Petroleum industry

U.S. DEPARTMENT OF LABOR
Bureau of Labor Statistics
Washington, D. C. 20210

# PRODUCTIVITY AND TECHNOLOGICAL CHANGE IN THE PETROLEUM REFINING INDUSTRY

Statement presented to the
Select Committee on Small Business
United States Senate
by
Leon Greenberg, Assistant Commissioner for
Productivity and Technological Developments

August 11, 1964



The Department of Labor published a report a few months ago entitled "Technological Trends in 36 Major American Industries." This report represents one phase of the Department's research program, designed to investigate important technological developments and their potential impact on manpower requirements throughout American industry. A thorough investigation of each industry takes time and more extensive study is under way or planned for the important industries in the economy. Meanwhile, however, there has been a great deal of interest in the pace of technological change, not only for the economy as a whole, but also for individual industries. The President's Advisory Committee on Labor-Management Policy is among those who felt the need for factual information on this important subject and urged the publication of a report on technological trends.

The report, which has been published, is in response to this need. It is based extensively on published materials such as technical and trade journals, annual corporate reports, and reports

[ Washington, 1964 ]

of government agencies. The statement for each industry was reviewed by experts in companies, unions, trade associations, and government, and their comments were considered in the final version of the report.

The petroleum refining industry is one of the industries included in the Technological Trends Report. Its publication, apparently, has come to the attention of the Select Committee on Small Business and the Committee has requested the Department of Labor to present a more comprehensive statement on technological developments in petroleum refining. We are, of course, pleased to comply with this request. However, we must point out that we have conducted no field studies nor any special inquiry through use of questionnaires. Our information for petroleum refining is based primarily on the sources mentioned above, and on our calculations of output per man-hour.

This statement will cover productivity, current technological developments, and the technological and employment outlook for the petroleum refining industry.

## PRODUCTIVITY, OUTPUT, AND EMPLOYMENT PER MAN-HOUR

New investment and the introduction of more advanced technology are usually reflected in the productivity of an industry, as measured by output per man-hour. This productivity ratio has increased fairly rapidly in the petroleum refining industry during the postwar period. Output per man-hour, including all employees of the industry, has more than doubled in the last 15 years.

Translated into an annual rate of change, the average increase in output per man-hour for the period 1947-62 is 5.2 percent. (Table 2) This is substantially higher than the average for all manufacturing industries combined, which rose less than 3 percent a year.

The rate of growth in productivity has been maintained throughout the postwar period, except for a few minor and short-term slowdowns as in 1953 and 1957. This steady rise in productivity has persisted despite some slowing down in the rate of increase in output. Output increased rather rapidly from 1947-51, a little more slowly from 1951-56, and still more slowly after 1956. In fact, in the early postwar years, output increased faster than productivity but in the last few years it has been the other way around--productivity has gone up faster than output.

The changing relationship between output and productivity has, of course, had an impact on employment. It went from 146,000 in 1947 to a peak of 160,000 in 1953, but then declined, rose a

little and declined again. Since 1957, when employment was about 154,000, it has declined and in 1962 it was down to 123,000.

The gains in productivity are related not only to output (and rate of capacity utilization) but also to capital expansion and modernization. The increases in productivity in this industry have been accompanied by substantial expenditures on new plants and equipment. They have averaged $530 million per year, the equivalent of $3,654 per worker, compared with $727 per worker for the average of all manufacturing industries.

Because of this Committee's interest in small businesses, we have prepared a special analysis of individual plants in the petroleum refining industry, based on data obtained from and with the cooperation of the Bureau of the Census, U.S. Department of Commerce. The analysis compares value-added per man-hour in 1954 and 1961, by size of establishment, for plants whose primary product is gasoline and jet fuel. First, a few words of caution are necessary.

1. These are <u>establishments</u> classified by size as of 1954. They may be owned by large or small <u>companies</u>.

2. Value added is in current dollars. The value-added per man-hour figures are useful for comparing different establishments but are not precise productivity measures because they are also affected by price changes and price differentials among plants.

