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SCIENCE, ENERGY AND KNOWLEDGE. AN ANALYSIS OF THE SCIENTIFIC LITERATURE ON THE SYNTHETIC FUELS IN THE 1970S AND 1980S

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FRANCESCO GERALI
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SCIENCE, ENERGY, AND KNOWLEDGE. AN ANALYSIS OF THE SCIENTIFIC LITERATURE ON THE SYNTHETIC FUELS IN THE 1970S AND 1980S

A THESIS APPROVED FOR THE
SCHOOL OF LIBRARY AND INFORMATION STUDIES

BY

Dr. June Abbas, Chair

Dr. Betsy Van der Veer Martens

Dr. Stephen Weldon

DEDICATION

Memento Audere Semper

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Table of Contents

List of Charts

List of Tables

List of Figures

Abstract

Research breeds research. When the environment (politics, human and capital resources, and the demand for the good) is right, research activity compounds itself. The growth rate continues until research activity is at the limiting level which its environment can support. However, what influences the work-flow of the research, and what is the limiting level? Does there really exist a breaking point where the scientist gives up discouraged by the surrounding and overwhelming odds? (Clewell, 1963).

This study documents the trend of scientific research on synthetic fuels production technologies between 1972 and 1988. The goal is to understand if the environment has really influenced the research; and, whether it is possible to determinate or not a precise breaking point in the flow of the research.

The conclusions reached in this thesis are based on the comparison of historical facts through the lens of a bibliographic study on the contemporary technical-scientific literature available from the Department of Energy.

Introduction

The historian generally looks at the bibliography as a list of references in which it is possible to find information on the recent and past production of scholarship on the specific subject of interest. In this thesis, the bibliography is used as a tool to study and enhance the interpretation of historical facts related to synthetic fuels production technology in the 1970s-1980s. In this thesis the bibliography serves as grid of interpretation in which to frame and compare the significant historical events happening during this time period. The result of this approach is twofold. On one hand, the bibliography allowed me to acknowledge the need to undertake a deeper historical analysis. On the other hand, the study of the historical context and the key events embedded in the timeline provided the answers that I was searching for to understand the publication trends of the literature on synthetic fuels.

This thesis is born from the idea to merge together history of science with a bibliographic study, to gain a better understanding of the publication trends of the literature produced about the research on synthetic fuels production technologies during 1972-1988. The quantity and the quality of the bibliographical records used in this thesis (a total of 9,317 books, journal articles, conference reports, technical reports, thesis/dissertations, and patents) is used as point of reference to enhance the understanding of the trend of research in the historical context of the time. I used DOE records because they are considered an authoritative source that include a wide range of relevant publications that allowed me to explore the phenomena I wanted to study

The scientist acts in a dynamic and well-defined environment and becomes part of it. The understanding of the environment and its components that interact and influence the scientist becomes a fundamental step to acknowledge the workflow and the results of his research. The early idea of this thesis arose while I was working on a bibliography for the history of the oil industry in the moment of the so-called *oil shocks* of the 1973 and 1979 (Sherril, 1982; Lifset, 2014). My aim was to map and record the resources published in the United States for the study of the history of synthetic fuels rendered from coal and shale rocks in the 1970s and the 1980s. At the beginning of the work, I defined two categories of sources: *energy studies* and *energy research*. The first are those more oriented to meet the contemporary needs for reports and commentaries on the energy situation; they comprise literature on economics, politics, society and environment. The second category includes sources aimed to offer answers for short and medium term application of new technologies to meet energy policy needs (Landsberg et al., 1974). The latter is produced generally by experts in the field and is addressed to scholars and practitioner insiders. I defined as the target of this earlier survey of gathering energy research literature published between 1974 and 1982. I selected this timeframe in consideration of the fact that historiography commonly agrees that most of the research and development on synthetic fuels production technologies in the United States decreased and then ceased around 1982-1983 (Hoffman, 1982; Meyers, 1984).

In the first steps of the research and in the information I gathered there was evidence of two unexpected anomalies. The first was the pretty stable and lower than expected rate of publications issued between 1974 and 1979. The second was the consistent bulk of literature on synthetic fuels issued far beyond the supposed 1982-1983 threshold of the *oblivion* that affected the development of technology to produce synthetic fuels (Probstein, 1982; Polaert, 1985; Yanarella and Green, 1987; Crow, 1988). After these unexpected results, I decided to outline a matrix of comparison to compare and analyze the bibliographic findings into a contemporary historical context. The expected result was to ascertain whether and how the uncertainty of the 1970s-1980s energy panorama in the U.S., with special reference to the *ups and downs* of oil prices, might have influenced the pace of scientific research – both in academy and corporate settings – and the development of more advanced synthetic fuels production technologies sought by government and entrepreneurship.

Historical Background on the Research of Synthetic Fuels in the United States

The modern history of synthetic fuel began in 1913 when in Germany the first process of direct coal liquefaction (DLC) was invented. The basic principle of DLC is the utilization of coal instead of conventional crude oil to obtain kerosene for aviation, and gasoline and diesel for automotive. The fuels obtained through this process are called synthetic fuels because the feedstock (coal or shale rock depending on the type of process utilized) undergoes several stages of heating, cooling, pressure, catalysis, enrichment, gasification and liquefaction. The original process was considered ineffective and of scarce utility until the 1930s, when the German chemical multinational *I. G. Farben*, after fifteen years of investments and efforts, developed a new process viable for industrial production. By the end of World War II, twelve industrial plants provided the German military with much of its fuel request (Dewey, 1946; Stranges 1985, 1993). Despite these great scientific and industrial efforts, synthetic fuels remained a difficult and imperfect technology. The production process devoured large amounts of energy and minerals. The yields were low and of lower quality than the same petroleum refined products. Germany used and squeezed the technology down to the last drop regardless of the cost because of the politics of war rather than for real economic convenience.

The *United States Bureau of Mines* first studied the extraction of oil from oil shale between 1924 and 1928, and later experimented with coal liquefaction by hydrogenation using the early German *Bergius* process. A small-scale test unit was constructed in 1937. This initial and inconsistent effort did not lead to any production, however it was precursor of the larger and much more ambitious *Synthetic Liquid Fuels Program*, which was run by the same Bureau and aimed to create the technology to produce synthetic fuel from coal and oil shale on a commercial scale. The program started in 1944 during World War II after the *Synthetic Liquid Fuels Act*, which authorized the use of $30 million US dollars over a five-year period for the construction and operation of demonstration plants. The goal was to produce synthetic liquid fuels from coal and oil shale in order to aid the prosecution of the war and to conserve and increase the oil resources of the nation (Stranges, 1997).

The United States were notably impressed by the German technological endeavor which was allowing them to fight and prolong the conflict virtually without crude oil. The awareness of the technological weakness and the related economic disadvantages were counterbalanced by the optimistic expectations of research, development and refinement of the German processes to which American scientists were called upon to cope. Between 1945 and 1948, new laboratories were constructed near Pittsburgh. In 1948, the program was extended to eight years. By 1949 the plant could produce 200 barrels of oil a day.

New facilities were constructed in 1951, but only produced 40,000 barrels of fuel until 1953. In the same year, the federal authorities abruptly ceased the funding for the research (Atwell, 1945; Standard Oil Company of New Jersey, 1946; United States, Bureau of Mines, 1950; Stranges, 1997).

After eight years of hiatus, the U.S. government attempted another national effort to develop coal into a more useful fuel resource, and that project included, even if in minor extent, to resume the coal liquefaction. On July 1961, President Kennedy established the Office of Coal Research (OCR). This effort was established with the thought that the declining coal industry of the 1960 could be revitalized and helping some of the United States economically depressed areas. In fact, social goals as opposed to technical goals were the driving force behind this new technology development push. Although funding was modest, the government set out on the course of developing a number of new options (Crow, 1988). However, the necessary basic research to overcome the fundamental problems and the limiting gaps of the engineering economics in the production of the synthetic fuels was still not receiving enough funding and attention. A principal reason for this continued attempt to develop a technology empirically rather than scientifically is linked to the social goals of the program. The program was designed to provide means for a short-term, quick, recovery of the coal industry. A fully working technological option for the synthetic fuels production would have instead included a medium-long term and costly investment plan, which was not the goal of the OCR.

In conclusion, until the early 1970s the development of synthetic fuels production technology in the United States has been discontinuous and featured by moments of advancement, limited interest, myopic policies, lack of funds, and hiatus.

The three stages of the government research and development legacy of the synthetic fuels in the United States (1925-1936; 1945-1953; 1961-1973), chiefly organized and implemented by the Bureau of Mines, the Office of Coal Research and by other minor and short-lived agencies, produced neither commercial-scale synthetic fuel plants in operation or planning, or relevant advancements in comparison to the "old" German engineering.

The industrial interests of the strong and politically influential oil industry, an integrated production system and a source of great earnings and jobs, had in part the role of deterrent. The petroleum leviathan had a limited interest in synthetic fuels, even though it did not deny the possibility of entering into the possible future business. (Brent and Stover, 1984)

Literature Review

The literature review that preceded the preparation of this research did not detect equivalent or similar studies preexisting in either the History of Science or in the Library and Information Studies disciplines, and linked to the production technology for fuels, or just related to the energy thematic in a broader sense. In the recent LIS literature on energy and bibliographical three studies stand out for originality Li et al, 2015, Magami et al, 2015 and Khan, 2016. These studies are focused respectively on (hydraulic) fracturing technologies, solar hydrogen power, and compressed (liquid) natural gas. These studies analyze their research subjects focusing more on a scientometrics and bibliometric perspective *per se*. The researchers' approach is very technical and closer to the practice of the applied scientist and the industry professional.

The historical context of the scientific literature analyzed is kept as background, and I see little interaction between history and bibliography in these studies. In this thesis the dialogue between bibliography and history is the backbone that sustains the entire analysis. However, these three studies are useful and their approach can be applied in the future to a further study on the synthetic fuels from the 1970s until today.

The two books closer to the rationale of my research are Yanarella's *The Unfulfilled Promise of Synthetic Fuels: Technological Failure, Policy Immobilism, or Commercial Illusion*, 1987, and Crow' *Synthetic Fuel Technology Development in the United States: A Retrospective Assessment*, 1988. Those sources question and investigate in detail what happened during the process of development of the synthetic fuel industry in the United States. They were sources of inspiration as much as of controversies in my study. I say that because I do not agree with some of their descriptions of facts and conclusions, and I think that the date of publication, 1987 and 1988, probably prevented the authors from considering part of the contemporary, on-going research and further resources – as is possible to infer from their bibliographies.

To find out the reason of the two supposed anomalies I followed two parallel tracks of research and types of resources: 1) a detailed study of the historical facts and 2) an analysis of authoritative sources of bibliographic information. In the first I was advantaged by the abundance of literature on the oil crises and the energy policies of the United States in the 1980s. To develop the second track I used official United States government sources produced and made available by the United States Congress and Federal agencies, with special reference to the Department of Energy. My research benefited especially from: United States, Congress (1981a, 1981b, 1982, 1983, 1986a, 1986b and 2003). These sources provided valuable materials on the workflow related to the outlining and application of the government policies on synthetic fuels.

The findings show how I categorized the sample of 9,317 records of scholarly and professional literature on synthetic fuels technology issued between 1972 and 1988. These publications are the result of initiatives of research sponsored by the Department of Energy (DOE) of the United States and the agencies preceding its establishment in 1977. This sample of literature is both academic and industrial, published by universities, the research centers of government agencies and corporate research centers (see Appendix 1). The DOE literature was chosen due to the quality and authoritative nature of the sources included in the repository, when assessed against the other repositories I reviewed, including the library catalogs of the Chemical Heritage Foundation, the University of Pennsylvania, and the United States Bureau of Mines. Those catalogs reported large but inconsistent volumes of information. It was not possible to map the time span of 1972-1988 with accuracy and continuity in any of these other catalogs. I also realized that the contents of those catalogs were overlapping, and would have yielded unreliable quantitative data.

The quality of the data collected in the DOE repository made possible the satisfactory definition of the trend of the research developed even during the years 1972-1973, the year immediately preceding age of the energy crises; and, more importantly, the 1983-1988 time frame, which was the moment of the supposed decline and hiatus of the studies on the synthetic fuels technology in the United States. These achievements give greater importance to the research. The bibliographical study and the data retrieved shed light on a thematic little considered by historians of science – the history of the synthetic fuels production technology after the 1985 shut down of the SFC.

Methodology

The main research question at the base of this work is: “How can historical and bibliographical research converge together to provide scholars with a better understanding of the publications of the scientists studying synthetic fuels production technology?”

My goal was to seek, collect and analyze a significant sample of references from which I could extrapolate the raw data necessary to quantify the scientific research literature on synthetic fuels production technology developed every year from 1972 to 1988. I could then compare the bibliographical data with significant events happening during this chronological period– the constant rising of the oil prices from 1973 to 1982, the creation of government agencies, and the creation of *ad hoc* programs funded to study new synthetic fuels technologies.

The thesis applies the principles of a retrospective study. This research method is commonly defined as the research design that involves repeated observations of the same variables over a long and defined period of time (Blossfeld & Rohwer, 2002). Yanarella (1987) and Crow (1988), used this method to execute their research. The utilization of this approach allowed me to focus my attention on the published outcomes of the research and development of production technology for synthetic fuels – the variable of the study – during the 15 year time span included between 1972 and 1988 in the United States. The data has been juxtaposed to the historical context and interpreted in the light of the facts and events which occurred in the environment of the scientific research on synthetic fuels. Through this process, I could frame and determine the main reasons of the research trend of the projects sponsored (directly and indirectly) by the U.S. Department of Energy.

The outcome of the bibliographical findings are processed and represented in 18 charts distributed along the narration. Part of the historical study merged as well in 17 tables which quantify the values related to the crude oil prices, production and imports in the United States. This study proved how the research on synthetic fuels has been in large part influenced by political choices, as it is commonly accepted by the recent historiography. However, the data collected in the bibliographic research also suggest that the so called moment of hiatus of the research on synthetic fuels production technology is nothing more than a slowdown of the research in the United States because the lack of available funds. The historical analysis completed until 1988, suggests also the possibility that this reduced but continuing research was now focused on the development of base technologies, the kind of fundamental studies that were partly left in the background from the 1960s to 1985.

