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The American Petroleum Industry

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Introduction

In this paper the authors have attempted (1) to present a summary of a large volume of previous research on the history of the American petroleum industry and (2) to develop several topics not explored in earlier studies.[1] Within this general framework, the major objective has been to provide a statistical basis for measuring the growth of the industry and its relative importance in the American economy for the period 1859–1914. On the supply side of the industry, we have accordingly indicated only the most significant determinants of outputs and the composition of the flow of related inputs in each of the industry's major sectoral divisions. Discussion of the demand for petroleum products is likewise confined to the principal factors that have affected sales over time. Only the bare essentials of technological developments affecting both supply and demand are presented.

In order to meet the necessary restriction on the length of this paper, many statements of facts and conclusions are presented without the a priori analysis used to arrive at these propositions. In all such cases, however, we have referred the reader to the sources where the analysis is more fully developed. One particular gap, not fully explored here but

[1] The works referred to and on which the bulk of the present paper is based are: Harold F. Williamson and Arnold R. Daum, *The American Petroleum Industry: The Age of Illumination, 1859–1899*, Evanston, 1959; Harold F. Williamson, Ralph L. Andreano, Arnold R. Daum, and Gilbert C. Klose, *The American Petroleum Industry: The Age of Energy, 1900–1959*, Evanston, 1964; and Ralph L. Andreano, "The Emergence of New Competition in the American Petroleum Industry Before 1911," unpublished Ph.D. dissertation, Northwestern University, 1960, available from University Microfilms, Ann Arbor, Michigan.

discussed at length elsewhere, concerns the determinants of vertical integration and their application to changes in the structure of the petroleum industry. Although the Standard Oil complex dominated the industry throughout most of the 1859–1914 period, we have not dealt specifically with the performance of the dominant firm nor have we made any assessment of its impact on the allocation of resources within the industry.

We have organized our presentation as follows: Part I contains aggregate data on the industry related to the general growth of the domestic economy and a sectoral analysis of the industry's output record. Part II presents an outline of the major technical changes which occurred within each sector and the associated changes in input requirements and costs. Part III is a discussion of the principal factors that affected demand for the major refined products. Part IV provides a condensed statement of the dynamics of the industry structure from the late 1870's until the dissolution of the Standard Oil combination in 1911.

I

Physical Outputs, Value Added, and Relative Position of Petroleum Industry in the American Economy

All available time series indicate a remarkable rate of growth for the American petroleum industry from its inception in 1859 to World War I. This section contains a comparison of the rate of growth, in both physical and value terms, of the major sectors of the industry with other relevant sectors in the economy, as well as a discussion of the growing over-all importance of the industry in the domestic economy.

Domestic production of crude oil, as shown in Table 1, was over 100 times as large in 1914 as in 1865. From 1879 (the first year for which comparable data are available) through 1889, output of crude oil grew at approximately the same rate as the domestic production of fuels and minerals. From 1889 through 1914, however, crude oil production increased over 7.5 times compared with a growth of 3.3 times in the output of fuels and 2.9 times in the output of minerals.

Output of refined products expanded even more rapidly than output of crude oil did, reaching a total in 1914 some 138 times larger than production in 1865. Output of refined products also grew at a much faster rate than the physical output of all manufacturing, which increased some 11 times during those years (Table 1).

The growth in physical production was accompanied by an impressive increase in the value of the output in each of the sectors of the industry.

TABLE 1

INDEX OF PHYSICAL OUTPUT OF CRUDE PETROLEUM, FUELS, TOTAL MINERALS, REFINED PRODUCTS, AND TOTAL MANUFACTURING PRODUCTION, 1865-1914
(1889 = 100)

Product	1865	1869	1873-75	1878-80	1883-85	1889	1894	1899	1904	1909	1914
Crude petroleum[a]	7.1	11.9	28.0	58.4	65.9	100.0	140.3	162.3	332.9	520.9	755.8
Fuels[b]				45.5[c]	67.7	100.0	108.1	149.5	207.1	278.8	329.3
Total minerals[b]				51.9[c]	69.2	100.0	105.3	147.4	193.9	261.6	290.9
Refinery products[d]	4.8	11.8	27.7	45.8	67.0	100.0	160.5	174.5	201.6	388.8	662.3
Total manufacturing production[e]	25.7	37.9	43.9	55.4	72.7	100.0	103.0	151.5	183.3	251.5	290.9

[a] *Historical Statistics of the United States, Colonial Times to 1957*, 1960, pp. 360-61.

[b] *Historical Statistics*, 1960 (computed from the Bureau of Mines Indexes of Physical Volume of Mineral Production), p. 353.