With these factors in mind, there seems to have been a difference in the productivity of small and large plants in 1954. The smaller plants, on the average, had lower value-added per man-hour than the larger plants. In fact, value-added per man-hour for the smallest group of plants was less than one-half of that for the industry as a whole. (Table 3) However, the largest plants had somewhat lower value-added per man-hour, on the average, than the moderately large plants.

By 1961, some major changes had taken place. Apparently, some of the small plants had engaged in major capitalization and expansion programs and had improved their productivity considerably. Thus, the productivity gap between small and large plants (classified by size as of 1954) was narrowed and in 1961 there was a small variation in value-added per man-hour among the different size groups.

However, if plants were reclassified by size as of 1961, the smallest plants in that year also had lower value-added per man-hour than the larger plants.

Tracing the changes in productivity among individual plants and determination of the factors responsible for these changes would require intensive examination of the individual plant schedules and possibly field visits to a sample of plants. We have not had the resources to undertake such an inquiry. Nevertheless, there seems to be a close correspondence between the size of operation and productivity, at least up to a point.

## CURRENT TECHNOLOGICAL DEVELOPMENTS

Although petroleum refining has already reached an advanced stage of technology, there are continuing developments which will affect the processes or products of the industry. Some of the major developments are described in this section.

### Increased Use of Computer Control

The processing of crude oil through its various stages to a final product requires the correlation of a large volume of data about process or product variables such as heat and flow, octane rating or other product specifications. In addition, the planning of economical processes and products also must take into account costs of materials and prices of different products. Because of the need for these complicated and time-consuming calculations, refineries have been introducting electronic data processing. In a few cases the computer is used for more advanced process control, where the control instruments are automatically adjusted.

According to one authoritative industry source, there were about 60 digital control computers in operation or planned at the end of 1963. 1/ Of this total, 25 were for petroleum refining and 35 in units used for processing petrochemicals. The industry began using process control computers in 1959, with most of the installations being made in 1962 and 1963. While computer control is most

---

1/ G. L. Farrar, "Computer Control Comes of Age," The Oil and Gas Journal, October 28, 1963, pp. 78-100.

often used by the large companies and for the operation of large units, computer manufacturers are developing smaller models for use in smaller refineries.

Adaptation to computer control seems to require several stages. The digital control computer is first installed on line, open loop. That is, it receives instrument signals and other data and turns out operating instructions, but the operator makes the indicated changes. As experience is gained and the computer operation becomes more sophisticated, instrument loops can be closed, with computer output signals directly positioning control valves. In other words, controls can become more and more automatic. 2/

Direct benefits of EDP include increased production with the same equipment, reduced operating costs, and improved quality control. In some cases, the payout has been found to amount to $100,000 to $500,000 annually per installation. Other benefits such as better technical and operating data, faster calculation, reduced inventory requirements, and improved plant safety have been estimated to provide substantial additional savings.

To a certain extent, computers enable refineries to perform calculations that would otherwise require hundreds of man-hours of engineering or other personal time. Such calculations were not previously undertaken because they were too costly. The

---

2/ "Computer Control Makes Solid Gains in Processing," The Oil and Gas Journal, October 22, 1962, pp. 84-101.

computer thus does not displace employees already in the plant but supplements their fund of knowledge. However, since the net result is improved output with the same work force, productivity is increased.

Improvements in Cracking

New techniques in cracking are concentrating on improving product quality and raw material utilization. The emphasis is on obtaining larger quantities of the more valuable products out of crude oil at the lowest possible cost. Hydrocracking, for example, results in upgrading heavy bottom oils to yield higher value distillate products. Some developments aid in the recovery of refinery gases. These improvements in processing have resulted in significant increases in output of the most valuable products from each barrel of crude, with less waste, faster production, higher product quality, and greater use of heavy-oil and crude-oil residues.

