculation because there is no polyvalent oil capacity. For the other countries however, the capacity factors calculated with the sum of mono- and poly-valent capacity are half the capacity factors that result when only monovalent capacity is counted. In this report, the capacity factors that result from method one will be used to evaluate the role of oil in generation in a given year, to identify the type of load (base, intermediate, or peak) it was used to meet.

Changes in the intensity of use over time, between 1973 and 1986, are the same when using capacity factors calculated with method one or two, for all countries except Italy. For Italy, the change in capacity factors between 1973 and 1986 calculated with method two (both mono and poly capacity) is decidedly larger than the change derived by using capacity factors calculated using only monovalent oil capacity. This is due to the large amount of polyvalent generation capacity (over 11 GW) that has come on line since 1973. For the other countries, there is only a small discrepancy in the change in capacity factors over time when the capacity factors are calculated using method one or two, because the amount of oil-using capacity did not increase so dramatically. Thus, when looking at how the intensity of use has changed over time, we use the monovalent oil capacity only in the calculation of the oil capacity factors.

The last application of capacity factors in this report is to estimate the maximum amount of electricity that could be generated with oil. In this case, we will calculate or report capacity factors that are calculated using the sum of monovalent and polyvalent oil generation capacity.

APPENDIX III:

Detailed Breakdown of Major Fuel Categories

In this Appendix, we provide a detailed breakdown of the energy sources included in each of the major fuel categories used in this report. Occasionally, the category inclusions differ slightly between a category for generation and the same category for capacity. If this difference exists, it is identified after each fuel category. The breakdown varies slightly from country to country. Also, this disaggregation is known better for some countries than others. "NA" indicates fuel category Not Applicable to a given country.

FRANCE

Oil. Includes fuel oil.

Natural Gas.

1973 generation: includes natural gas.

1973 capacity: Is include in "Other" category.

1985 generation: includes natural gas.

1985 capacity: includes natural gas.

Other Gases.

1973 generation: Is included in "Other" category.

1973 capacity: Is included in "Other" category.

1985 generation: Is included in "Other" category.

1985 capacity: Is included in "Other" category.

Coal. Includes hard coal.

Nuclear. Includes uranium.

Hydro. Includes hydropower.

Geothermal. Includes geothermal power.

Other.

1973 generation: Includes other gases, lignite, and diesel.

1973 capacity: Includes natural gas, other gases, lignite, and diesel.

1985 generation: Includes other gases, lignite and diesel.

1985 capacity: Includes other gases, lignite and diesel.

WEST GERMANY

Oil.

1973 generation: Includes fuel oil and diesel.

1973 capacity: Includes fuel oil.

1986 generation: Includes fuel oil and diesel.

1986 capacity: Includes fuel oil.

Natural Gas. Includes natural gas.

Other Gases.

1973 generation: Includes coke gas, liquified natural gas, liquified petroleum gas, refinerie gas, blast furnace gas, gas from waste treatment processes (gas turbines).

1973 capacity: Is included in "Other" category.

1986 generation: Includes coke gas, liquified natural gas, liquified petroleum gas, refinerie gas, blast furnace gas, gas from waste treatment processes (gas turbines).

1986 capacity: Is included in "Other" category.

Coal. Includes hard coal and lignite (also known as soft or brown coal).

Nuclear. Includes uranium.

Hydro. Includes hydropower.

Geothermal. Includes geothermal power.

Other.

1973 generation: Includes other solids: brown coal coke, sludge from waste treatment processes, peat and garbage.

1973 capacity: Includes diesel, Other Gases (gas turbines) and Other Solids (brown coal coke, sludge from waste treatment processes, peat and garbage).

1986 generation: Includes other solids: brown coal coke, sludge from waste treatment processes, peat and garbage.

1986 capacity: Includes diesel, Other Gases (gas turbines) and Other Solids (brown coal coke, sludge from waste treatment processes, peat and garbage).

ENGLAND & WALES

Oil. Include fuel oil.

Natural Gas. NA

Other Gases. Includes miscellaneous gases used in gas turbines.

Coal. Includes hard coal.

Nuclear. Includes uranium.

Hydro. Includes hydropower.

Geothermal. Includes geothermal power.

Other. NA

ITALY

Oil.

1973 generation: Includes fuel oil.

1973 capacity: Includes fuel oil and diesel.