[c] Outputs are for the year 1880.

[d] Table A-3.

[e] *Historical Statistics*, 1960 (computed from Frickey's Index of Manufacturing Production), p. 409.

TABLE 2

VALUE OF CRUDE OUTPUT AS PERCENTAGE OF VALUE OF MINERAL FUELS AND VALUE OF ALL MINERAL PRODUCTS, 1880-1914

	1869	1879	1889	1899	1904	1909	1914
Crude petroleum ($ mill.)	24	17	29	65	101	128	214
Mineral fuels ($ mill.)	--	112	221	392	543	705	936
Total minerals ($ mill.)	--	293	489	900	1,126	1,530	1,813
Crude as per cent of mineral fuels	--	15.3	12.2	16.5	18.6	18.2	23.0
Crude as per cent of total minerals	--	5.8	5.5	7.2	9.0	8.4	11.8
Mineral fuels as per cent of total minerals	--	38.2	45.1	43.5	48.2	46.0	51.6

Source: *Historical Statistics*, 1960, p. 350.

As shown in Table 2, after declining from approximately $24 million in 1869 to $17 million in 1879, the total value (at the wells) of crude production rose to $214 million in 1914. The value of crude as a proportion of the value of total mineral fuels rose from 15.3 per cent in 1879 (the first year comparable data are available) to 23.0 per cent in 1914. Since the relative importance of mineral fuels to total minerals rose from 38.2 per cent to 51.6 per cent during those years, the value of crude as a percentage of the value of total minerals also rose, from 5.8 to 11.8.

The net and gross values added by refining rose, respectively, from $9 million and $27 million in 1879 to $71 million and $147 million in 1914. In general, both the gross and net value added by refining, as indicated in Table 3, rose at a faster rate than the value added by all manufactures during that period.

TABLE 3

GROSS AND NET VALUE ADDED BY REFINING AS PERCENTAGE OF VALUE ADDED BY ALL MANUFACTURES, 1880-1914

	1879	1889	1899	1904	1909	1914
Net value added by refining ($ mill.)[a]	9	17	21	36	38	71
Per cent of value added by all manufactures	0.45	0.41	0.45	0.59	0.46	0.76
Gross value added by refining ($ mill.)[a]	27	40	43	67	86	147
Per cent of value added by all manufactures	1.36	0.97	0.92	1.11	1.05	1.56
Value added by all manufactures ($ mill.)	1,973	4,102	4,647	6,019	8,160	9,386

Source: *Historical Statistics*, 1960, Table 5, p. 409.

[a]Table 4 figures rounded.

TABLE 4

VALUE OF CRUDE AT WELLS, COST TO REFINERIES OF TRANSPORT AND STORAGE, AND VALUE ADDED BY REFINING, AS PERCENTAGE OF VALUE OF REFINED PRODUCTS AT REFINERY, 1879-1914
(dollars in thousands)

	1879	1889	1899	1904	1909	1914
Value of crude[a] at well prices	16,198	23,579	58,772	57,605	84,543	154,923
Per cent	27.2	27.7	47.4	32.9	35.6	39.08
Net value added by refining	8,706	17,083	21,070	35,618	37,734	71,097
Per cent	14.6	20.09	17.0	20.3	15.9	17.9
Value of materials other than crude	18,658	23,039	22,435	31,900	47,966	75,536
Per cent	31.3	27.1	18.1	18.2	20.2	19.0
Gross value added by refining	27,364	40,122	43,505	67,518	85,690	146,633
Per cent	45.9	47.2	35.1	38.5	36.1	36.9
Transportation and storage costs to refineries	16,000	21,300	21,652	49,882	66,765	94,805
Per cent	26.8	25.1	17.5	28.5	28.5	23.9
Value of refined products at refinery	59,562	85,001	123,929	175,005	236,997	396,361

Source: *Census of Manufactures*, 1914, Vol. II, pp. 581-83; Special Report of the Census Office, *Manufactures*, 1905, Part IV, pp. 569-71; *Historical Statistics*, 1960, pp. 360-61.

[a]Used by refineries.

TABLE 5

VALUE OF OUTPUT AT REFINERIES, AND ESTIMATED VALUE ADDED BY TRANSPORT AND MARKETING, AS PERCENTAGE OF TOTAL VALUE, 1880-1914
(dollars in thousands)

	1879	1889	1899	1904	1909	1914
Value of output at refineries	60,376	86,771	133,425	201,662	275,347	461,136
Per cent of total value	56.9	50.5	52.9	54.1	50.4	51.5
Estimated value added by transport and storage[a], and by wholesaling and retailing	45,752	84,958	118,729	171,144	270,382	433,291
Per cent of total value	43.1	49.5	47.1	45.9	49.6	48.5
Total value	106,128	171,729	252,154	372,806	545,729	894,427

Source: Table A-1.