For example, one new refinery installation for the catalytic cracking of crude-oil residues reports an increase in the refining capacity of the total plant of more than 20 percent and substantially reduced refining costs and has eliminated the yield of unprofitable residual products. 3/ In another refinery, installation of a hydrocracking unit resulted in an increase from about 50 percent to 90 percent in yield of gasoline for every barrel of crude. 4/

---

3/ G. E. McKenna, C. H. Owen, and G. R. Hettick, "Heavy Oil Catalytic Cracking Key to Refinery Modernization," The Oil and Gas Journal, May 18, 1964, pp. 106-107.

4/ C. J. Lawrence, "Signal Jumps Gasoline Yield to 90 Percent at Bakersfield," The Oil and Gas Journal, June 17, 1963, pp. 46-48.

Improvements in the quality and chemistry of catalysts also result in gains in the efficiency of refineries and in product quality. One company claims a major advance in catalytic cracking through the use of a unit (known as Met-X) which removes metal contaminants and, therefore, improves the efficiency of catalytic action. By removing coke-producing metal contaminants, the refinery obtained a 12 percent increase in the output of gasoline per 1,000 pounds of coke. 5/

Product Mix and Petrochemical Products

Gasoline has for years been the dominant product of the petroleum refining industry, accounting for 56 percent of total output in 1962, up slightly from 1947. Distillate fuel oil has become more important because of its use in transportation as well as in home heating. And, as previously indicated, the production of liquified petroleum gases has increased with the development of the petrochemical industry. (Table 4)

Most other products of this industry have declined in relative importance. The greatest change between 1947 and 1962 was the decline in the relative importance of residual fuel oil from 13 percent to 5 percent, reflecting substitution for residual fuel oil for industrial uses and the increasing importance of other

---

5/ R. J. Dilliplane, G. P. Middlebrooks, R. C. Hicks, and E. P. Bradley, "Met-X Boosts Gasoline Output 12 Percent Per Unit of Coke for Atlantic," The Oil and Gas Journal, August 5, 1963, pp. 119-126.

petroleum products. Among other products declining in relative importance were kerosene, lubricating oil, petroleum coke, and road oil, and still gas. The relative declines in the production of these products reflect changes in demand and improvements in utilization of raw materials.

Growing demand for synthetic materials is resulting in the diversion of more crude to the lighter hydrocarbons, which, along with natural gas and gas liquids, form the basis for petrochemical production. Petrochemicals are used in the production of plastics, synthetic fibers, synthetic rubber, detergents, solvents, insecticides, and fertilizers. While the total production of raw materials for chemical conversion is still small compared with the total amount of petroleum products (less than 5 percent of the total), it is a new and fast-growing segment of the petroleum refining industry.

Refiners were induced to convert some of their excess capacity to petrochemical production in the late 1950's. One factor was the ease with which refining plant conversion could be made. The growing demand for synthetic products also encouraged a trend among refiners towards the integration of petroleum refining, gas processing, and petrochemical operations. It was claimed that such physical and administrative integration resulted in improvements in operating efficiency and capacity utilization through rationalization. 6/

---

6/ "Petrochemical's Greener Fields Lure Refiners," The Oil and Gas Journal, December 17, 1962, pp. 78-81.

New petrochemical plants being built are making extensive use of computers for process control.

Increased Size and Complexity of Plants

Between 1947 and 1962, the number of operating refineries in the industry decreased from 361 to 287. In the same period, crude oil throughput capacity of operating refineries rose 5.3 million barrels per day to 9.8 million barrels per day and total refinery capacity rose from 5.5 million to 10.1 million barrels per day. The average size of operating refineries increased by 132 percent, from 14.7 thousand barrels per day throughput capacity to 34.1 thousand barrels per day.

As indicated in an earlier section, scale of operations can have an important bearing on productivity--the larger the operation, the higher the productivity. Closely related is the capacity of the catalytic cracking unit used by each refinery. For example, a 90,000 barrel capacity unit requires substantially less manpower than 3 units, each with a capacity of 30,000 barrels. The ratio of manpower required is nearly 3 to 1. While factors such as markets and location may be related to the size of the unit in use, an important factor has been the improvement in metallurgy. The metals of a cracker corrode and the unit has to be shut down periodically for repairs. New metals last much longer with a resultant decrease in frequency of repair. Since the shut-down periods are reduced, the refinery can afford to install a larger cracking unit.