The sample of my survey included a selection of books, journal articles, conference proceedings, technical reports, thesis and patents selected and collected from the U.S. Department of Energy (DOE) platform SciTech Connect. This is a platform to free DOE-sponsored Research and Development results, which include books, technical reports, bibliographic citations, journal articles, conference papers, books, multimedia, software, patents and data information. SciTech Connect is developed and maintained by the U.S. Department of Energy’s Office of Scientific and Technical Information

(OSTI) to guarantee access to science, technology, and engineering research information produced from DOE and its predecessor agencies in the past seventy years. The platform gathers a total of almost three million of DOE research entries from 17 national laboratories and more than 2,500 contributing organizations. SciTech Connect includes sources sponsored by DOE through grants, contracts, cooperative agreements, or similar types of funding mechanisms from the 1940s to today.

I have utilized several Congressional Hearings to develop the historical findings, and selected yearbooks from the U.S. Bureau of Census and Statistics to retrieve official data on oil prices, production and import to develop the tables featured in the text. The average high level of accuracy and reliability guaranteed by the government documents convinced me to develop the bibliographical study using SciTech Connect. There is no authoritative source in the literature on synthetic fuels; that gap initially led me to work on a smaller sample of records retrieved from a random search implemented on different university library catalogs. The fact that SciTech Connect is the repository of the sources from the DOE, the main federal office in charge at the time of almost all the phases of the synthetic fuels development program, made me confident about the quality and the pertinence of the contents. The SciTech Connect catalog search system allowed me to search year by year (1972-1988) for the document format I selected (books, journal articles, conference proceedings, technical reports, thesis and patents), using the subject “synthetic fuels”. The system allowed me the option to save my search on MS Excel sheets, including all the metadata available. The wealth of data collected allowed me to build the 18 charts that accompany my study on the scientific literature. In conclusion, the bibliographic tool I used allowed me to gather relevant information to my research, which I then could synthesize in graphs that clearly convey the qualitative and quantitative value of the work developed by scientists supported by the Department of Energy from 1972 to 1988.

Findings: Synthetic fuels between history and literature (1972-1988)

1972 - 1981. Crises, investments and research

1972-1973. The Status Quo

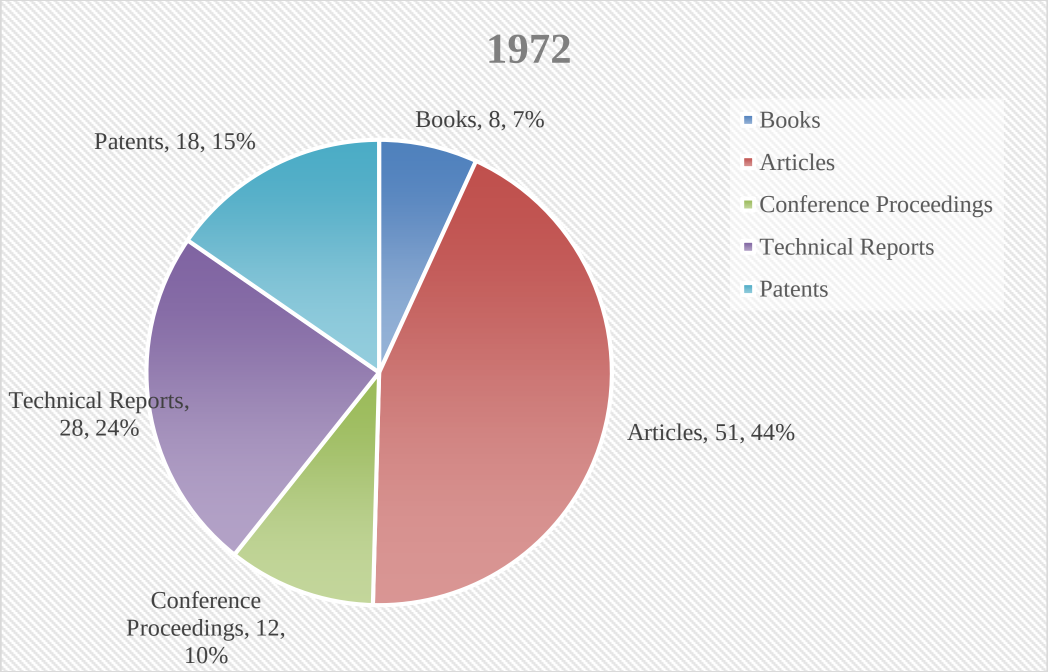
President Richard Nixon presented his plan for an energy agency in his first energy message to the Congress in June 1971. He cited the *brownouts* which had occurred in recent months, the natural gas shortages, the increasing fuel prices, and overall the lack of an integrated national energy policy. The president proposed, for the first time in the energy history of the country, the consolidation of all of the major energy programs into the new *Department of Natural Resources* (Buck, 1982). Oil imports and prices in 1972 and 1973 (Tables 1 and 2) were pretty aligned with the trend followed in the previous 5 years. However, President Nixon was concerned with the fragmentation of the energy administration of the country.

Table 1. Prices, production and import of crude oil in the U.S. in 1972
(Data sourced and elaborated from the U.S. Bureau of Statistics).

1972	
National crude oil production	3,455,000,000 barrels
Imports of crude oil	811,000,000 barrels
Average price per barrel	$ 3.39
Total cost to supply the national demand	$ 14,461,740,000

Two years later, in June 1973, President Nixon again urged Congress to take action on his energy legislation, and now called for a *Department of Energy and Natural Resources*, also, an *Energy Research and Development Administration* that would be responsible for developing fossil fuels, nuclear power, and potential new forms of energy. In the interim, President Nixon took a number of executive actions to deal with the situation. On June 29, 1973, the responsibilities of the already existing Special Energy Committee and the National Energy Office were combined and expanded in a new Energy Policy (Rocks, 1980; Lifset, 2014).

Chart 1.
Synthesis of the scientific literature on synthetic fuels for the year 1972: 117 items published (Data estimated from the DOE-OSTI).



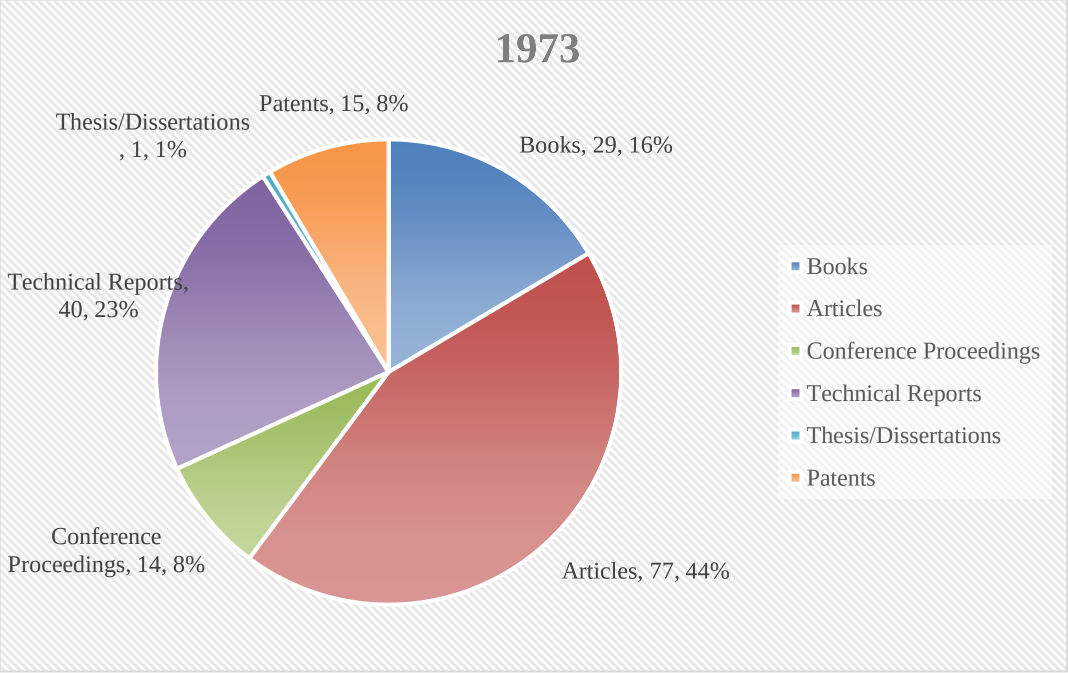
When the Arab oil embargo, caused by diplomatic tensions on the Middle East geopolitics and not by oil shortages or sudden market fluctuations, was announced on October 16, 1973, it had an immediate impact on the United States. On November 8 President Nixon sent a message to Congress stating that the energy crisis which had “once seemed a distant threat” was now closing in quickly, and that the Nation “faced the most acute shortages of energy” since World War II. The President reiterated his desire for a cabinet-level energy department but at the same time urged Congress to give priority to the establishment of the Energy Research and Development

Administration. Although increasing public concern over the energy crisis lent a certain urgency to the President's proposals, Congress did not act immediately. Months of tension over the Watergate situation as well as numerous debates among congressional committees over the size and shape of the new agencies caused the delay. On December 4 the Federal Energy Office was established in the Executive Office of the President with control over fuel allocation, rationing, and prices. The Federal Energy Office advised the President on energy policy issues, and assumed responsibility for implementing "Project Independence," Nixon's plan for achieving national energy self-sufficiency by 1980 (Holl, 1981; Buck,1982). Tables 1 and 2 show the stable level of the oil prices between in 1972 and 1973; those values are reported as point of reference to better understand the magnitude of the events to come in the crises and post crises moments.

Table 2.
Prices, production and import of crude oil in the U.S. in 1973
(Data sourced and elaborated from the U.S. Bureau of Statistics).

1973	
National crude oil production	3,361,000,000 barrels
Imports of crude oil	1,184,000,000 barrels
Average price per barrel	$ 3.89
Total cost to supply the national demand	$ 17,680,050,000

Chart 2.
Synthesis of the scientific literature on synthetic fuels for the year 1973: 176 items published (Data estimated from DOE-OSTI).



In 1972-1973, the research published on synthetic fuels recorded in the DOE_OSTI database (293 works) were the last financed projects by the still active OCR. Those studies were more theoretical rather than referring to or describing the productive processes (See above Charts 1 and 2).

1974. The Energy and Research Development Agency

On January 23, 1974, Nixon again appealed to Congress to take action on his legislative proposals, now enforced by the recent dramatic event and the price of gasoline that almost doubled in a period of a few months (see Table 3). He called again for the establishment of a new energy research and development administration and a department of energy and natural resources to provide a balanced energy program for the future.

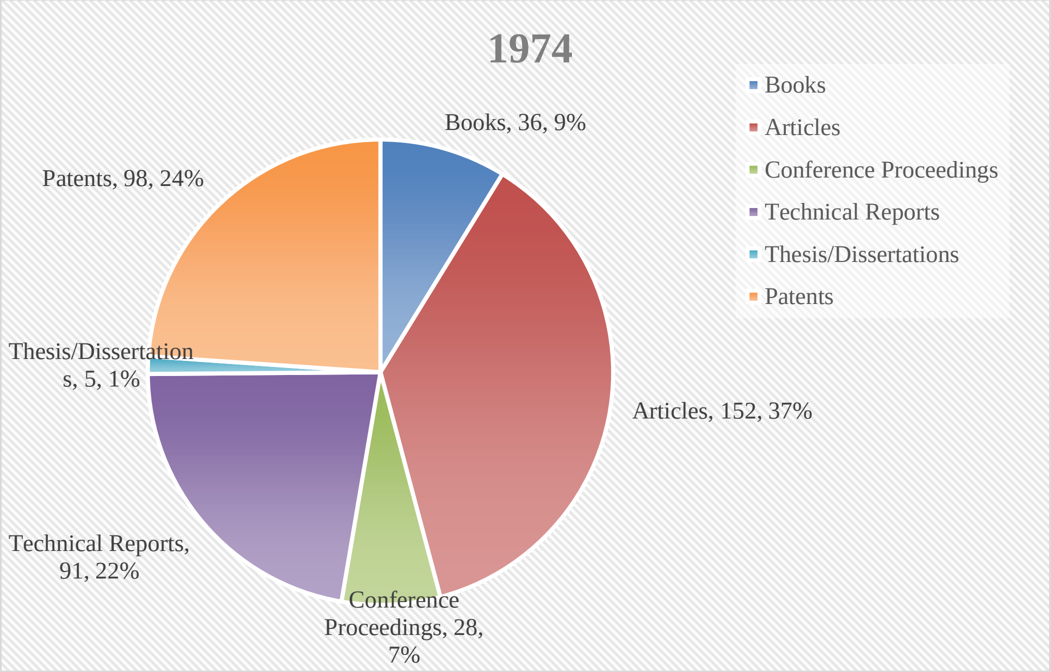
Table 3.
Prices, production and import of crude oil in the U.S. in 1974
(Data sourced and elaborated from the U.S. Bureau of Statistics).

1974	
National crude oil production	3,203,000,000 barrels
Imports of crude oil	1,269,000,000 barrels
Average price per barrel	$ 6.74
Total cost to supply the national demand	$ 30,141,280,000

The President's efforts to have his energy legislation passed continued into the spring with little success. Finally, on May 7, he signed into law the act creating the *Federal Energy Administration* (FEA) as a new and independent agency. With his resignation in August 1974, however, it remained for Nixon's successors to sign into law the final versions of his original energy proposals (Holl, 1981; Buck, 1982). Congress created the Energy Research and Development Administration (ERDA) on October 11, 1974, in response to the Nation's growing need for additional sources of energy. The new agency would coordinate energy programs formerly scattered among many federal agencies, and serve as the focal point for a major effort by the Federal Government to expand energy research and development efforts. New ways to conserve existing supplies as well as the commercial demonstration of new technologies were the target of the Government's first significant effort to combine energy resource development programs (Szyliowicz and O’Neill, 1975).

The Energy Research and Development Administration brought together for the first time the major programs of research and development for all forms of energy. Along with the programs, a total of 7,222 employees made the transfer to the new agency (Striner, 1979). The call for the diversification of energy production to face this emergency is reflected in the doubling of the studies on synthetic fuels published in 1974 (See Chart 3).

Chart 3.
Synthesis of the scientific literature on synthetic fuels for the year 1974: 365 items published (Data estimated from the DOE-OSTI).