[a]Other than from well to refinery.

Combined transport and storage costs of shipping crude from wells to refineries, shown in Table 4, rose from an estimated $16 million in 1879 to almost $95 million in 1914. These amounts added between 17.5 per cent and 28.5 per cent to the total value of refined products at refineries, a value which expanded during that period from approximately $59.5 million to over $396 million.

The value of crude (at wells) as a proportion of total value of refined products ranged between 27.2 per cent and 47.4 per cent; in contrast, the net value added by refining varied only between 14.6 per cent and 20.3 per cent. Only the value added by materials (other than crude) showed a sharp drop from about 31 per cent in 1879 to a range varying roughly between 18 per cent and 20 per cent from 1899 through 1914. Despite this trend, expenditures by the industry for purchase of materials outside the industry rose from $18.6 million in 1879 to $75.5 million in 1914.

As shown in Table 5, in 1879 the crude oil, crude transport, and refining sectors contributed almost 57 per cent to the total value of the output of the industry, while an estimated 43 per cent was contributed by distribution and marketing. Over the succeeding years, these proportions remained relatively stable, although there was a slight upward trend in the contribution of marketing and distribution to the total value of the products of the industry from approximately $106 million in 1879 to over $894 million in 1914. (A more detailed breakdown of the data in Table 5 is contained in Table A-1.)

Table 6 provides a rough over-all measure of the growing importance of the petroleum industry in the American economy. At a time when the

TABLE 6

VALUE OF INDUSTRY OUTPUT AS PERCENTAGE OF NET NATIONAL PRODUCT, 1880-1914

Year[a]	Net National Product (mill. dollars)	Year	Value of Industry Output (mill. dollars)	Per Cent
1877-81	8,480	1879	106	1.25
1887-91	11,000	1889	172	1.56
1897-1901	15,000	1899	252	1.68
1902-06	21,200	1904	373	1.76
1907-11	27,200	1909	546	2.00
1912-16	34,600	1914	894	2.58

Source: *Historical Statistics*, 1960, pp. 143 and Table A-1.

[a]Five-year periods are annual averages.

net national product of the United States grew over fourfold, from approximately \$8.5 billion in 1879 to \$34.6 billion in 1914, petroleum's relative contribution more than doubled, from 1.25 per cent to 2.58 per cent.

II

Sectoral Developments in Crude Oil Production

OUTPUT

Because the basic statistical series on crude production, drilling activity, proved reserves, footage drilled, and the like are available in a number of publications, reproduction of that data here would seem inappropriate.[2] Rather, a few summary comments on the output record will be noted with only brief explanations.

1. Output of crude petroleum grew from approximately 2.5 million barrels in 1865 to 265.8 million barrels in 1914, or at a compound annual rate of about 9.8 per cent.

2. Yearly additions to output showed no clear relationship to the number of new wells drilled. During several periods, in fact, notably between 1900–01 and 1905-06, 1910-11 and 1913-14, the two series moved in opposite directions (see Chart 1). Over the long pull, however, output did grow as more wells were drilled. The short-period relationship is noted here as evidence of the episodic nature of crude oil production in the early years of development.

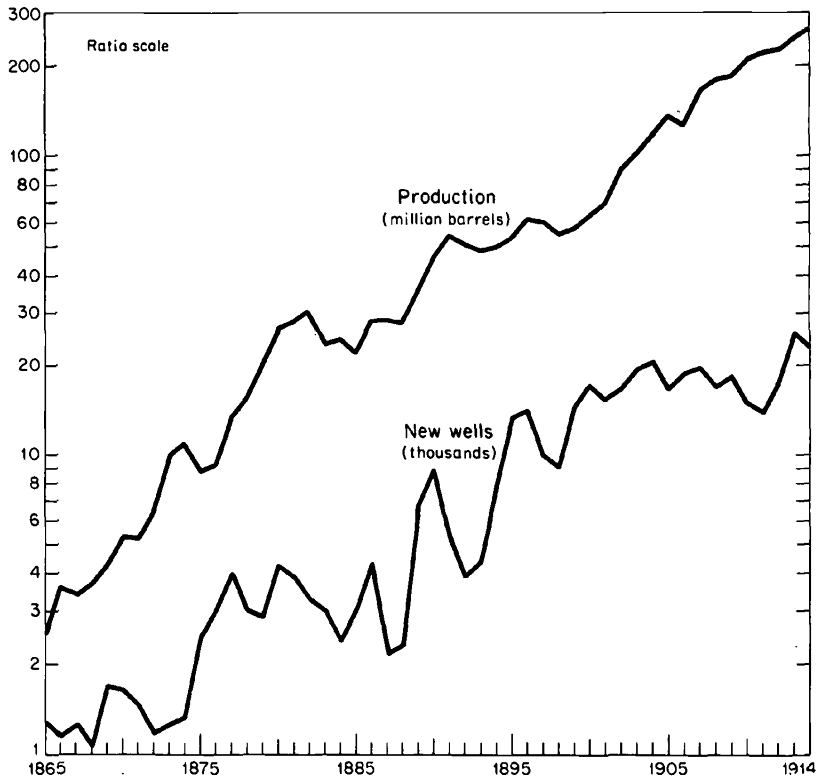
3. Dry holes as a percentage of total wells drilled fell substantially from the mid-1870's until 1880 and then increased for the remainder of the period. Roughly, about one well in eight was dry in the mid-1870's and about one in five or six after 1900. During that period, as most of the new wells drilled were heuristically, if not actually, of the wildcat variety, the dry-hole rate is probably a rough approximation of the risk burden in drilling decisions (see Chart 2).