## OUTLOOK FOR PETROLEUM REFINING INDUSTRY

Advances in technology and productivity will probably continue at a fairly rapid pace over the next few years. Although the rate of change is difficult to estimate, two factors affecting the outlook can be briefly described.

### Increasing Expenditures for Research and Development

The petroleum industry (including refining and extraction) spent $302 million on R and D in 1962, a 66 percent increase over the 1956 expenditures. (Table 5) The industry employed 8,800 scientists and engineers in 1962--28 percent more than in 1956.

Virtually all of these R and D expenditures were company financed, rather than from Federal government sources as is the case in several other industries. The largest petroleum companies accounted for more than 90 percent of the total R and D expenditures. Most of the expenditures were for refining and extracting techniques and petroleum chemistry. The industry also benefits from research conducted by the electronics and instrument industries.

Although the petroleum industry spends only about 1 percent of its sales on R and D, it is one of the leaders among nondefense industries. According to a 1964 McGraw-Hill Company survey, R and D expenditures planned by the industry are expected to increase by 16 percent between 1963 and 1967.

Capital Expenditures

Expenditures for new plant and equipment in the petroleum refining industry rose during the postwar years to a peak of around $875 million in 1951. They have declined since then and annual expenditures during the period 1959-63 have averaged something over $400 million. 7/ However, the annual forecast by The Oil and Gas Journal 8/ estimates an increase of about 19 percent in 1964 (from 1963) and a sustained increase through 1970.

According to the 1964 McGraw-Hill Survey of Business' Plans for New Plants and Equipment, integrated companies in the petroleum industry (including extraction, refining, and related activities) plan capital expenditures of $3.3 billion in 1964, up 12 percent from 1963. Preliminary plans indicate that this level of capital spending will be sustained for the period 1965-67.

Of the $3.3 billion expenditures planned by the petroleum industry for 1964, 80 percent will be for replacement and modernization with 20 percent for capacity expansion. Outlays for expansion are slightly higher than in the past few years. According to McGraw-Hill surveys, the petroleum and coal products industry has been operating below the preferred rates of capacity utilization, but there has been some increase in operating rates during the past

---

7/ Annual Survey of Manufactures, Bureau of the Census, U.S. Department of Commerce, 1962.

8/ "More Spending Seen for '64," The Oil and Gas Journal, January 27, 1964, p. 138.

few years over the lower levels of the later 1950's. The planned capacity expansion between 1963 and 1967 (about 3 percent) will probably come from expenditures for modernization and replacement.

Projected Production and Employment Trends

The long-term outlook for petroleum production is for gradual increase over the 1960 and 1970 decades. Projections of production trends in the petroleum refining industry have been prepared by the Resources for the Future, a leading research organization, based on varying estimates of population growth for 1970 and 1980. (Table 6) The high projection of output would imply an annual growth rate of about 4 percent, which is the same as the postwar rate of advance. However, output per man-hour during this period rose more than 5 percent a year.

If the postwar rate of increase in productivity is maintained or only slightly reduced as industry continues its R and D and modernization programs, the projected rates of production will not offset the impact of labor-saving technology. A lower level of employment may be expected, continuing a decline which began in the 1950's. The demand for engineers, scientists, technicians, computer specialists, and highly-skilled maintenance craftsmen, however, will probably remain strong.