1975. “Creating energy choices for the future”

After the establishment of the ERDA, the transition from theory to practice for the new, urgent, energy policy of the country was announced to the President and the Congress on June 28, 1975 through the *National Energy Research, Development and Demonstration Plans*, also known as *Creating Energy Choices for the Future*. Developed in consultation with other government agencies and representatives of the private sector, the two-volume report outlined short-term (to 1985), mid-term (1985-2000), and long-term (after 2000) programs for developing energy resources.

Table 4.
Prices, production and import of crude oil in the U.S. in 1975
(Data sourced and elaborated from the U.S. Bureau of Statistics).

1975	
National crude oil production	3,057,000,000 barrels
Imports of crude oil	1,498,000,000 barrels
Average price per barrel	$ 7.67
Total cost to supply the national demand	$ 34,963,850,000

The plan called for a shift to new primary forms of energy, and outlined five changes that should be made rapidly and simultaneously in the nature and scope of energy research, development and demonstration programs:

- to overcome the technical problems (primarily operational reliability and environmental impact) preventing an expansion of current major energy sources such as coal plants;
- to emphasize energy conservation;
- to accelerate the capability to extract gaseous and liquid fuels from coal and shale;
- to include electricity generated by solar power as a high priority development;
- to concentrate on underused technologies capable of being rapidly developed for the mid-term and beyond, such as solar heating and cooling and the use of geothermal power.

ERDA's first national energy plan called for an early demonstration of the technical feasibility of new energy systems, and the research on synthetic fuels production technologies was considered a top priority. The Federal Government would have provided overall leadership and undertook only those efforts that industry could not initiate. As a technology approached the stage of commercialization, industry would have assumed the initiative.

A sense of urgency ran through the plan: the effort was formidable; the margin for failure was small; but, the schedule would have to be adhered to if results were to be achieved and overall goals fulfilled. The near-term results would require an immediate expansion of existing energy resources and the implementation of conservation technologies, while mid-term results would require the establishment of the synthetic fuels industry. Long-term results would require the development of technologies to unlock the potential of essentially inexhaustible sources of energy such as breeder reactors, fusion and solar electric.

The plan pushed the idea of a new synthetic fuels industry to create American energy independence and linked it to the American synthetic rubber experience during the Second World War. The effect of this explicit call to this source was the immediate growth of the studies published on synthetic fuels (United States Congress, 1975a and 1975b) (See Charts 4 and 5).

Chart 4.
Synthesis of the scientific literature on synthetic fuels for the year 1975: 422 items published (Data estimated from the DOE-OSTI).

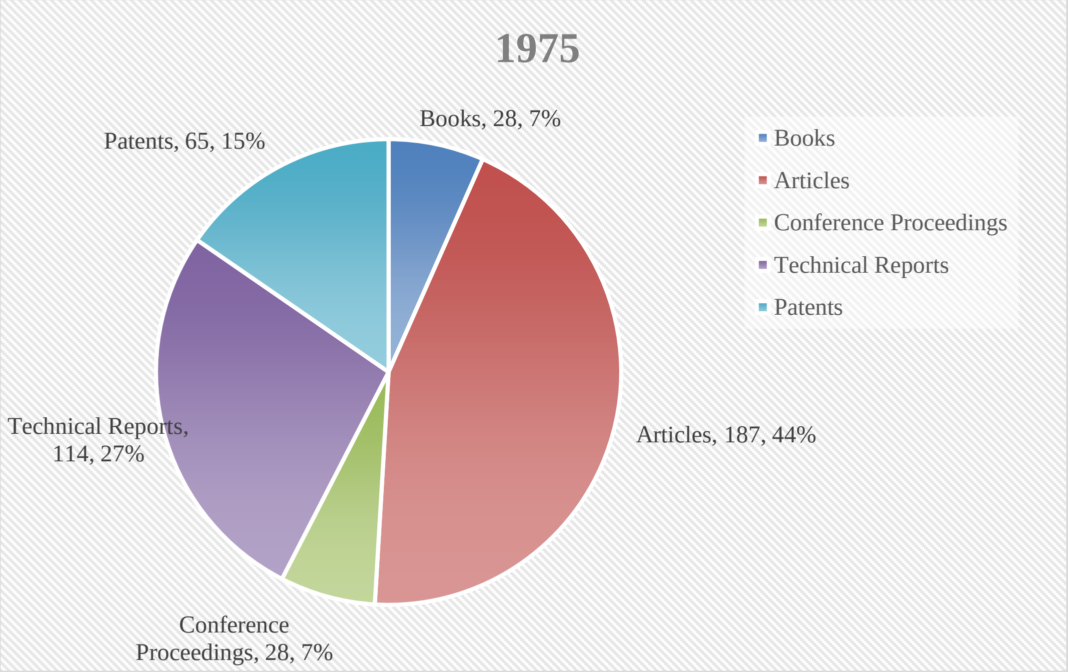


Table 5.
Prices, production and import of crude oil in the U.S. in 1976
(Data sourced and elaborated from the U.S. Bureau of Statistics).

1976	
National crude oil production	2,972,000,000 barrels
Imports of crude oil	1,935,000,000 barrels
Average price per barrel	$ 8.11
Total cost to supply the national demand	$ 39,795,770,000

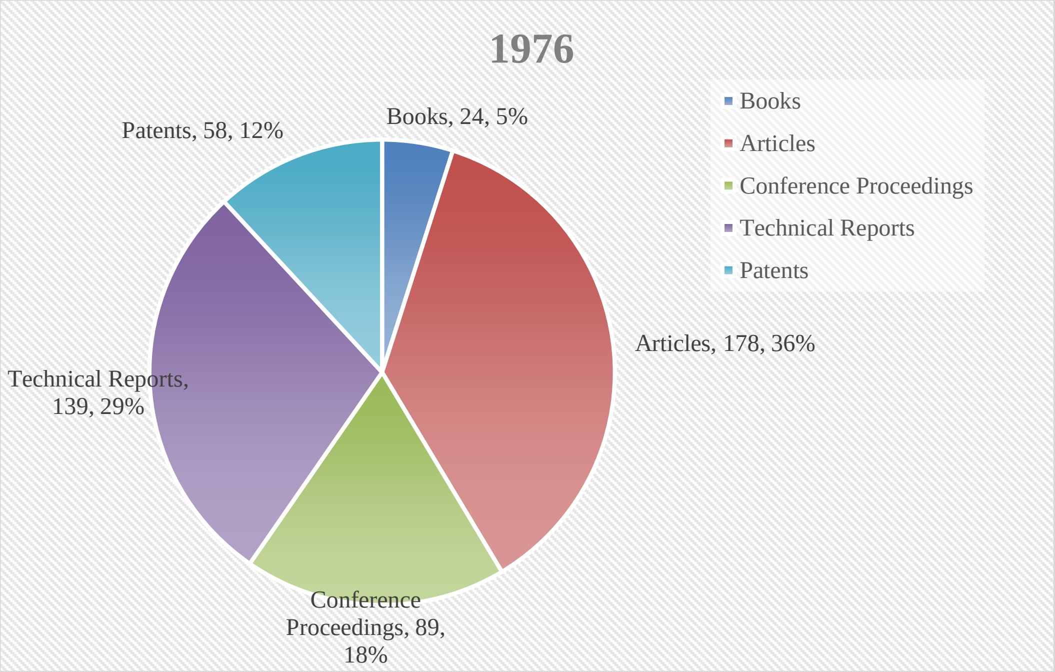
A revised edition of the national energy plan was submitted on April 15, 1976. The basic goals and strategy remained much the same, but the concept of *energy efficiency* was singled out for increased attention and ranked with several supply technologies as being of the highest national priority. The increased emphasis on the energy efficiency principles would have helped to provide more time to develop new energy sources. (Green, 1977).

Federal programs to assist industry in accelerating the commercialization of near-term technologies were a key element in the plan. The growing interest in the development of synthetic fuels as a mean of responding to looming shortfalls in oil and natural supplies took place in higher policy making circles. As part of state support for energy research & development to convert coal into gas and liquid fuels, the Energy Research and Development Administration issued a program opportunity notice in the late March 1976 designed to stimulate interest in the integration and evaluation of coal gasification technology in an operational environment. This federal energy program, known as the Gasifiers in Industry program, elicited a total of thirteen applications. The only three applications selected for funding were projects in Georgetown, Hitchens, and Pikeville, in Kentucky (Green, 1977; Boyte, 1980).

Continuing in 1976, the fear of natural gas shortages together with the unstoppable growth of the oil prices (See Tables 4 and 5) motivated Congress to authorize a federal research initiative, the *Unconventional Gas Research* (UGR) program, to study technologies for recovering gas from complex unconventional gas resources, such as tight sandstones and Devonian-age shales. In the same year, the *Gas and Research Institute* (GRI) was founded.

Synthetic fuels were now considered a strategic technology. In the 1975's plan, they were inserted in the mid-term technology achievement category, but the truth was there were high expectations for the rapid improvement of existing technologies. Those expected new fuels were seen as the possible best substitute of gasoline, the price of which was close to tripling since 1973 (Anderson, 1979; Edewor, 1979). (See Tables 4 and 5).

Chart 5.
Synthesis of the scientific literature on synthetic fuels for the year 1976: 488 items published (Data estimated from the DOE-OSTI).



1977. The Department of Energy

Fig. 1
Seal of the United States Department
of Energy

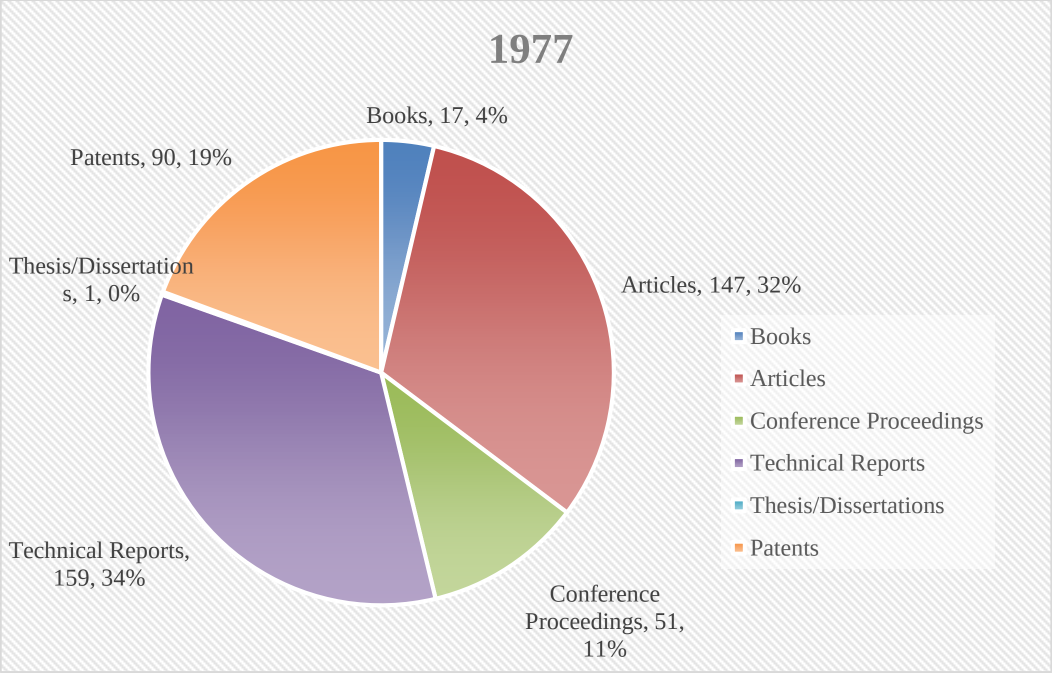
On August 4, 1977, President Jimmy Carter signed into law *The Department of Energy Organization Act* of 1977 which created the *Department of Energy* (Fig 1). The new agency, which began operations on October 1, 1977, consolidated the Federal Energy Administration, the Energy Research and Development Administration, the Federal Power Commission, and programs of various other agencies. The oil price was substantially in line with the previous year (See Table 5 and 6). The apparent stability of the market boosted the purchase of foreign oil in order to supply the internal request without draw upon the national wells.

Table 6.
Prices, production and import of crude oil in the U.S. in 1977
(Data sourced and elaborated from the U.S. Bureau of Statistics).

1977	
National crude oil production	3,009,000,000 barrels
Imports of crude oil	2,414,000,000 barrels
Average price per barrel	$ 8.57
Total cost to supply the national demand	$ 46,475,110,000

President Carter sought to create a stronger national energy agency with the powers that were necessary to develop the ambitious but necessary synthetic fuels program. Synthetic fuels legislation was well supported during the Ford Administration, and it found even more momentum during Jimmy Carter's tenure (Buck, 1982; Hamilton 2013). However, in spite the efforts, the number of published research in 1977 did not increased, but in contrary it had a small reduction.

Chart 6.
Synthesis of the scientific literature on synthetic fuels for the year 1977: 465 items published (Data estimated from the DOE-OSTI).

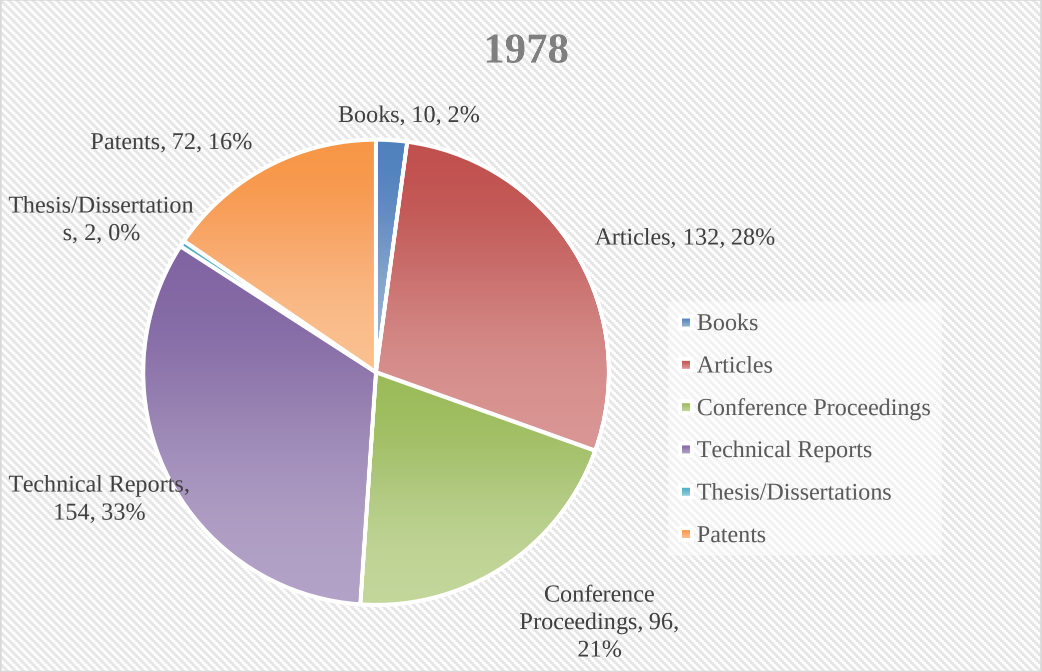


Between 1974 and 1978, the governments of the two administrations in concert with several industrial partners embarked on the course of attempting to develop a number of synthetic fuel options as rapidly as possible (Hamilton, 2013). Because of the crisis nature of the period, oil prices rose slightly again in 1978, (See Table 7), the projects selected for development were those that in theory had the best chance of providing replacement fuels for the economy in the short-term. Remained virtually unchanged from the previous year (See Chart 7).