1986 generation: Includes fuel oil.

1986 capacity: Includes fuel oil and diesel.

Natural Gas. Includes natural gas.

Other Gases. Includes light distillates, coking gas, refinerie gas, residual gases of chemical processes, blast furnace gas and gas from oxygen steel plants.

Coal. Includes hard coal and lignite (also known as brown or soft coal).

Nuclear. Includes uranium.

Hydro. Includes hydropower.

Geothermal. Includes geothermal power.

Other.

1973 generation: Includes diesel and other solids: oil coke, tar, heat recovered from pyrites and "others" (mostly burned in mixed-fired capacity).

1973 capacity: NA

1986 generation: Includes diesel and other solids: oil coke, tar, heat recovered from pyrites and "others" (mostly burned in mixed-fired capacity).

1986 capacity: NA

SWEDEN

Oil.

1973 generation: Includes various grades of fuel oil, gasoline, kerosene and diesel.

1973 capacity: Includes capacity that burns various grades of fuel oil, gasoline, kerosene and diesel, natural gas, other gases, coal, and other solids.

1986 generation: Includes various grades of fuel oil, gasoline, kerosene and diesel.

1986 capacity: Includes various grades of fuel oil, gasoline, kerosene and diesel.

Natural Gas.

1973 generation: NA

1973 capacity: Is included in oil.

1986 generation: NA

1986 capacity: NA

Other Gases.

1973 generation: Includes blast furnace gas, natural gas and coking gas.

1973 capacity: Is included in oil.

1986 generation: Includes blast furnace gas, natural gas and coking gas.

1986 capacity: Includes blast furnace gas, natural gas and coking gas.

Coal.

1973 generation: Is included in "Other" category.

1973 capacity: Is included in "Other" category.

1986 generation: Is included in "Other" category.

1986 capacity: Is included in "Other" category.

Nuclear: Includes uranium.

Hydro. Includes hydropower.

Geothermal. Includes geothermal power.

Other.

1973 generation: Includes coal and other solids: peat, wood, wood waste and garbage.