A priori, in any given pool the probability of a dry hole falls initially as more wells are drilled; then rises as the deposits either become thoroughly defined or trapping and faulting occur and other technical difficulties develop, making even offset wells a risky venture. It is not suggested that the ratio of dry holes to total wells drilled is an absolute measure of risk but only a relative approximation imputed to each drilling decision. Rank

[2] These series may be found in Williamson and Daum, *American Petroleum Industry, 1859–1899;* Williamson, Andreano, Daum, and Klose, *American Petroleum Industry, 1900–1959;* Ralph Arnold and William J. Kemnitzer, *Petroleum in the United States and Its Possessions*, New York, 1931; and various editions of *Petroleum Facts and Figures*, American Petroleum Institute (API), New York.

CHART 1

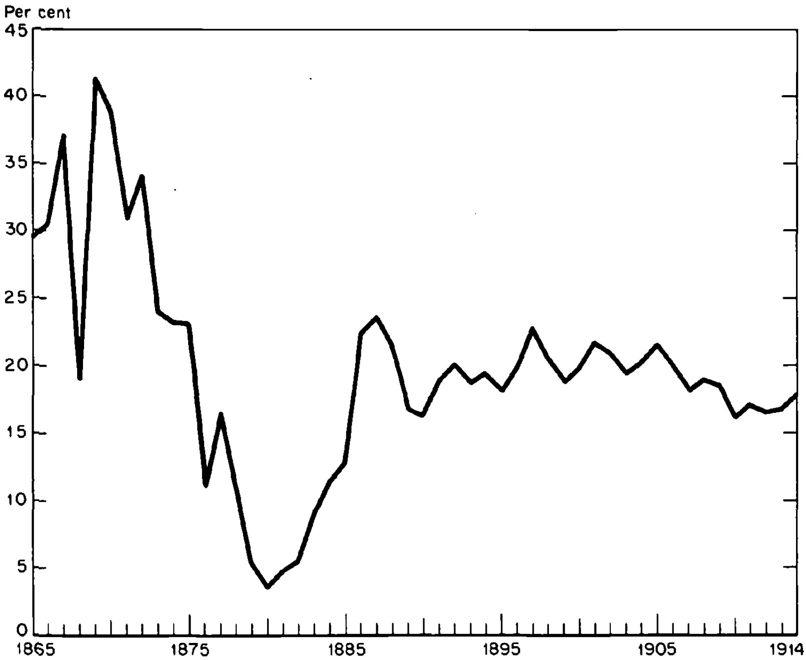
New Wells Drilled and Total Crude Oil Production, 1865–1914



Source: For production, *Mineral Resources of the U.S.*, 1883–1915, and *Derrick's Hand-Book*, I; for new wells, Arnold and Kemnitzer, *Petroleum in the U.S.*, and *Derrick's Hand-Book*, I.