Table 7.
Prices, production and import of crude oil in the U.S. in 1978
(Data sourced and elaborated from the U.S. Bureau of Statistics).

1978	
National crude oil production:	3,178,000,000 barrels
Imports of crude oil:	2,319,000,000 barrels
Average price per barrel	$ 8.96
Total cost to supply the national demand	$ 49,253,120,000

Chart 7.
Synthesis of the scientific literature on synthetic fuels for the year 1978: 467 items published (Data estimated from the DOE-OSTI).



Due to the rush and the anxiety to achieve results rapidly there was again little opportunity to conduct fundamental, or base, research. The result was that only those processes that had been under development in the previous era appeared to be viable as a course of action (Hendrickson and Cameron Engineers, 1975; Meyers, 1984). This draconian criteria of selection and granting explains the first anomaly detected in my early research – that is, the tepid increase and then a downturn in the trend of research and publication during this time period (1974 and 1978) that was considered of primary interest for the development of the synthetic fuels technology (See Charts 3 to 7). However, this sort of wacky race aimed to satisfy the synthetic fuels' *hunger-game* continuation was close to a radical change in 1979; in part because the new trajectory decided by Carter, but in greater extent because of the almost $4 extra cost per gallon of gasoline to Americans (See Figure 2 and Table 7).

Fig. 2.
The effect of the gas shortage at a
Gasoline pump in San Francisco, 1979.

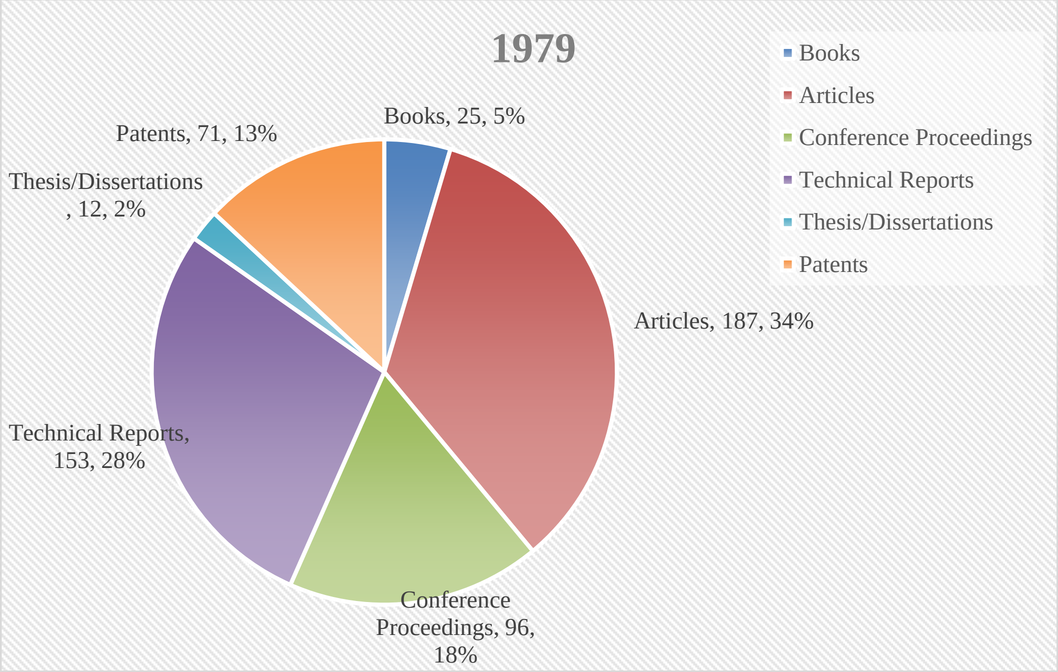
In 1979, like in 1973-74, the second oil shock of the decade was associated with events in the Middle East, but it was also driven by a strong global oil demand. The Iranian Revolution began in early 1978 and ended a year later when the royal reign of Shah Mohammad Reza Pahlavi collapsed and Sheikh Khomeini took control as Grand Ayatollah of the Islamic republic. In conjunction with the revolution, Iranian oil output declined by 4.8 million barrels per day (7% of world production at the time) by January 1979 (See Table 8).

Table 8.
Prices, production and import of crude oil in the U.S. in 1979
(Data sourced and elaborated from the U.S. Bureau of Statistics).

1979	
National crude oil production	3,121,000,000 barrels
Imports of crude oil	2,380,000,000 barrels
Average price per barrel	$ 12.64
Total cost to supply the national demand	$ 69,532,640,000

However, this supply disruption may not have been the most important factor pushing oil prices higher. Rather, the Iranian disruption may have prompted a fear of further disruptions and spurred widespread speculative hoarding. Oil prices began to rise rapidly in mid-1979, ending almost double between April 1979 and April 1980. The surging oil demand - coming both from a booming global economy and a sharp increase in precautionary demand - was responsible for much of the increase in the cost of oil during the crisis. These events boosted again the growing trend of the research, which gained a 20% more since the previous year (See Chart 8)

Chart 8.
Synthesis of the scientific literature on synthetic fuels for the year 1979: 544 items published (Data estimated from the DOE-OSTI).



1980. The Synthetic Fuel Corporation

In 1980, the *Synthetic Fuels Corporation* (SFC) is established by the Congress under the *Energy Security Act.* It represents a landmark in U.S. energy history, and the moment of apogee for research and development financed with public money.

The intended goal of the Synthetic Fuel Corporation was to boost the start-up, the implementation and the completion of commercially available processes for the production of synthetic fuels in great quantities. Congress did not leave the SFC financially impoverished in assisting in this task.

Table 9.
Prices, production and import of crude oil in the U.S.
in 1980 (Data sourced and elaborated from the U.S. Bureau of Statistics).

1980	
National crude oil production	3,146,000,000 barrels
Imports of crude oil	1,926,000,000 barrels
Average price per barrel	$ 21.59
Total cost to supply the national demand	$ 109,504,480,000

With an $88 billion endowment to the SFC, the development of synthetic fuels virtually became in that historical moment the *driving* national energy policy. Oil in 1980 burned out the symbolic threshold of $20 per barrel (see Table 9). In the light of that shocking number, every investment aimed to foster the national energy security was considered legit and necessary. The SFC looked to private industry to build a synthetic fuels industry yielding 500,000 barrels per day by 1987, a then ambitious, short-term project, but considered necessary to test and assess the true reliability, effectiveness and long-term potential of the technology. The generous capital endowed to corporations that would develop and build working technologies was supposed to be funded by a windfall-tax on excessive oil company profits. At the time, the oil firms seemed relatively on board with these developments, as corporations like Exxon invested heavily in Colorado's massive oil shale reserves.

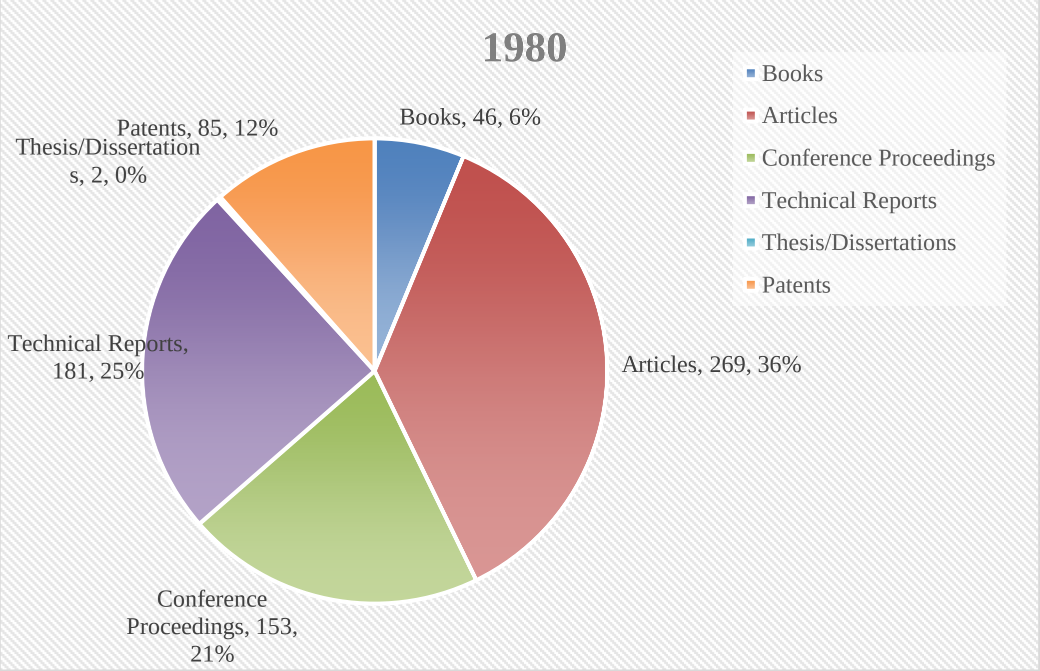
The SFC was a challenge; its goals were defined more on the desirable amount of fuel necessary to guarantee a safe supply rather than consider the available technology and the real chance of development. The SFC was to some extent a government-conceived *gamble* on the desired boost of the research and development system of the country (Crow et al, 1988). They were charged to break down the walls of the technological gap that was rendering synthetic fuels so inconvenient. From 1973 to

1980, the oil price multiplied 10 times, but in spite of that a gallon of traditional gasoline was cheaper that a gallon of synthetic. In 1980, even the civil society was perceiving this situation. The boundaries of the *puzzling* science and technology, the prerogative of selected cadres, were now colliding with popular science and the curious masses. The issues related to synthetic fuels – represented often in a bombastic way to the public as the *panacea* of all the energy disgraces – started to leak outside the laboratory and the experimentation plants.

Fig 3.
The 1980's *The Formula* wall-paper.

Even Hollywood rode the wave of the synthetic fuels question. On Christmas 1980, the American theaters projected the movie *The Formula* (See Figure 3). The exceptional cast featured by two Academy Award winners played out the romance on the shady businesses of the Big Oil, who hid for forty years the genuine and working German formula, to produce abundant and cheap synthetic fuels (Wade, 1980). The contemporary science did know very well that there was nothing hidden that could instantly solve the problem. As it has been pointed out previously, the original German synthetic fuel processes presented in the 1940s, contained structural engineering gaps. The establishment of the SFC had a direct effect on the research on synthetic fuels. In 1980, the number of publications grew almost 50% in just one year (See Chart 9).

Chart 9. Synthesis of the scientific literature on synthetic fuels for the year 1980: 736 items published (Data estimated from the DOE-OSTI).



The SFC in 1980 planned to reach its goal following a two-phase strategy. The emphasis during the first phase was on developing new fundamental experience with diverse basic technologies, meanwhile building the commercial base necessary to achieve the production goal. In the second phase, the SFC established a comprehensive production strategy to be implemented using the widest diversity of feasible technologies. All this was expected to happen in the very short term of five years.

Table 10.
Prices, production and import of crude oil in the
U.S. in 1981 (Data sourced and elaborated from the U.S. Bureau of Statistics).

1981	
National crude oil production	3,129,000,000 barrels
Imports of crude oil	1,605,000,000 barrels
Average price per barrel	$ 31.77
Total cost to supply the national demand	$ 150,399,180,000

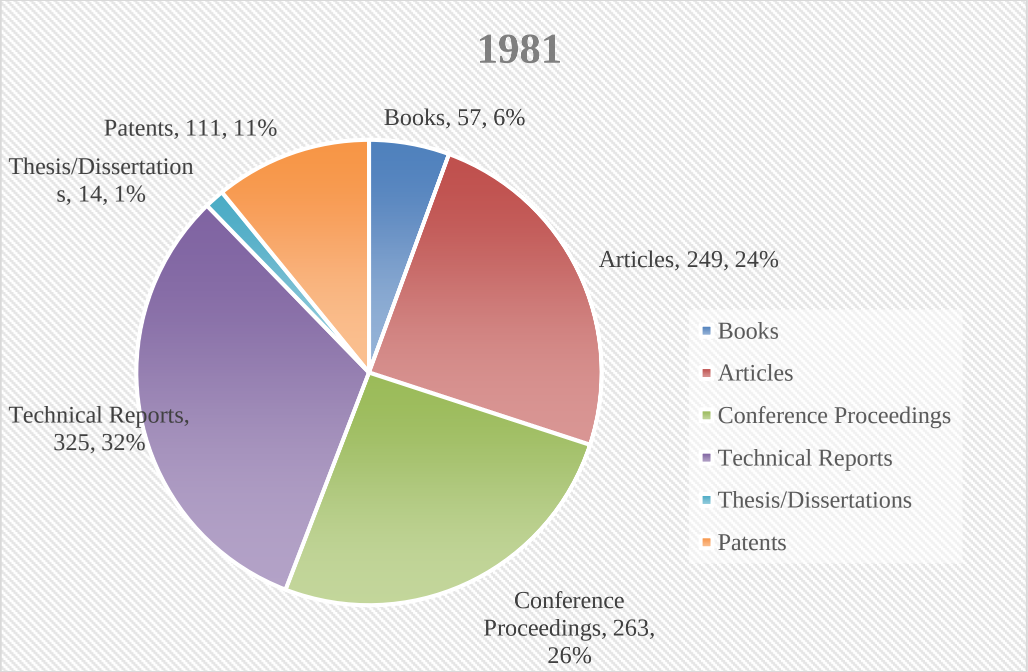
The year 1980 starts the new positive trend in synthetic fuels research and publications; in 1981, the number of literature published almost doubled and appears in line with the new political trajectory to finance a wider range of projects (See Charts 9 and 10). However, the year 1981, unexpectedly, turned out to be another 1953. The arrival of Ronald Reagan in the White House and the onset of a major oil glut again wiped out the political will and the economic justification for synthetic fuels production in government circles.