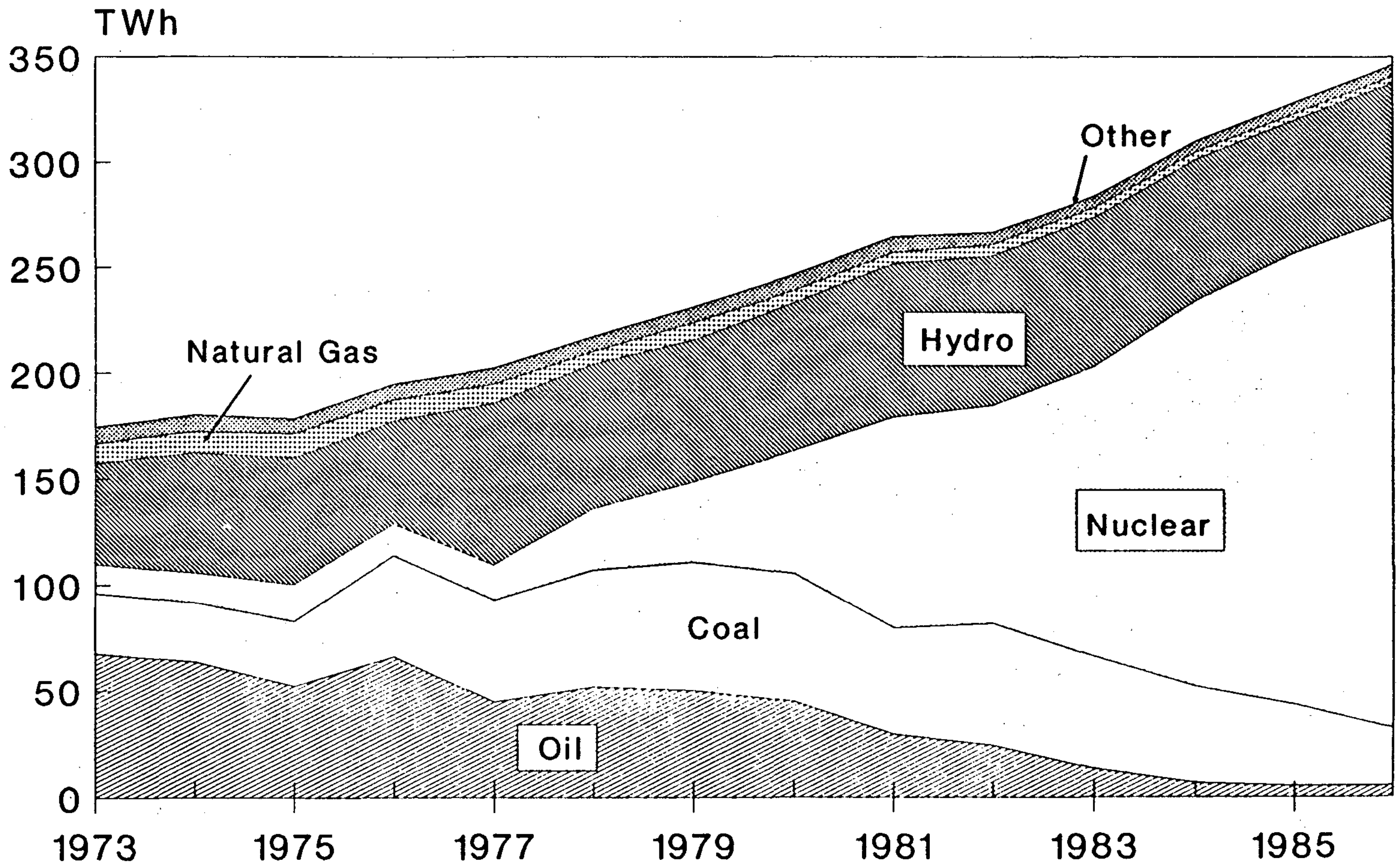
1973 capacity: NA

1986 generation: Includes coal and other solids: peat, wood, wood waste and garbage.

1986 capacity: Includes coal and other solids: peat, wood, wood waste and garbage.