Table 1. Petroleum Refining
Output Per Man-Hour, Unit Labor Requirements, and Related Data, 1939 and 1947-62
(Indexes, 1957-59=100)

| Year | Output per-- | | | | Related data | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Employee | Production worker | Man-hour | | Output | Employment | | Man-hours | |
| | | | All employees | Production workers | | All employees | Production workers | All employees | Production workers |
| 1939 | (1/) | (1/) | (1/) | 55.9 | 42.0 | (1/) | (1/) | (1/) | 75.1 |
| 1947 | 60.8 | 57.0 | 57.5 | 53.5 | 60.9 | 100.1 | 106.9 | 106.0 | 113.8 |
| 1948 | (1/) | (1/) | (1/) | (1/) | 66.9 | (1/) | (1/) | (1/) | (1/) |
| 1949 | 65.7 | 60.9 | 63.8 | 59.1 | 65.0 | 98.9 | 106.8 | 101.9 | 109.9 |
| 1950 | 73.9 | 71.2 | 71.4 | 68.3 | 70.6 | 95.5 | 99.2 | 98.9 | 103.3 |
| 1951 | 77.0 | 74.6 | 74.5 | 71.8 | 80.0 | 103.9 | 107.3 | 107.4 | 111.4 |
| 1952 | 77.8 | 76.0 | 76.4 | 74.6 | 81.8 | 105.1 | 107.7 | 107.1 | 109.7 |
| 1953 | 78.4 | 76.8 | 77.9 | 76.4 | 85.9 | 109.5 | 111.9 | 110.2 | 112.4 |
| 1954 | 81.9 | 80.5 | 81.8 | 80.5 | 86.1 | 105.1 | 106.9 | 105.3 | 106.9 |
| 1955 | 90.5 | 88.5 | 89.3 | 87.8 | 93.1 | 103.5 | 105.2 | 104.2 | 106.0 |
| 1956 | 93.9 | 92.5 | 93.2 | 91.7 | 99.2 | 105.6 | 107.3 | 106.4 | 108.2 |
| 1957 | 94.1 | 94.0 | 93.4 | 93.2 | 99.4 | 105.6 | 105.7 | 106.4 | 106.6 |
| 1958 | 97.4 | 97.2 | 98.0 | 98.1 | 97.6 | 100.2 | 100.4 | 99.6 | 99.5 |
| 1959 | 109.5 | 109.6 | 109.5 | 109.7 | 103.0 | 94.1 | 94.0 | 94.1 | 93.9 |
| 1960 | 113.6 | 115.2 | 113.0 | 114.1 | 105.2 | 92.6 | 91.3 | 93.1 | 92.2 |
| 1961 | 120.6 | 122.8 | 120.3 | 122.0 | 106.5 | 88.3 | 86.7 | 88.5 | 87.3 |
| 1962 2/ | 130.2 | 133.3 | 129.7 | 132.4 | 110.0 | 84.5 | 82.5 | 84.8 | 83.1 |

1/ Not available.
2/ Preliminary.

Sources: Output based on data from the Bureau of Mines, U.S. Department of the Interior, and the Bureau of the Census, U.S. Department of Commerce. Employment and hours based on data from the Bureau of the Census, U.S. Department of Commerce, and the Bureau of Labor Statistics, U.S. Department of Labor.

## Petroleum Refining

Table 2. Output, Employment, and Output Per Man-Hour
Average Annual Rates of Change, 1947-62 and Subperiods

| | 1947-62 | 1947-57 | 1957-62 |
|---|---|---|---|
| Output | 4.0 | 5.2 | 1.9 |
| All employees | -0.9 | 0.8 | -3.7 |
| Output per all employee man-hour | 5.2 | 5.0 | 5.8 |
| Output per production worker man-hour | 5.9 | 5.8 | 6.2 |

Computed by least squares method. Basic data, Table 1.

## Petroleum Refining

**Table 3. Selected Establishments, 1/ Value-Added Per Production Worker Man-Hour, 1954 and 1961, by Size of Establishments 2/**

| Value added of establishments, 1954 ($1,000) | Value-added per production worker man-hour (dollars) | |
|---|---|---|
| | 1954 | 1961 |
| Total ..... | 8.99 | 15.80 |
| Less than 1,000 ..... | 3.61 | 12.19 |
| 1,000 - 1,999 ..... | 7.25 | 14.61 |
| 2,000 - 3,999 ..... | 7.75 | 16.20 |
| 4,000 - 7,999 ..... | 10.06 | 19.43 |
| 8,000 - 15,999 ..... | 10.78 | 17.13 |
| 16,000 - 31,999 ..... | 9.89 | 17.74 |
| 32,000 and over ..... | 8.08 | 13.26 |

1/ Establishments whose primary product class in 1958 was 29111 (gasoline and jet-propulsion fuel).