In spite of the fact that the country paid at the end of the year the highest oil check ever recorded (See Table 10), the administration quietly let the largest single domestic program ever passed in the United States up to that point expire by 1984, and it dispersed hardly any of its $88 billion in funds. Although the fundamental issue of reliance upon foreign petroleum for liquid fuels had not been solved in any permanent fashion, the alignment of interests between the Saudi monarchy and the United States – caused by the Iranian Revolution, the Iran-Iraq War, and the Soviet Invasion of Afghanistan – had been enough to bury and forget the oil shock under another lake of oil for the incoming future.

In 1981, politics wins over research and science. The price to pay was the *interim* crazy cost of crude oil and refined products, which was expected to decrease in

1982 due to the new agreement between the U.S government and some exporter countries in the Middle East (See Table 11). Scientists found themselves powerless to the *sabotage* of the thriving Synthetic Fuels Corporation's program that just in two years doubled the research on production technology in the attempt to meet the demands of the original 5-year timeline (See Chart 10).

Chart 10.
Synthesis of the scientific literature on synthetic fuels for the year 1981: 1019 items published (Data estimated from the DOE-OSTI).



1982 -1985. Disinvestments and research

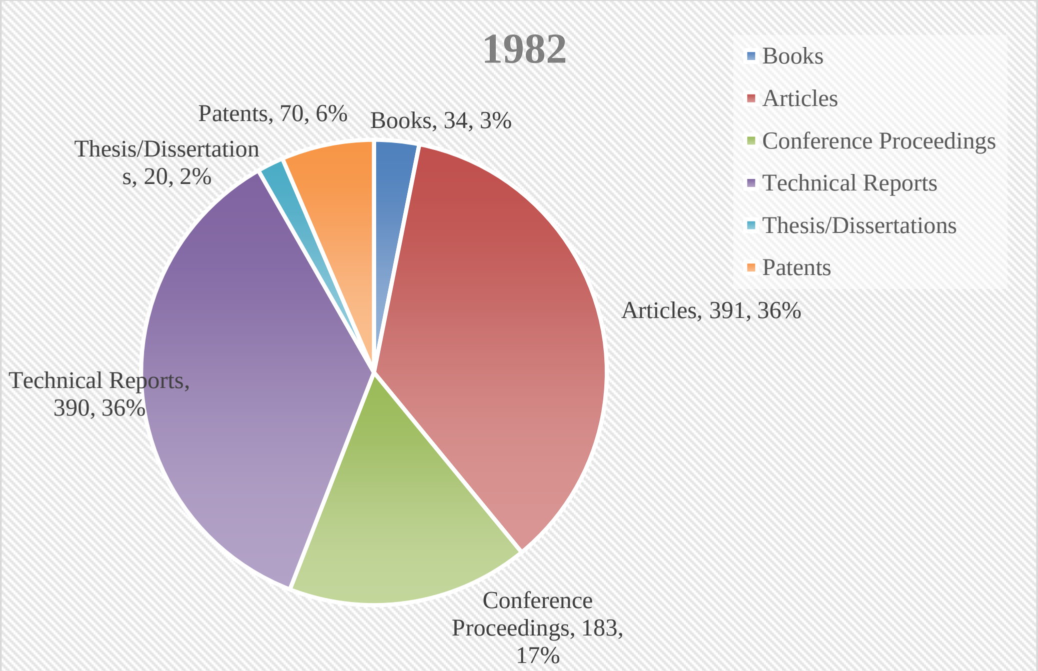
The threat of the funding cuts and the loss of political favor were real. But, the projects that had already received grants and in-kind support were fully operative, maximizing time and resources.

Table 11.
Prices, production and import of crude oil in the U.S.
in 1982 (Data sourced and elaborated from the U.S. Bureau of Statistics).

1982	
National crude oil production	3,157,000,00 barrels
Imports of crude oil	1,273,000,000 barrels
Average price per barrel	$ 28.52
Total cost to supply the national demand	$ 126,343,600,000

In 1982, the most notable effect of the *research thrust* fueled by money and driven by the concern for the future, was the higher number of publications on synthetic fuels technology ever documented in the Department of Energy records (See Chart 11).

Chart 11.
Synthesis of the scientific literature on synthetic fuels for the year 1982: 1088 items published (Data estimated from the DOE-OSTI).



Forecasting is dangerous if you believe in the inevitability of the forecast. Prophetry is the second oldest profession, and sometimes it somehow gets a reputation similar to that of the oldest. Forecasting is most helpful, however, if it is looked upon as a preview of possibilities that then become a challenge to accomplish. Forecasting, in the latter frame of mind, removes any reluctance to update continuously and, indeed, gives positive incentive to do so.

Table 12.
Prices, production and import of crude oil in the U.S.
in 1983 (Data sourced and elaborated from the U.S. Bureau of Statistics).

1983	
National crude oil production	3,171,000,000 barrels
Imports of crude oil	1,215,000,000 barrels
Average price per barrel	$ 26.19
Total cost to supply the national demand	$ 114,869,340,000

Unfortunately, the forecasts on oil crude oil prices and synthetic fuels in 1979-1980 came under the pressure of hurry and technological miscalculation. Since the adjustment of oil prices started in 1982, experts began predicting more stable oil supplies and a declining costs in the next several years (See Tables 11 and 12). The public's fear of a massive energy shortage subsided (Bunneil, 1984; Marshall, 1984).

Chart 12.
Synthesis of the scientific literature on synthetic fuels for the year 1983: 635 items published (Data estimated from the DOE-OSTI).

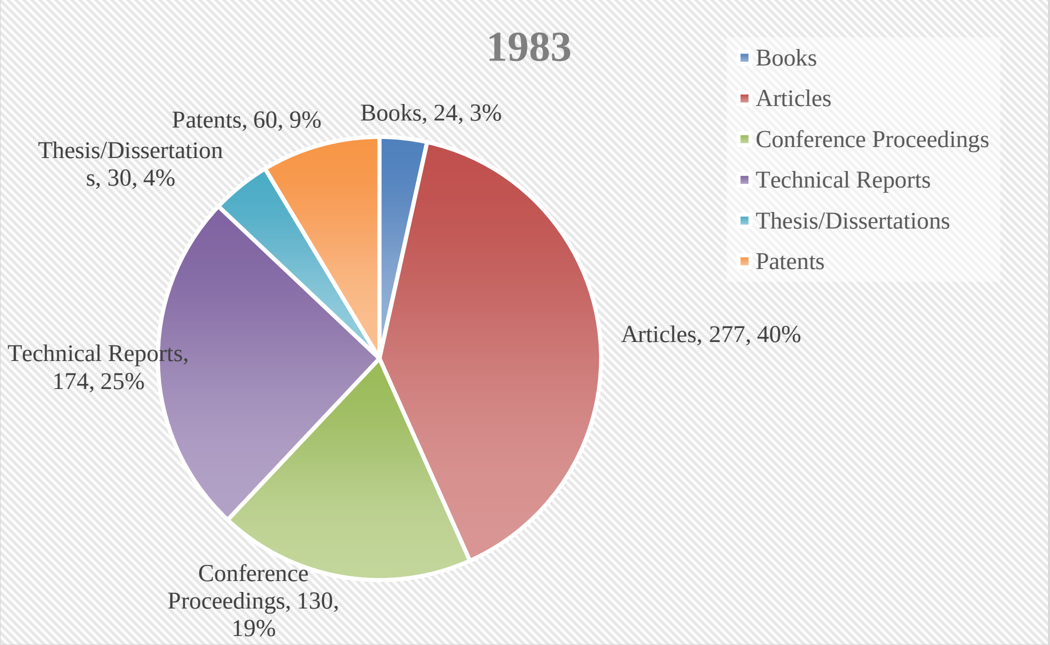
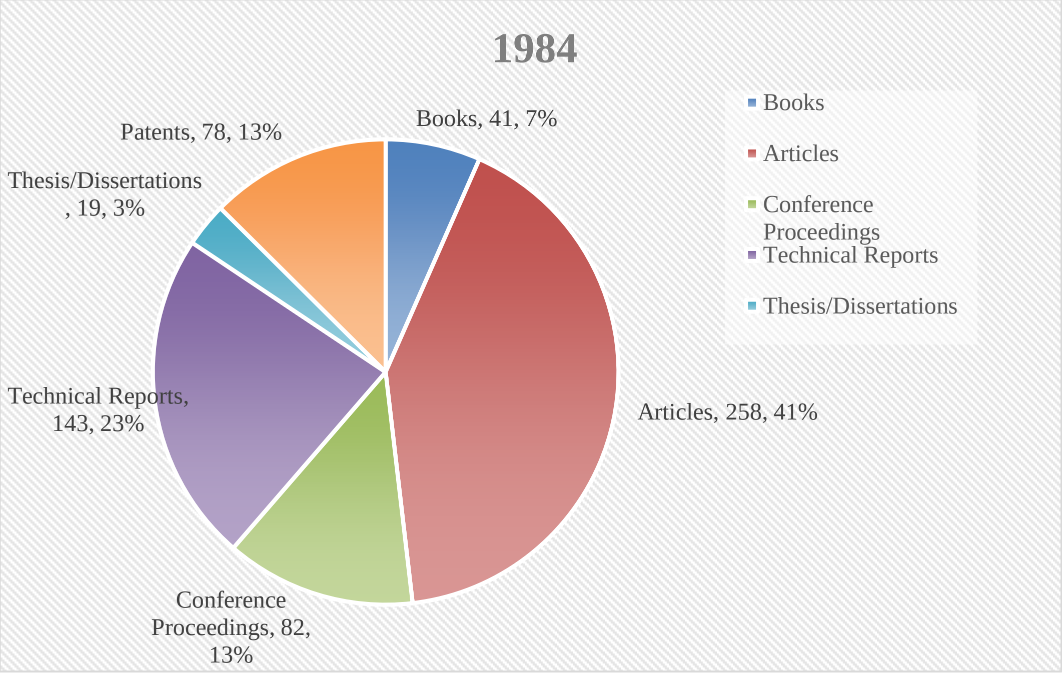


Table 13.
Prices, production and import of crude oil in the U.S. in 1984
(Data sourced and elaborated from the U.S. Bureau of Statistics).

1984	
National crude oil production	3,250,000,000 barrels
Imports of crude oil	1,254,000,000 barrels
Average price per barrel	$ 25.88
Total cost to supply the national demand	$ 116,563,520,000

In 1984 the officers of the Synthetic Fuels Corporation claimed that the general situation was stable; the SFC was not about to go out of business, but ready to discuss the prospects for 1984 and to establish a schedule for 1985. However, the real schedule emerging during the year suggested that the SFC had really little to do after 1984 beyond monitoring projects already in the pipeline. The SFC's targets declared for 1984 was to assist about a dozen projects which represented a diversity of resources and technologies in order to establish an industry and environmental infrastructure and to develop the management and manufacturing capability to assure that synthetic fuels would be available on time if and when they are needed (Bunneil, 1984; Marshall, 1984; United States Congress, 1984a, 1984b; Yanarella and Green, 1987).

Chart 13.
Synthesis of the scientific literature on synthetic fuels for the year 1984: 621 items published (Data estimated from the DOE-OSTI).



From 1980 to 1984 more than 160 projects were evaluated and approved, but in 1985 almost 150 were turned down (Bunneil, 1984). In 1984 and 1985 the effects of this turn in the funding policy is evident by the decrease of research published and recorded by the DOE_OSTI. However, in spite of this discouraging *bulletin of casualties*, the trend of the research stabilized within the 1975-1978 quota (See Charts 13 and 14)

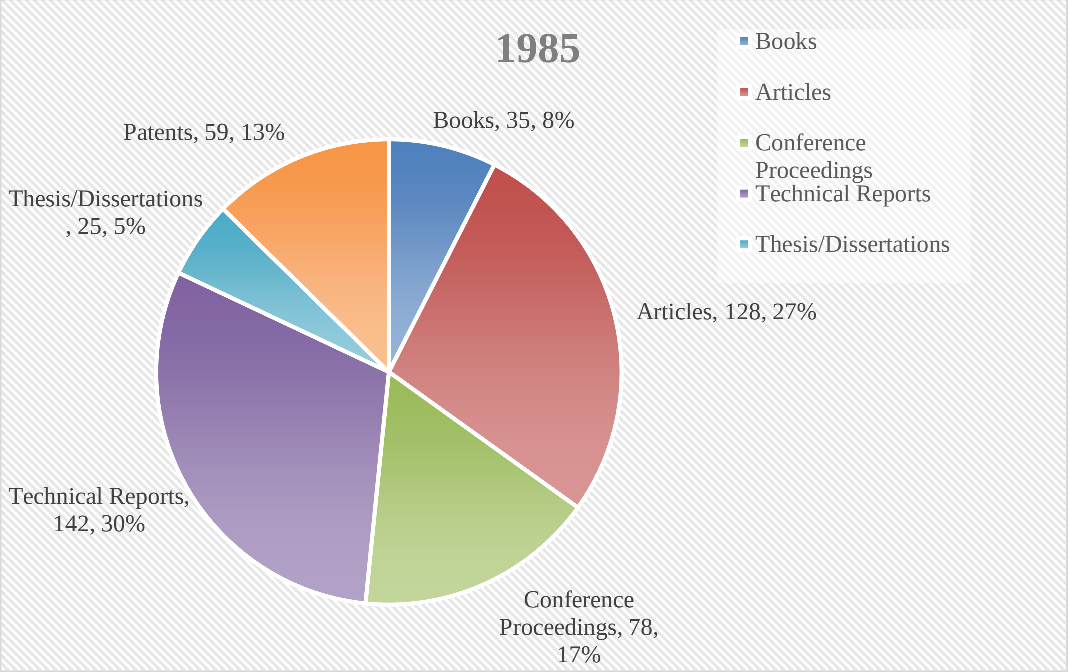
Table 14.
Prices, production and import of crude oil in the U.S.
in 1985 (Data sourced and elaborated from the U.S. Bureau of Statistics).