Figure 1

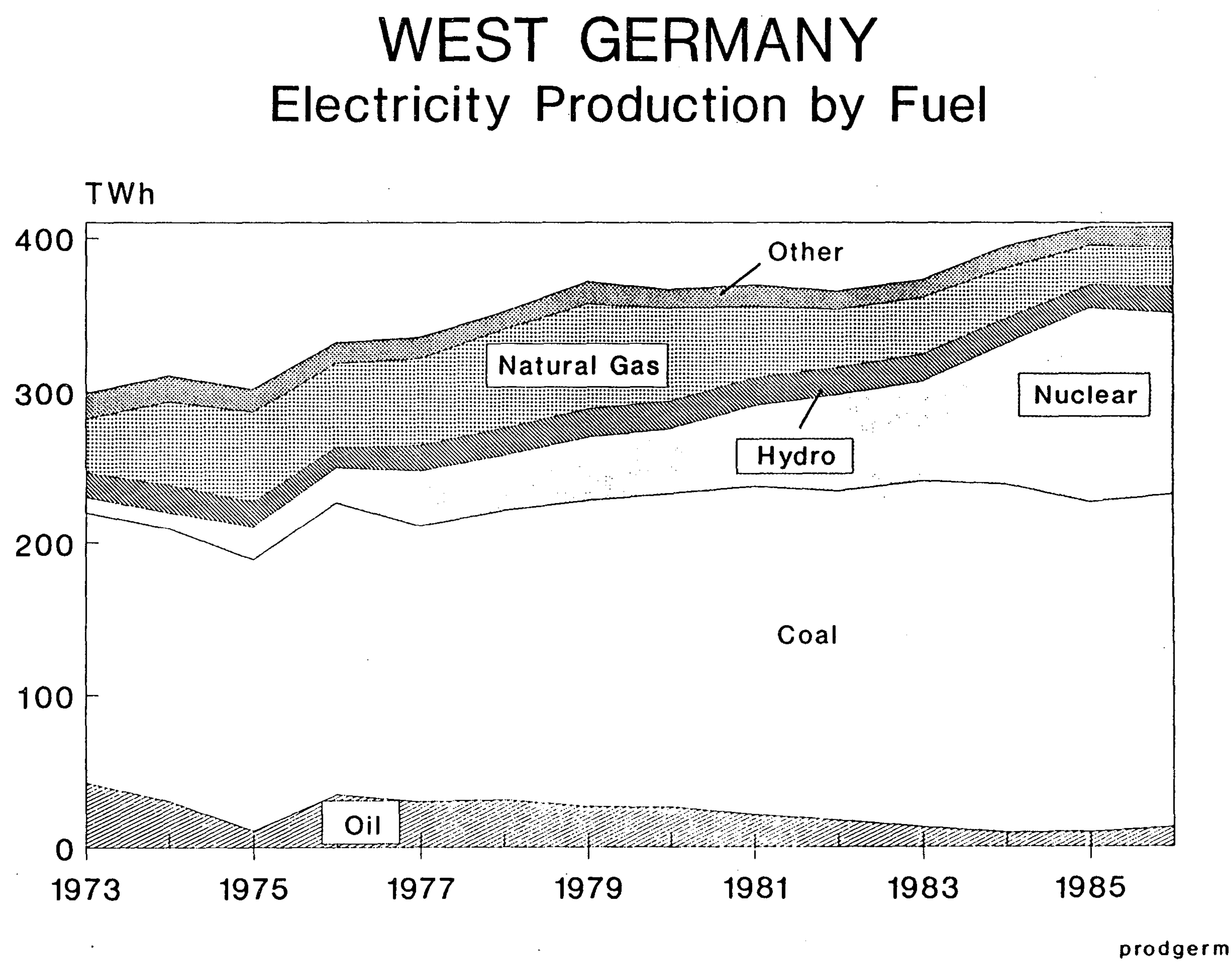
FRANCE
Electricity Production by Fuel



prodfran

Source: IES/LBL