2/ Establishments classified by value added in 1954.

Source: Annual Survey of Manufactures Time Series Records, Bureau of the Census, U.S. Department of Commerce.

## Petroleum Refining

### Table 4. Percent Distribution of Major Products Included in Total Output, 1947 and 1962

| Product | 1947 | 1962 |
|---|---|---|
| Total | 100.0 | 100.0 |
| Aviation gasoline | 2.3 | 2.5 |
| Other gasoline | 50.5 | 53.3 |
| Kerosene | 5.7 | 4.4 |
| Distillate fuel oil | 15.0 | 19.0 |
| Residual fuel oil | 13.3 | 4.8 |
| Jet fuel | (1/) | 2.8 |
| Lubrication oil | 7.4 | 4.8 |
| Wax | .8 | .7 |
| Petroleum coke | .4 | 1.3 |
| Asphalt | 2.1 | 2.5 |
| Road oil | .3 | .1 |
| Still gas | 1.1 | .9 |
| Liquefied petroleum gases | 1.3 | 2.8 |

1/ Included with "other gasoline" since only small amounts of jet fuel were produced in 1947.

Source: Basic data on output are from issues of the Minerals Yearbook and Mineral Industry Survey, published by the Bureau of Mines. Percent distribution shown is the distribution of the weighted aggregate, that is, physical units times 1958 unit value weights.

Table 5. Research and Development in the Petroleum Industry, 1956 to 1962 1/

| | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 |
|---|---|---|---|---|---|---|---|
| Total funds for R and D performance (millions) ..... | 182 | 211 | 239 | 276 | 290 | 294 | 302 |
| Company financed ..... | -- | 207 | 231 | 257 | 284 | 275 | 281 |
| Total number of R and D scientists and engineers ..... | 6,900 | 7,400 | 7,700 | 9,100 | 8,800 | 8,900 | 8,800 |
| Percent distribution of R and D expenditures, by size of company: | | | | | | | |
| Less than 1,000 employees ..... | -- | -- | -- | -- | -- | -- | n.a. |
| 1,000-4,999 ..... | -- | -- | 6 | 7 | 3 | 3 | n.a. |
| 5,000 or more ..... | 91 | 93 | 91 | 90 | 90 | 92 | n.a. |

1/ Includes SIC 13 and 29 (crude oil extraction and petroleum refining). Geological and geophysical exploration activities of petroleum companies are excluded from the definition of research and development.

Data not separately available indicated by dash.

Source: National Science Foundation.

Table 6. Projected Changes in the Production of Crude Petroleum and Petroleum Products, 1960-1970 and 1970-1980

| | 1960-1970 | | 1970-1980 | |
|---|---|---|---|---|
| | Total percent change | Average annual percent change | Total percent change | Average annual percent change |
| Total U.S. crude petroleum consumption (mil. bbl.) | | | | |
| High | 45 | 3.8 | 45 | 3.8 |
| Medium | 28 | 2.5 | 31 | 2.7 |
| Low | 13 | 1.2 | 22 | 2.0 |
| Petroleum products production 1/ | | | | |
| High | 47 | 3.9 | 49 | 4.1 |
| Medium | 30 | 2.7 | 31 | 2.7 |
| Low | 16 | 1.5 | 22 | 2.0 |

1/ Projections of Federal Reserve Board index of production.

Source: Based on data from: H. H. Landsberg, L. L. Fischman, and J. L. Fisher, Resources in America's Future, Johns Hopkins Press, 1963. Average annual rates of change computed by the compound interest method.