1985	
National crude oil production	3,275,000,000 barrels
Imports of crude oil	1,168,000,000 barrels
Average price per barrel	$ 24.09
Total cost to supply the national demand	$ 107,031,870,000

With the 1984-1985 *oil glut* and the forecast of lower prices President Ronald Reagan signed into law the *Consolidated Omnibus Budget Reconciliation Act* of December1985

(Law 99-272) which among other things abolished the Synthetic Fuels Corporation (Copulos, 1985).

Chart 14.
Synthesis of the scientific literature on synthetic fuels for the year 1985: 467 items published (Data estimated from the DOE-OSTI).



1986 - 1988. The non-hiatus: a lesson from the past?

The demise of the Synthetic Fuel Corporation in 1985, together with the dramatic reduction of the federal synthetic fuel research funding since 1981 of more than 90% (in 1974 dollars, from $377 to $20 million), and the post-1982 shut down of the major synthetic fuels research labs in industry, the United States ended its fourth synthetic fuels technology development thrust in this century, without having demonstrated the commercial viability of the mass production process. At the end of 1986, neither government nor private industry has constructed a commercial-size coal liquefaction plant in the United States, and it is simply not known whether Direct Coal Liquefaction is a viable technology. Between 1986 and 1988, the oil prices stepped back to the pre-

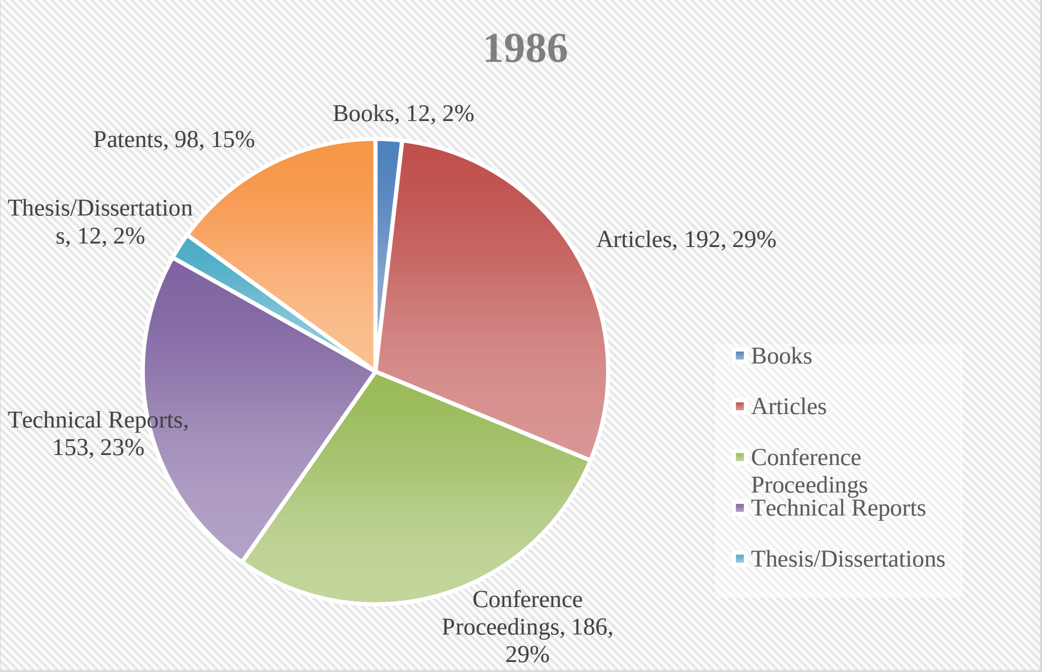
1980 levels and the premises of further prices reductions virtually erased any request for synthetic fuels in the short-medium term (See Tables 15, 16, and 17).

More than six years after the creation of the SFC and almost one year after its demise, the program have produced no new synthetic oil, but much controversy. On the other hand, for the first time in its energy history, the United States produced an exceptional and unheard-of wealth of knowledge on synthetic fuels (See Chart 15)

Table 15.
Prices, production and import of crude oil in the U.S.
in 1986 (Data sourced and elaborated from the U.S. Bureau of Statistics).

1986	
National crude oil production	3,168,000,000 barrels
Imports of crude oil	1,525,000,000 barrels
Average price per barrel	$ 12.51
Total cost to supply the national demand	$ 58,709,430,000

Chart 15.
Synthesis of the scientific literature on synthetic fuels for the year 1986: 653 items published (Data estimated from the DOE-OSTI).



Between 1920s and 1960s, the development failure associated with synthetic fuels production technology in the United States is partly explained by: 1) the economics of the oil market, 2) the difficult coordination between private and public sectors, 3) the politics of the energy crises. However, finally in the mid-1980s it was perceived in the scientific community the damage that could be procured by the discontinuous scientific and engineering activity associated with synthetic fuel technology. Subsequently, scientists understood how deleterious another hiatus would be. The development of efficient and commercial production of synthetic fuels in the United States has experienced several major hiatuses where little or no significant research, development, or demonstration was carried out or where insufficient time and effort were devoted to the technology. These hiatus periods were the product of inconsistent public policy and underinvestment in basic research by industry and government, and had the result of limiting the sought after fuel replacement process.

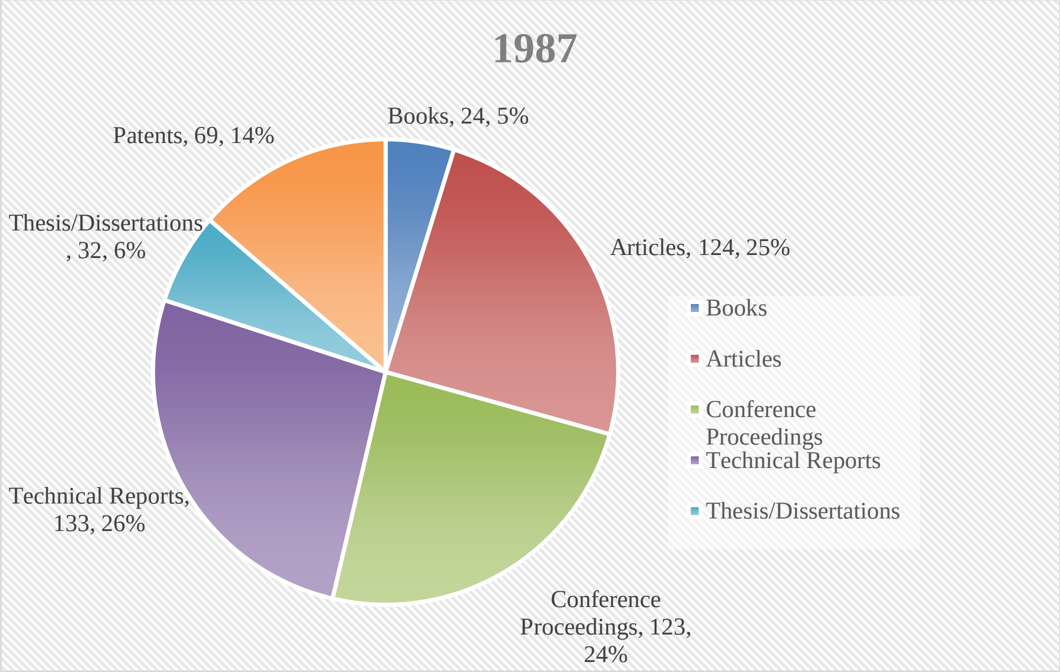
In 1986, the situation was different. After twelve years of intensive research (1974-1985), it was understood that a further hiatus period would have irreparably wasted the results achieved with the nearly-completed research, development, and demonstration program. The discontinuous support or breaks in the process development cycle are critical factors that could undermine, for example, the information/knowledge survival rates. Both in private firms and government settings, information and knowledge regarding process technologies may be lost during prolonged periods of non-R&D activity. Another important *loss factor* is connected to the person-to-person knowledge transfer. When an R&D team is dismantled and assigned to new duties, the loss of information is high and disrupts that process of continuous incremental improvements.

When the U.S. Synthetic Fuels Corporation was abolished by law on April 18, 1986, the responsibility of monitoring the existing synthetic fuels project was transferred to the Office of the Secretary of the Treasury. In addition, on April 19, 1986, the Secretary established the *Office of Synthetic Fuels* to monitor, technically and environmentally, every federal synthetic fuel project. The trends of publication recorded in Charts 15, 16 and 17 confirmed the continuity of the research that was now entrusted to the *Office of Synthetic Fuels* of the Secretary of Treasury. Like in 1984 and 1985, the period 1986-1988 maintains the 1975-1979 research levels. This data shows that the dismissing of the SFC dramatically affected research activity, but this trend did not fall back to the pre-1973 levels, which is when oil abundancy and low prices were granting energy wealth to the country. The new energy wealth of the late 1980s (See Tables 15, 16, 17) was indelibly marked by the 1970s fears. The synthetic fuels were no more a feedstock of primary necessity, but still a "spare tire to keep in the trunk".

Table 16.
Prices, production and import of crude oil in the U.S.
in 1987 (Data sourced and elaborated from the U.S. Bureau of Statistics).

1987	
National crude oil production	3,047,000,000 barrels
Imports of crude oil	1,706,000,000 barrels
Average price per barrel	$ 15.41
Total cost to supply the national demand	$ 73,243,730,000

Chart 16.
Synthesis of the scientific literature on synthetic fuels for the year 1987: 505 items published (Data estimated from the DOE-OSTI).



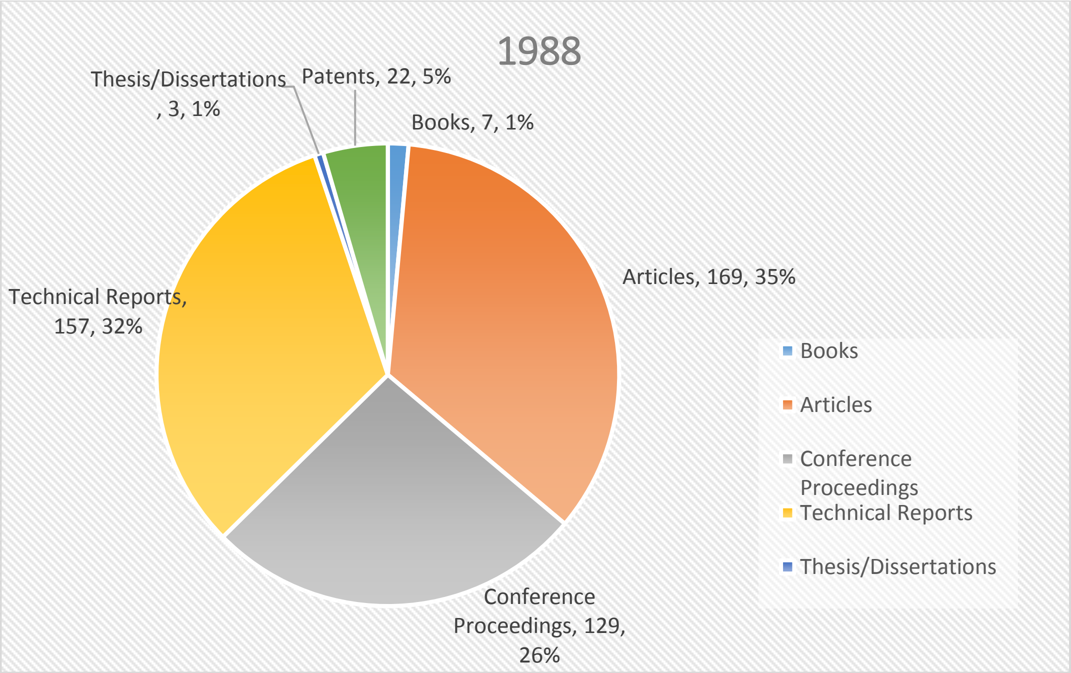
The oil industry was divided over when oil prices would rise again and how they would last. The uncertainty made it difficult to know when, if ever, synthetics fuels will be profitable.

Underlying this seeming resilience of synthetic fuels was the fact that the fundamental problem of a dwindling domestic supply of liquid fuels had remained unsolved. Foreign petroleum supplies, even, or perhaps especially, when they were inexpensive, posed national security problems. The use of cheap imported oil conserved the American petroleum reserves, which was considered an important prerogative (See Table 17). On the other hand, this trend and the extremely low prices of the imported crude would have threatened the development of the domestic petroleum industry (featured by higher maintenance and operational costs), and at the same time the country would have remained vulnerable to enemy interference in the oil fields of foreign exporter countries. Attempting to utilize primarily domestic sources of petroleum kept the domestic oil industry relatively strong and minimized the threat of foreign control, but it meant higher fuel prices for American consumers and led to the accelerated draining of American reserves (United States. General Accounting Office, 1983).

Table 17.
Prices, production and import of crude oil in the U.S.
in 1988 (Data sourced and elaborated from the U.S. Bureau of Statistics).