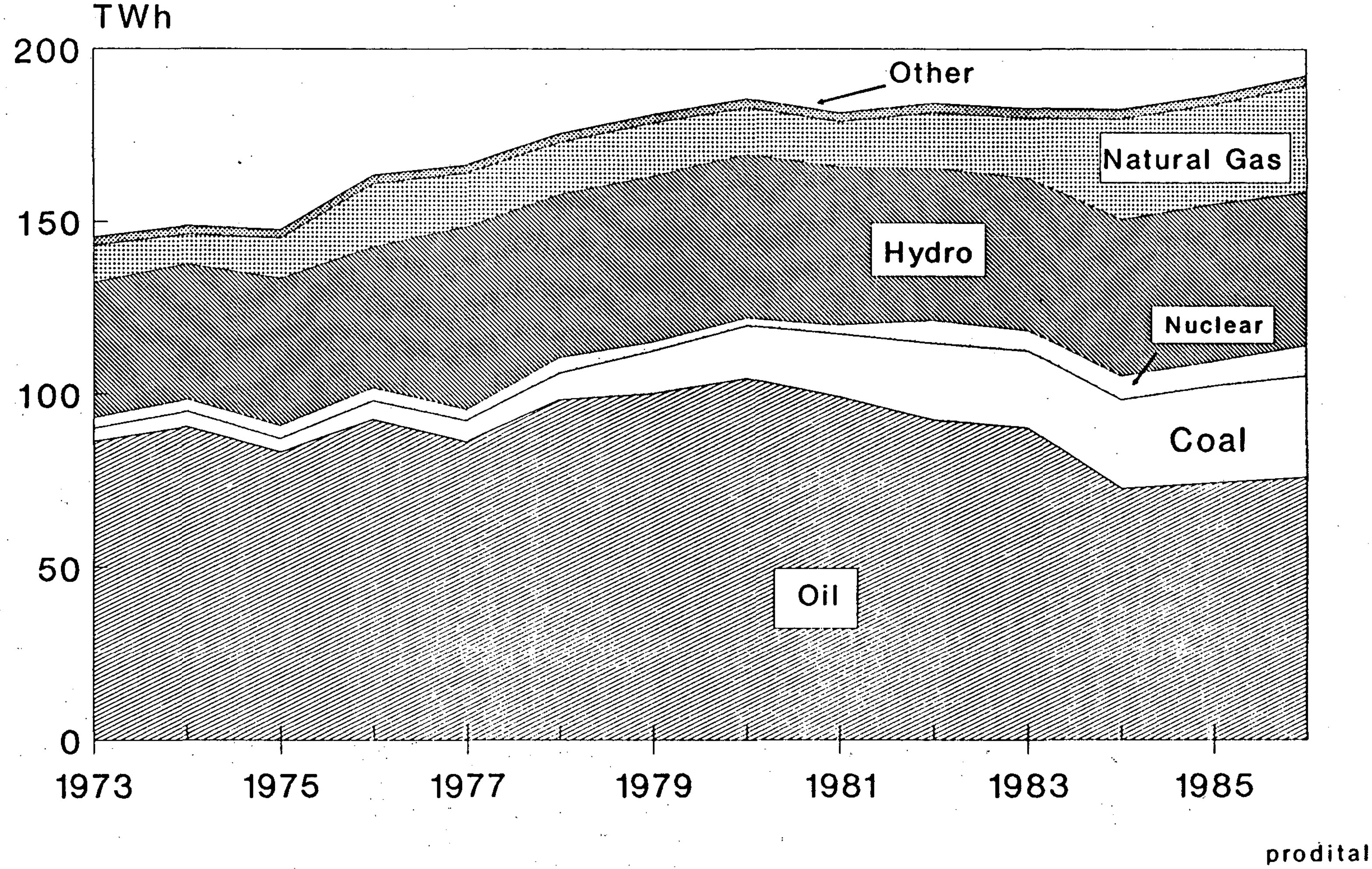
Figure 2



Source: IES/LBL

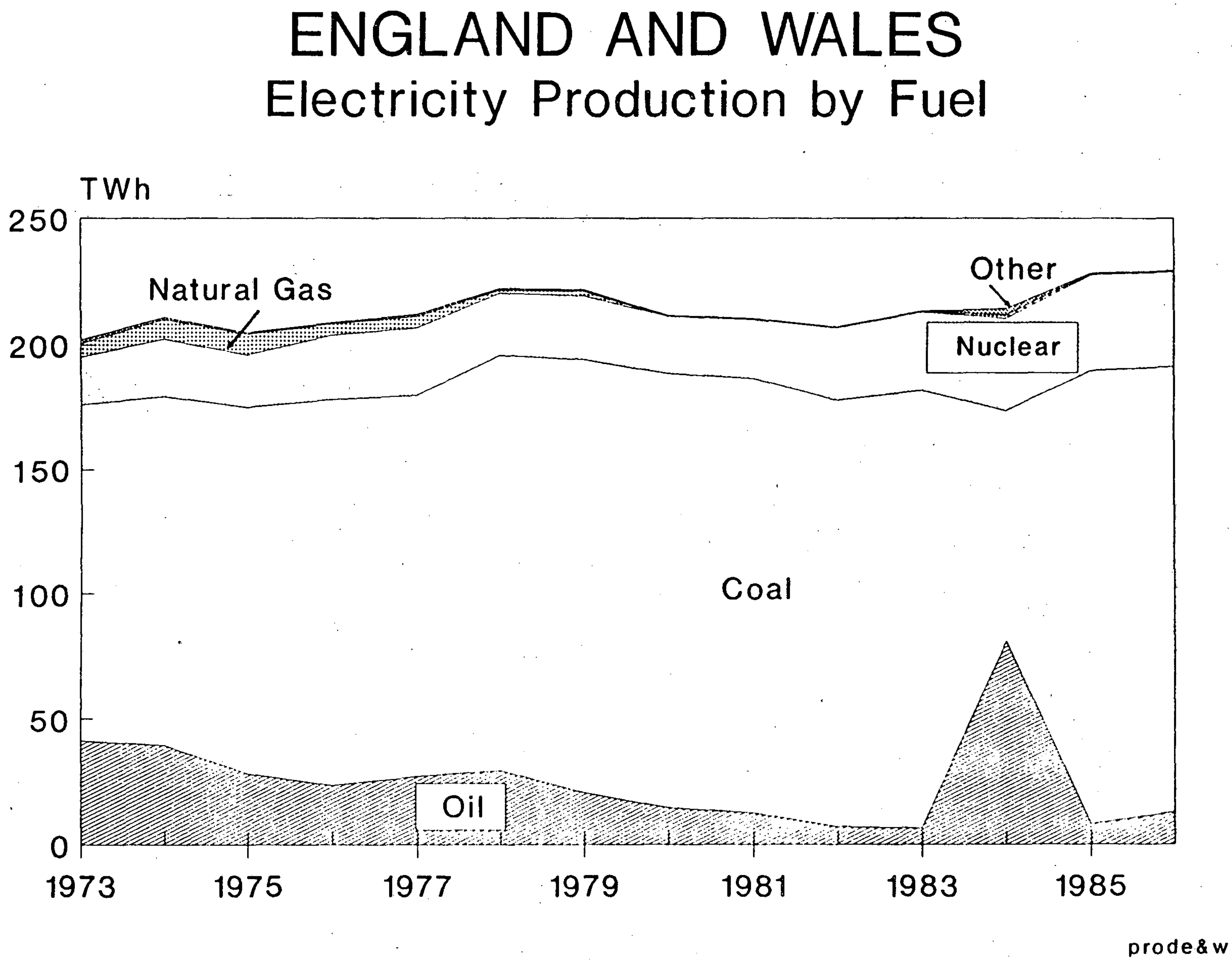
Figure 3

ITALY
Electricity Production by Fuel