1988	
National crude oil production	2,979,000,000 barrels
Imports of crude oil	1869,000,000 barrels
Average price per barrel	$ 12.58
Total cost to supply the national demand	$ 60,987,840,000

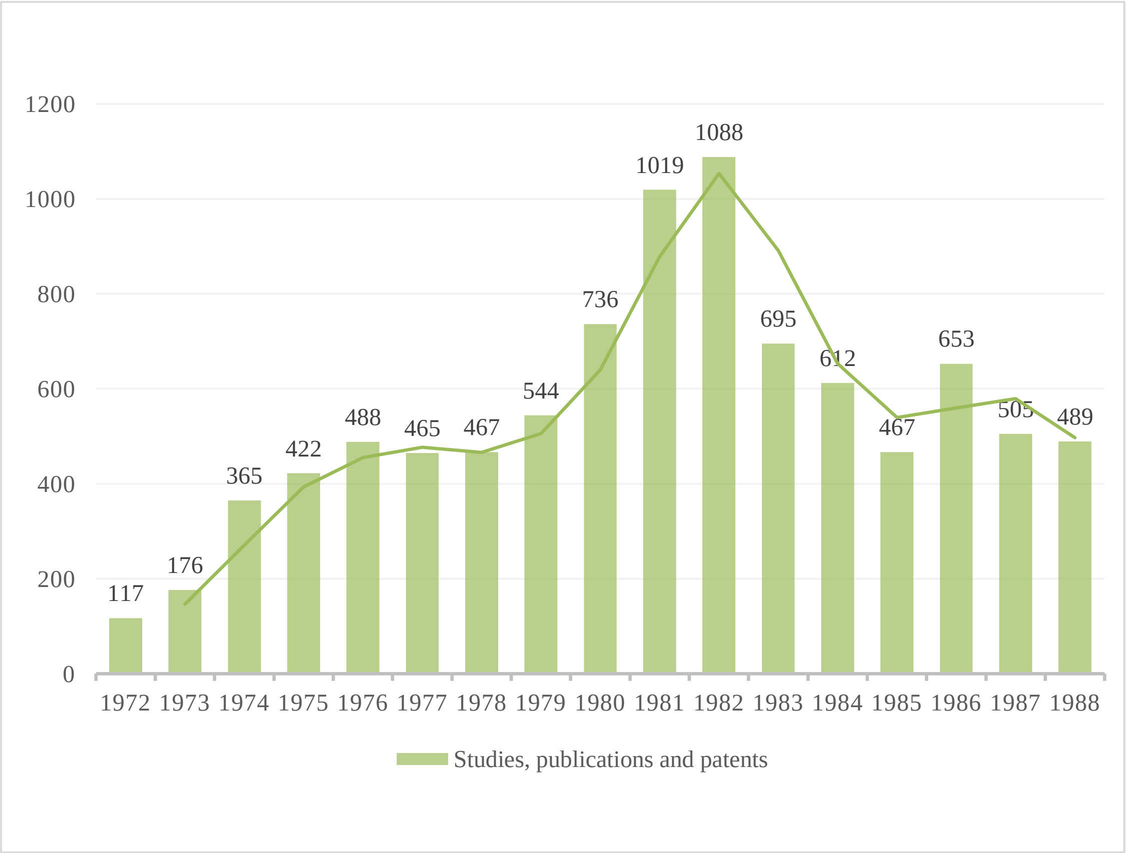
Chart 17.
Synthesis of the scientific literature on synthetic fuels for the year 1988: 489 items published (Data estimated from the DOE-OSTI).



Conclusions

It is commonly accepted that the failure of the Synthetic Fuels Program did spell the end for American attempts to develop coal-based synthetic fuels. However, the data retrieved from the Department of Energy showed that the slowing down during the 1980s in the development of national technology was not so dramatic and sudden, but better equated and stabilized to the average levels recorded between the 1974 creation of ERDA and the 1979 oil crisis (See Chart 18).

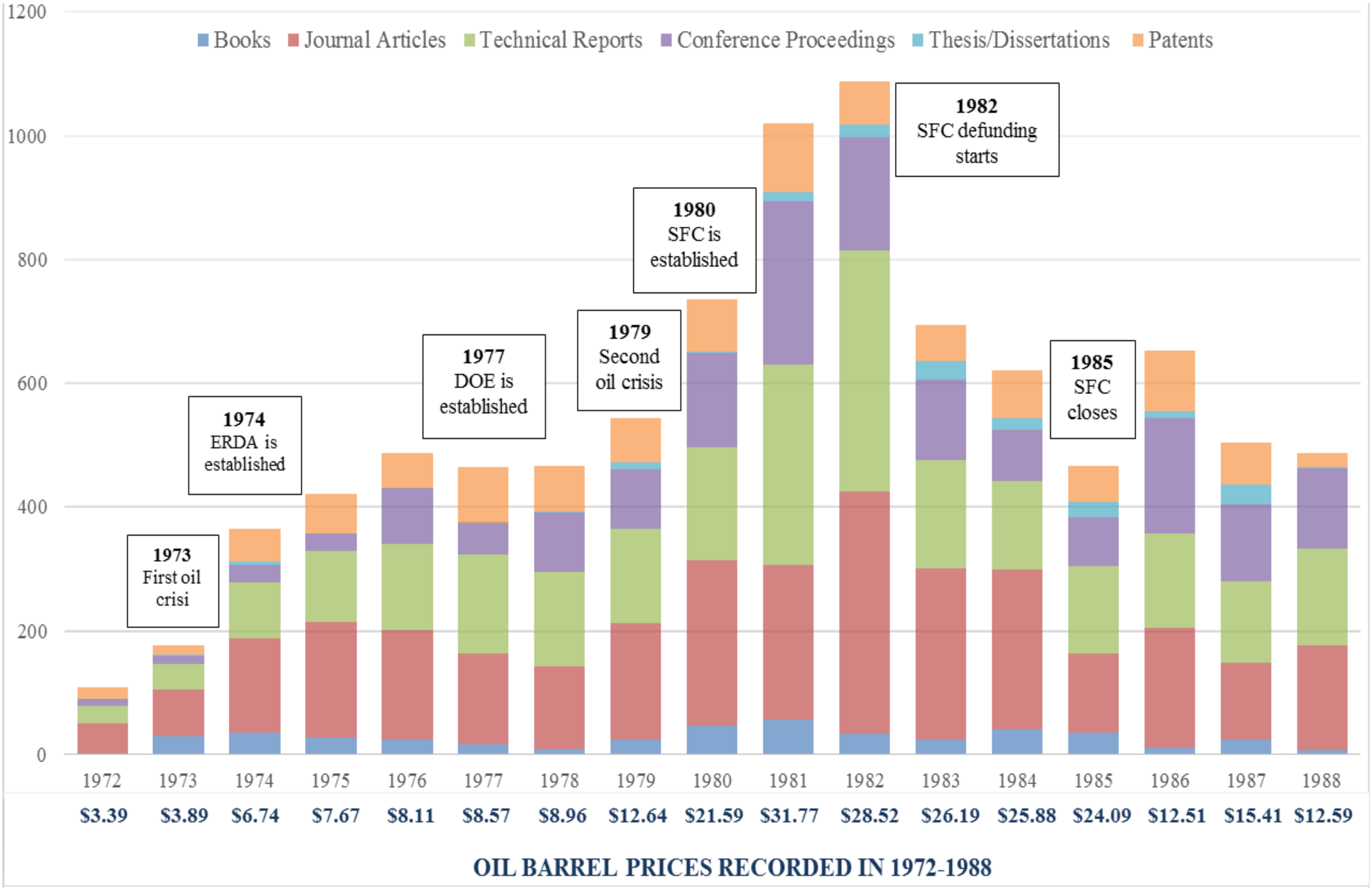
Chart 18.
Comparative time series of the scientific literature on synthetic fuels published from 1972 to 1988 (Data estimated from the DOE-OSTI).



The researchers still committed to the synthetic fuel challenge in the second half of the 1980s agreed on the necessity of long-term studies to achieve the base-research required to successfully experiment with new pioneering technologies. The short term project finalized to develop ready-to-go technology for immediate use did not pay off. On the other hand, it was now clear that resources allocated by the Synthetic Fuel Corporation a few years earlier were spread too thinly over multiple and uncoordinated projects. The low but consistent trend of publications detected between the 1985 and 1988 in the records of the United States Department of Energy might illustrate the answer to the call for long-term base research. Unfortunately this research could not ascertain that fact with certainty. However, that trend might be found in the several successful activities that, although still not executed on an industrial scale, granted good yields and good results (Collings, 2002).

Chart 19 shows the most important data that allowed the completion of this research and the achievement of the expected aims. The reader finds the prices of oil recorded from 1972 to 1988 in correspondence to the number of the literature on synthetic fuels published in the same year. Also in evidence are the key events that influenced the increasing and the lowering of the publications issued. The reader can acknowledge how the constant increase of the energy prices between 1974 and 1981 was the main reason behind the urgency to set up major national energy policies that involved in large extent the development of synthetic fuels production technologies. Therefore, the research proved the dependence of publications issued to changing? oil prices. In 1973 and 1979 energy crises triggered the creation of, respectively, the ERDA (1974), the DOE (1977), and the Synthetic Fuel Corporation (1980). Those have financed and fostered the creation of the program aimed to sustain the hundreds of research institutes that from 1972 to the 1980's peak, boosted by ten times the production of studies on synthetic fuel technology. Lastly, the 1982's rumors and 1985 definitive confirmation of the trend reversal of the government energy policy has simply diminished and not erased the development of studies on this questioned and so long waited technology. These data show the consciousness of the government who promptly addressed the energy issues with a massive initiative; and, at the same time, dismissed the investment of large capital when the state of emergency was solved with an alternative (political) solution.

Chart 19.
The scientific literature on synthetic fuels published from 1972 to 1988. The data are framed between the major events that influenced the trend of the publications and the timeline of the crude oil prices (Data estimated from the DOE-OSTI, U.S. Bureau of Statistics, Yanarella, 1987, Crow, 1988, Lifset, 2014).



However, in spite of this achievement, I also acknowledge the most important limit of my research. My study did regard only the sources I detected and gathered in the databases of the Department of Energy. The timing and the target of this research prevented me from extending my analysis using a larger pool of sources. The most relevant example of sources that could have enriched my work is the journal *Fuel Processing Technology*. The first issue of this journal was published in August 1977, right in the middle of the two crises, and this journal is still active. Published by Elsevier, in 2017 the journal celebrated 40 successful years of activity. It is listed in the Clarivate Web of Science index, and considered one of the authoritative sources of communication in the field of synthetic fuels production technologies. Since 1977, the journal published at an international level about 9,500 articles. This journal is one of the many physical proofs that the research on synthetic fuels did not suffer the commonly believed dramatic hiatus.

There is no easy road to instant commercialization of new unconventional technologies. Research and development requires years of testing, billions of dollars in new capital and the construction of highly complex facilities (Hughart, 1977). The attempted development of the synthetic fuels production technology represents technological advance but competitive failure because of overemphasis on a quick-fix development program rather than basic research (Bourji, 1985). "The rush is a bad counselor", might be the sentence that sums up the sense of this story. *Schizophrenic* investments, the unwise use of science only for political goals, and the need to privilege a secure, economic and efficient resource (oil) to guarantee energy to preserve the peace of the civil society have motivated the non-development of a difficult technology.

Too rapid changes result in inefficiency. Being unable or unwilling to stay with a new product or process long enough to perfect it loses the advantages of specialization. The accelerated pace of technological change requires an accelerating growth in wisdom. This is a faculty that enables people to choose what is worth changing because it needs changing and can be changed. Also, it enables people to decide what is worth preserving because it is already good; it is inevitable; and it should be adapted. The society who has this gift can distinguish between mere change and true progress.

When thinking about changing the technology, a society must think of research and development: scientific research represents the distance between technological problems and their answers. Research might be defined as an *attack* on the status quo. Development is the consolidation of the gains made during a successful attack. The researcher involved in studies on the synthetic fuels in the 1970s and 1980s soon learned a lesson: as he sought for the answer to a given problem, he usually uncovered new problems. Probably, that challenged him as much, or even more, than the original problem. The research goes on (Estonia & United States, 2012).

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Appendix A: Sample of the institutes supported by the Department of Energy in 1972, 1980 and 1988

1972

1. Office of Science and Tech., Washington, D.C. (USA)
2. University of Utah, Salt Lake City, (USA)
3. Syncrude Canada Ltd
4. Bureau of Mines, Pittsburgh, PA (USA)
5. Bureau of Mines West Virginia University, Morgantown (USA)
6. Oklahoma State University, Stillwater (USA)
7. Shell Cent., Shell Int. Pet. Co. Ltd., London, England
8. Soc. Mallet, Male, Brazil
9. Australian Defense Scientific Service, Adelaide, Aust.
10. Noyes Data Corp., Park Ridge,, NJ (USA)
11. Langley Res. Cent., NASA, Hampton, VA (USA)
12. Laramie Energy Res. Cent., Bur Mines., Laramie, WY(USA)
13. Inst. Gas Technol., Illinois Inst. Technol., Chicago, IL (USA)
14. Dep. Min., Metall. Fuels Eng., University Utah, Salt Lake City, Utah (USA)
15. Laramie Energy Res. Cent., Bur. Mines, Laramie, Wyo. (USA)
16. Consolidation Coal Co., Library, PA (USA)
17. J. J. Jones Assoc., Villanova, PA (USA)
18. Inst. Gas Tech., Chicago, IL (USA)
19. U. S. Dept. of the Interior, Bur. of Mines, Laramie, WY (USA)

20. Escher Technol. Assoc., St. Johns, MI (USA)
21. Selas of America (Nederland) N.V., The Hague
22. Bureau of Mines, Washington, D. C. (USA)
23. National Chemical Lab. for Industry, Tokyo, Japan
24. Mobil Res. and Dev. Corp., New York, NY (USA)
25. Garrett Research and Development Co., Inc., Los Angeles (USA)
26. Escher Technology Associates
27. Stanford University, Calif. (USA). Dept. of Aeronautics and Astronautics
28. Bureau of Mines, Washington, D.C. (USA)
29. National Aeronautics and Space Administration, Cleveland, Ohio (USA). Lewis Research Center
30. National Aeronautics and Space Administration, Cleveland, Ohio (USA). Lewis Research Center
31. Bureau of Mines, Pittsburgh, Pa. (USA). Pittsburgh Mining and Safety Research Center
32. Hittman Associates, Inc., Columbia, Md. (USA)
33. Bureau of Mines, Bartlesville, Okla. (USA). Bartlesville Petroleum Research Center
34. Office of Coal Research, Washington, D.C. (USA)
35. General Electric Co., Santa Barbara, Calif. (USA)
36. Mitre Corp., McLean, Va. (USA)
37. Institute of Gas Technology, Chicago, IL (USA)
38. California University, Livermore (USA). Lawrence Livermore Lab.