Source: IES/LBL

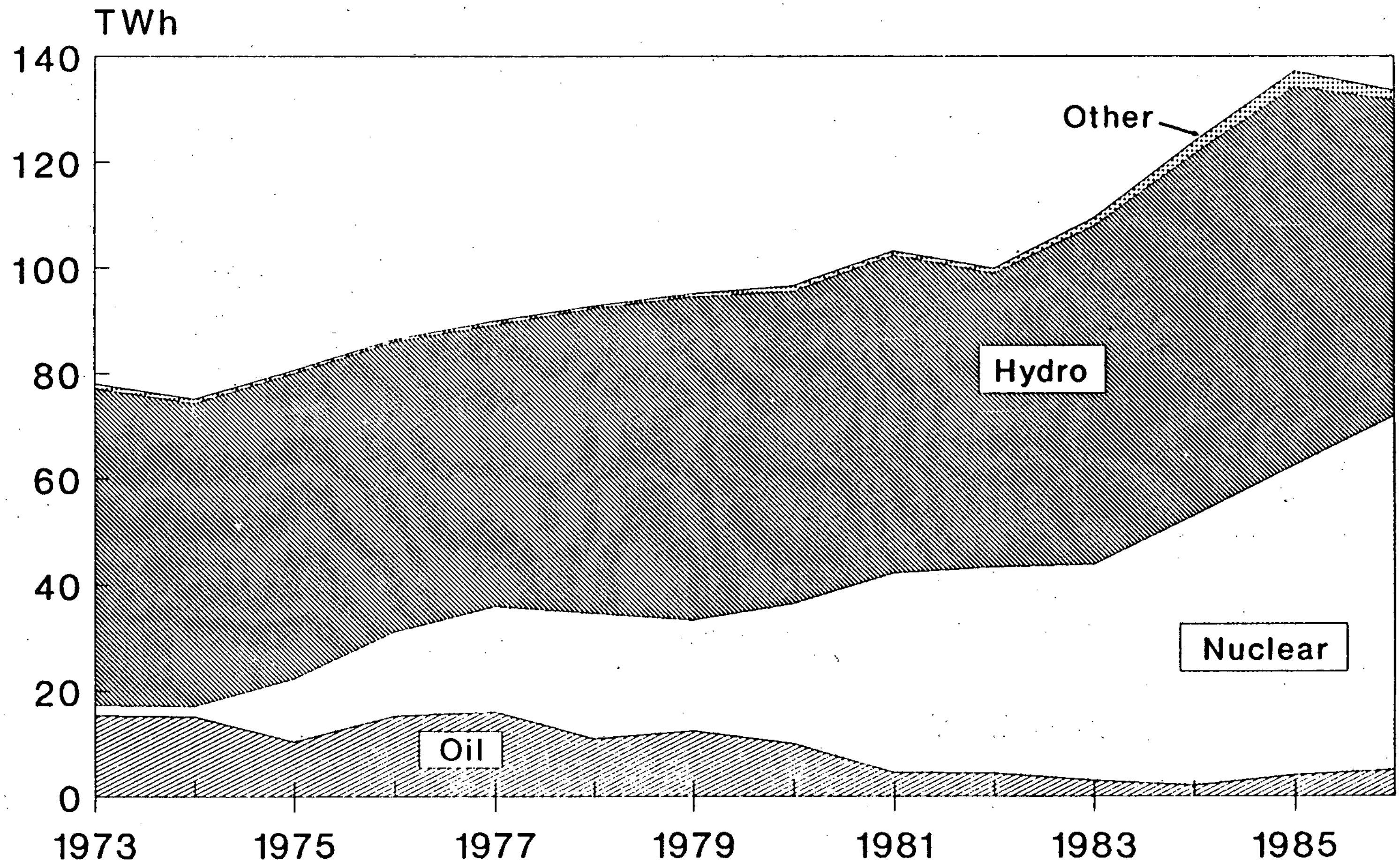
Figure 4



Source: LBL/IES

Figure 5

SWEDEN
Electricity Production by Fuel



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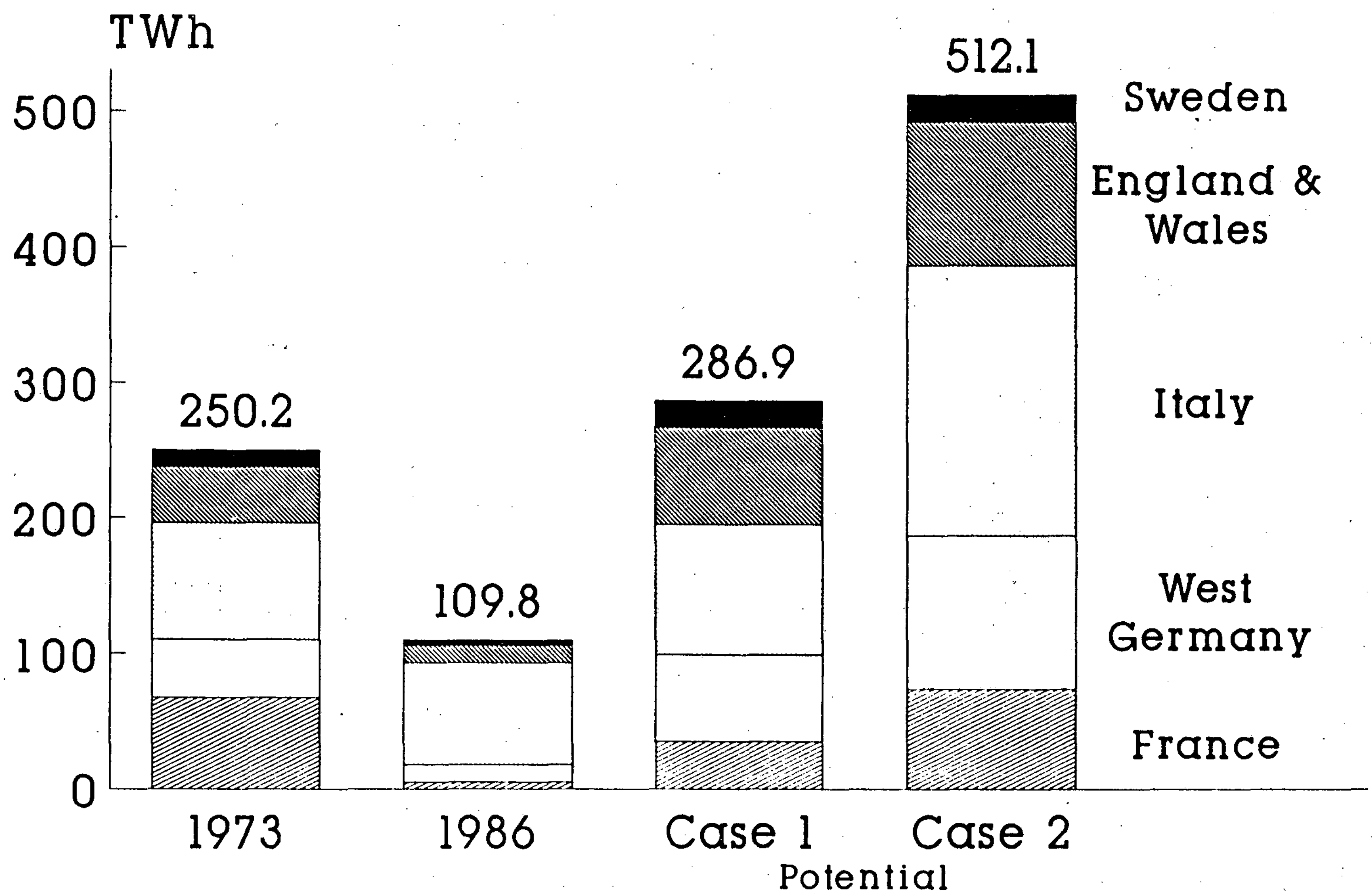
Source: IES/LBL