39. Engineering Foundation, New York (USA)

40. Division of Reactor Development and Technology (AEC), Washington, DC

41. Department of Transportation, Washington, D.C. (USA)

42. Federal Council for Science and Technology, Washington, D.C. (USA). Committee on Scientific and Technical Information

43. Consolidation Coal Co., Library, Pa. (USA). Research Div.

44. Lockheed-California Co., Burbank (USA)

45. Upper Midwest Council, Minneapolis, Minn. (USA)

46. Maryland University, College Park (USA). Dept. of Mechanical Engineering

47. Tennessee University, Knoxville (USA)

48. Department of the Interior, Washington, D.C. (USA)

1980

1. ONERA, Chatillon-sous-Bagneux, Hauts-de-Seine, France

2. NASA, Lewis Research Center, Cleveland, Ohio (USA)

3. Univ of Texas-Austin, Austin, TX (USA)

4. Princeton Univ, NJ (USA)

5. La State Univ, Baton Rouge (USA)

6. Princeton Univ, NJ (USA)

7. GE, Schenectady, NY (USA)

8. Oak Ridge National Lab., TN (USA)

9. Exxon Res and Eng. Co

10. Oak Ridge National Lab., TN (USA)

11. Pacific Northwest Lab., Richland, WA (USA)
12. National Estimating Society, Huntsville, AL (USA)
13. National Aeronautics and Space Administration, Cleveland, OH (USA). Lewis Research Center
14. Wisconsin University, Madison (USA). Dept. of Mechanical Engineering
15. Chevron Research Co.
16. Saarberg-Fernwaerme, GmbH, Saarbruecken, Germany
17. Pennsylvania State University, PA (USA)
18. Dow Chemical Co.
19. Enerco, Inc., Langhorne, PA (USA)
20. Chevron Res. Co.
21. University of Delaware, DE (USA)
22. Shell Dev. Co.
23. Dept. of Energy, Washington, D.C. (USA)
24. Conoco Coal Dev Co, USA
25. D'Appolonia Consult Eng Inc, Pittsburgh, PA, USA
26. Ruetgerswerke AG, Duisburg-Meiderich, Germany
27. University of Oregon, Eugene, OR (USA)
28. Dept. of Energy, Washington, D.C. (USA)
29. Stanford Res. Inst. Int.
30. Fluor Power Services, Inc., Chicago, IL (USA)
31. Bio-Energy Council, Washington, DC
32. University of California, Berkeley

33. Brookhaven National Lab., Upton, NY
34. University of Santa Clara, CA
35. University of Michigan, Ann Arbor
36. India Inst. of Tech., Madras
37. California State University, Long Beach
38. National Aeronautics and Space Administration, Cleveland, OH (USA). Lewis Research Center
39. University of Wisconsin, Madison
40. University of California, Berkeley
41. Warren Spring Lab.
42. Ebasco Services, Inc., New York City, NY
43. State University of New York at Buffalo, Amherst
44. Wayne State University, Detroit, MI
45. Ames Lab., IA
46. Michigan State University, East Lansing
47. Exxon Res and Eng Co, Linden, NJ
48. Union Carbide Corp., South Charleston, WV
49. California Inst. of Tech., Pasadena
50. Ryckmans Emergency Action and Consulting Team, St. Louis
51. Dordt Coll.
52. University of Colorado
53. Louisiana State University
54. Pacific Northwest Laboratory, Richland, WA 99352

55. Stanford University, CA

56. Energy Research Institute (SERI)

57. University of Manchester Inst. of Science and Technology, England

58. Union Carbide Corp.

59. Argonne National Lab., IL

60. Pennsylvania State University, University Park

61. University of Massachusetts, Amherst

62. Wright State University, Dayton, OH

63. Dept. of Agriculture, Fort Collins, CO

64. University of Massachusetts, Amherst

65. University of California, Los Angeles

66. Shell Res. B.V.

67. Exxon Research and Engineering Co., Linden, NJ

68. National Bureau of Standards, Washington, DC

69. Yale University, New Haven, CT

70. Yale University, New Haven, CT

71. Virginia Polytechnic Inst. and State University, Blacksburg

72. Northwestern University

73. McMaster University

74. Northwestern University

75. Bechtel Inc.

76. US Forest Service's Forest Products Laboratory, Madison, WI

77. Forest Service, Madison, WI

78. Northwestern University, Evanston, IL
79. Northwestern University, Evanston, IL
80. Mound Facility, Miamisburg, OH (USA)
81. Clark Oil and Refining Corp., Milwaukee, WI (USA)
82. Bureau of Mines, Albany, OR (USA). Albany Research Center
83. National Research Council, Washington, DC (USA). Committee on Alternative Fuels for Maritime Use
84. Massachusetts Inst. of Tech., Oak Ridge, TN (USA). School of Chemical Engineering Practice
85. Committee on Science and Technology (U.S. Congress. House), Washington, DC Subcommittee on Energy Research, Development and Demonstration (Fossil Fuels)
86. Rice University, Houston, TX (USA)
87. USDOE Technical Information Center, Oak Ridge, TN
88. Department of Energy, Washington, DC (USA)
89. Lindsey-Kaufman Co., Tenafly, NJ (USA)
90. Council for Scientific and Industrial Research, Pretoria (South Africa). National Mechanical Engineering Research Inst.
91. Catalysis Research Corp., Palisades Park, NJ (USA)
92. Michigan University, Ann Arbor (USA). Dept. of Mechanical Engineering
93. Council for Scientific and Industrial Research, Pretoria (South Africa). National Mechanical Engineering Research Inst.

94. Department of Energy, Pittsburgh, PA (USA). Pittsburgh Energy Technology Center

95. National Alcohol Fuels Commission, Washington, DC (USA)

96. Bureau of Mines, Albany, OR (USA). Albany Research Center

97. Jones (John David) and Associates, Inc., Cuyahoga Falls, OH (USA)

98. Oak Ridge National Lab., TN (USA)

99. California University, Berkeley (USA). Lawrence Berkeley Lab.

100. Brigham Young University, Provo, UT (USA)

101. National Technical Information Service, Springfield, VA (USA)

102. National Technical Information Service, Springfield, VA (USA)

103. Institute of Gas Technology, Chicago, IL (USA)

104. Geokinetics, Inc., Concord, CA (USA)

105. Purdue University, Lafayette, IN (USA). Automotive Transportation Center

106. California University, Livermore (USA). Lawrence Livermore Lab.

107. National Aeronautics and Space Administration, Cleveland, OH (USA). Lewis Research Center

108. Oak Ridge National Lab., TN (USA)

109. Department of Energy, Pittsburgh, PA (USA). Pittsburgh Energy Technology Center

110. Department of Energy, Laramie, WY (USA). Laramie Energy Technology Center

111. Department of Energy, Laramie, WY (USA). Laramie Energy Technology Center

112. Exxon Research and Engineering Co., Linden, NJ (USA)

113. Oak Ridge National Lab., TN (USA)

114. Kansas Energy Office, Topeka (USA)

115. TRW, Inc., McLean, VA (USA). Energy Systems Group

116. California University, Livermore (USA). Lawrence Livermore Lab.

117. Gas-Cooled Reactor Associates, La Jolla, CA (USA)

118. Chevron Research Co., Richmond, CA (USA)

119. Georgia Inst. of Tech., Atlanta (USA). Engineering Experiment Station

120. Institute of Gas Technology, Chicago, IL (USA); Brooklyn Union Gas Co., NY (USA)

121. California Energy Commission, Sacramento (USA)

122. Radian Corp., Pasadena, CA (USA)

123. Department of Energy, Washington, DC (USA). Energy Information Administration

124. Badger Plants, Inc., Cambridge, MA (USA)

125. Oak Ridge National Lab., TN (USA)

126. Badger Plants, Inc., Cambridge, MA (USA)

127. Department of Energy, Pittsburgh, PA (USA). Pittsburgh Energy Technology Center

128. Ocean Management Associates, Saunderstown, RI (USA)

129. Collieries Management Corp., Philadelphia, PA (USA)

130. Engineering Societies Commission on Energy, Inc., Washington, DC (USA)

131. Kansas Energy Office, Topeka (USA)

132. Department of Energy, Washington, DC (USA). Assistant Secretary for Conservation and

133. RAND Corp., Santa Monica, CA (USA)

134. California University, Berkeley (USA). Lawrence Berkeley Lab.

135. Massachusetts Inst. of Tech., Oak Ridge, TN (USA). School of Chemical Engineering Practice

136. California University, Berkeley (USA). Lawrence Berkeley Lab.

137. Oak Ridge National Lab., TN (USA)

138. American Energy Research Co., McLean, VA

139. National Alcohol Fuels Commission, Washington, DC (USA)

140. Fluor Engineers and Constructors, Inc., Houston, TX (USA)

141. Wilco Research Co., Provo, UT (USA)

142. National Alcohol Fuels Commission, Washington, DC (USA)

143. North Carolina Energy Inst., Research Triangle Park (USA)

144. Publicker Industries, Inc., Greenwich, CT (USA)

145. Brookhaven National Lab., Upton, NY (USA)

146. California University, Berkeley (USA). Lawrence Berkeley Lab.

147. Oak Ridge National Lab., TN (USA)

148. Core Labs., Inc., Mt. Pleasant, MI (USA)

149. Aerospace Corp., El Segundo, CA (USA). Mobile Systems Directorate;

150. Northern Energy Corp., Boston, MA (USA)

151. New Hampshire University, Durham (USA). Dept. of Chemical Engineering

152. North Carolina State University, Raleigh (USA). Dept. of Chemical Engineering

1988

1. EG and G Idaho, Inc., Idaho Falls (USA); USDOE, Washington, DC; Florida University, Gainesville (USA)
2. North Dakota University, Grand Forks, ND (USA). Energy and Environmental Research Center
3. Pittsburgh Energy Technology Center, PA (USA)
4. Sandia National Laboratories, Albuquerque, NM (USA)
5. University of Oklahoma, Norman (USA)
6. University of Manitoba, Winnipeg (Canada)
7. Case Western Reserve University, Cleveland, OH (USA)
8. Ministry of Energy, Mines and Resources, Ottawa, Ontario (Canada)
9. Sandia National Laboratories, Albuquerque, NM (USA)
10. Illinois Institute of Technology, Chicago (USA)
11. Princeton University, NJ (USA)
12. CSIRO Division of Fossil Fuels, North Ryde (Australia)
13. West Virginia University, Morgantown, WV (USA)
14. Institute of Gas Technology, Chicago, IL (USA)
15. USDOE Pittsburgh Energy Technology Center, PA
16. Oak Ridge National Lab., TN (USA)
17. Mechanical Technology, Inc., Latham, NY (USA)
18. Argonne National Lab., IL (USA)

19. Cornell University, Ithaca, NY (USA). Sibley School of Mechanical and Aerospace Engineering
20. Argonne National Lab., IL (USA)
21. Argonne National Lab., IL (USA). Center for Transportation Research
22. Brookhaven National Lab., Upton, NY (USA)
23. Sandia National Labs., Albuquerque, NM (USA)
24. Mitre Corp., McLean, VA (USA); USDOE, Washington, DC
25. Argonne National Lab., IL (USA)
26. Institute of Gas Technology, Chicago, IL (USA)
27. Oak Ridge National Lab., TN (USA); Solar Energy Research Inst., Golden, CO (USA)
28. Institute of Gas Technology, Chicago, IL (USA); Gas Research Inst., Chicago, IL (USA)
29. Lawrence Livermore National Lab., CA (USA)
30. Pacific Northwest Lab., Richland, WA (USA)
31. Electric Power Research Inst., Palo Alto, CA (USA)
32. Chemistry Div., AEE Winfrith, Dorchester, Dorset (GB)
33. CANMET/ERL, 555 Booth Street, Ottawa, Ontario K1A 0G1 (CA)
34. Div. of Chemistry, National Research Council of Canada, Ottawa, Ontario, K1A 0R9 (CA)
35. Pacific Northwest Lab., Richland, WA (USA)
36. Pacific Northwest Lab., Richland, WA (USA)

37. Lawrence Livermore National Lab., CA (USA); General Motors Research Labs., Warren, MI (USA)
38. Pacific Northwest Lab., Richland, WA (USA)
39. Lawrence Livermore National Lab., CA (USA)
40. CSIRO Division of Fuel Technology, Menai (Australia)
41. Pennsylvania State University, University Park (USA)
42. ARCO Chemical Co., Newtown Square, PA (USA)
43. Institute of Gas Technology, Chicago, IL (USA)
44. University of Twente, Enschede (Netherlands)
45. Yamaguchi University, Tokiwadai (Japan)
46. Brookhaven National Lab., Upton, NY (USA)
47. Lawrence Livermore National Lab., CA (USA)
48. Energetics, Inc., Columbia, MD (USA)
49. Petro-Canada Products, Ontario (Canada)
50. Sandia National Labs., Albuquerque, NM (USA)
51. National Bureau of Standards, Washington, DC (United States)
52. Laboratorium voor Petrochemische Techniek, Rijksuniversiteit Gent, B-9000 Gent (BE)
53. Lawrence Berkeley Lab., CA
54. Exxon Research and Engineering Co., Florham Park, NJ (USA)
55. Solar Energy Research Institute, Golden, CA (USA)
56. Chemical Engineering Dept., Montana State University, Bozeman, MT (US)
57. Dept. of Chemistry, Brigham Young University, Provo, UT (US)

58. The Naval Research Lab., Code 6180, Washington, DC (US)

59. L. V. Pisarzhevskii Institute of Physical Chemistry, Kiev (USSR)

60. Dept. of Chemistry, Brigham Young University, Provo, UT (US)

61. Simon Fraser University, Burnaby, British Columbia (Canada)

62. University of North Carolina, Chapel Hill (USA)

63. University, of New Mexico, Albuquerque

64. Imperial Chemical Industries plc, Cheshire (England)

65. State Institute of Applied Chemistry, Leningrad (USSR)

66. Chemistry Dept., University of Manitoba, Winnipeg, Manitoba R3T 2N2 (CA)

67. Dept. of Chemical Engineering, University of Waterloo, Waterloo, Ontario N2L 3G1 (CA)

68. Exxon Chemical Co., P.O. Box 241, Baton Rouge, LA (US)

69. Dept. of Mechanical Engineering, University of Leeds, Leeds (GB)

70. Texas A M University, College Station (USA)

71. Case Western Reserve University, Cleveland, OH (USA)

72. University of Pittsburgh, PA (USA)

73. University of Virginia, Charlottesville (USA)

74. University of Cambridge (England)

75. Haldor Topsoe Research Labs., Lyngby (Denmark)

76. Zhdanov Irkutsk University (USSR)

77. N. D. Zelinskii Institute of Organic Chemistry, Moscow (USSR)

78. Exxon Research and Engineering Co., Annandale, NJ (US)

79. Auburn University, AL (USA)

80. BP America, Independence, OH (USA)

81. University of Pittsburgh, PA (USA)

82. Kentucky Energy Cabinet Lab., Lexington (USA)