Figure 6

OIL-BASED ELECTRICITY GENERATION
Past, Present, & Potential



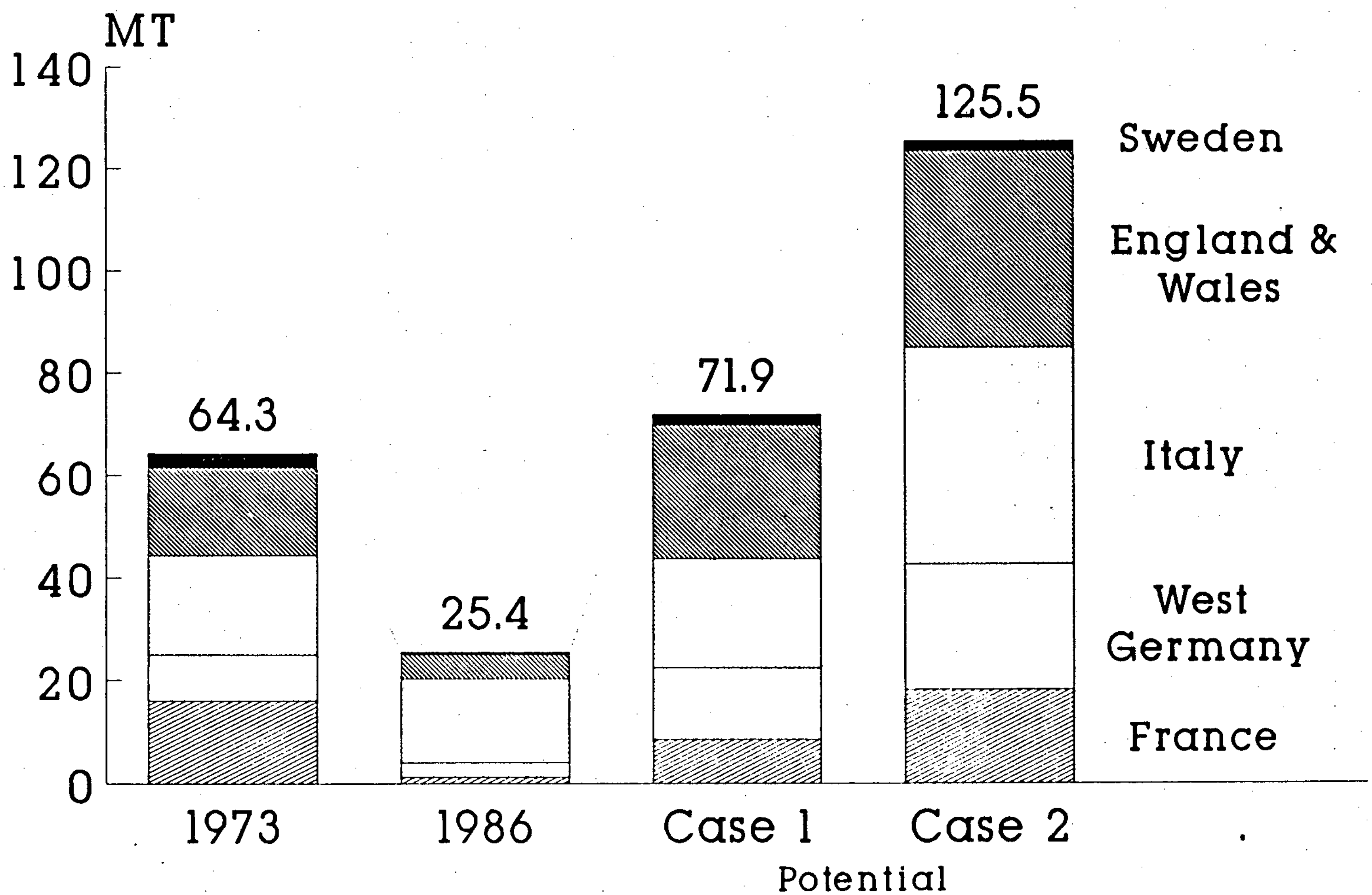
Source: IES/LBL

oilgen

Figure 7

OIL USE BY THE POWER SECTOR

Past, Present and Potential



Source: IES/LBL

oiluse

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