CHART 2

Dry Holes as Percentage of Total Wells Drilled, 1865–1914



Source: For 1865–82, *Derrick's Hand-Book*, I, Folger Report, Wrigley Report, and Carll Report; for 1883–1914, *Mineral Resources of the U.S.*, 1883–1914.

wildcat wells fall more under the conventional definition of uncertainty rather than risk.[3]

4. The ratio of net well abandonments to new wells completed appeared to widen rather than narrow, over time; between 1900 and 1919, for example, average well life increased (in years) by about $\frac{2}{3}$ over the highest well life estimated for the pre-1900 years. Well life is, in this context, a secular rate between the ratio of wells abandoned to new wells drilled. The reasons for abandonments are, of course, related to new drilling, the most obvious being the prevailing market price for crude. In modern production practices, the cost function of a producing well of average productivity has a large, flat segment—and this was no less true for the flush fields treated in this paper. Abandonments, on the other hand, were also a function of other nonmarket forces, such as loss of oil by faulting and the infiltration of water.[4]

[3] These issues are explored in a number of sources. The technical problem of faulting, etc., and its effect on dry hole rates is discussed in Lester C. Uren, *Petroleum Production Engineering*, New York, 1946, Vol. II, pp. 11–14, 87–88, 101. A useful article with a theoretical decision-making model of short- and long-term production is Paul Davidson, "Public Policy Problems of the Domestic Crude Oil Industry," *American Economic Review*, March 1963, pp. 85–108. The data on dry holes and total wells drilled were compiled from *Mineral Resources of the U.S.*, Dept. of Interior, Geological Survey, beginning in 1883 and published annually until reorganization of the Geological Survey in 1923. Thereafter, the compendium was expanded and published by the Bureau of Mines until 1929, and then issued as *Minerals Yearbook of the United States*. All the basic production data for the crude oil sector in this paper were compiled from the Geological Survey reports. Arnold and Kemnitzer (*Petroleum in the United States*) also used the Geological Survey data in compiling their basic series. A careful check of Arnold and Kemnitzer against the Geological Survey reports revealed that they followed the annual reports on *Mineral Resources*, without exception. The quality of the Geological Survey varied from year to year: the least satisfactory and reliable reports were in the early 1880's; coverage and accuracy improved in the mid-1890's. The reports of 1896-97 and of 1905 were exceptionally useful.

The following sources were also used for all the data relevant to the production section, and were most valuable for the pre-1880 period.

S. F. Peckham, *Production, Technology, and Uses of Petroleum and Its Products*, 47th Cong., 2d Sess., H. R. Misc. Doc. 42, Part 10, 1884 (Peckham Report); *The Derrick's Hand-Book of Petroleum: A Complete Chronological and Statistical Review of Petroleum Developments from 1859 to 1898*, Oil City, Pa., 1898; J. T. Henry, *The Early and Later History of Petroleum, with Authentic Facts in Regard to Its Development in Western Penna.*, Phila., 1873; S. S. Hayes, *Report of the U.S. Revenue Commission on Petroleum as a Source of National Revenue, Special Report Number 7*, 39th Cong., 1st Sess., H. Ex. Doc. Dec. 51, 1866 (Hayes Report); Commonwealth of Pa., *Annual Report of the Secretary of Internal Affairs*, XX, *Industrial Statistics*, 1892, Part 3, Harrisburg, 1893 (Folger Report); J. F. Carll, *Geological Survey of Pa.*, 7th Report on the Oil and Gas Fields of Western Pa., for 1887 and 1888, Harrisburg, 1890 (Carll Report); H. E. Wrigley, *Second Geological Survey of Pa.*, 1874, *Special Report on the Petroleum of Pa., Its Production, Transportation, Manufacturing and Statistics*, Harrisburg, 1875 (Wrigley Report).

[4] See Davidson, "Public Policy Problems." The data on abandonments were taken from Arnold and Kemnitzer, *Petroleum in the United States*.

5. Variations in new drilling were positively correlated with variations in posted field crude prices. Decisions to drill new wells were probably much more rationally formed than popular notions about the derring-do of "wildcatters" might suggest.

6. Average yields per well per day rose appreciably over time by about 80 per cent between the late 1880's and 1910. This suggests that wells were kept in production longer, that the number of single prolific wells increased, and that technical improvements expanded the recovery of crude from existing wells.

7. The value of crude oil processed as a percentage of the total dollar value of refined products at the retail level (see Table A-1) rarely exceeded 25 per cent and, for the six census dates, averaged closer to 18 per cent.

INSTITUTIONAL FACTORS AFFECTING PRODUCTION[5]

The exploitation of underground deposits of crude petroleum was from the beginning a random process at best. The methods commonly used today for reducing uncertainty—geological and modern technological ways of prospecting and reservoir engineering—were not available to potential oil producers to any great extent before World War I. "Oil science," or petroleum geology, as the field was to be known professionally, was rudimentary and virtually ignored, even when its limited findings might have been of assistance to oil producers in evaluating drilling decisions. Even after an initial oil strike in previously untested areas, predicting the relative probability of success of wells in the same area was virtually impossible. The modern developments noted help to explain why early production practices were, by necessity, random. Among the unknown or imperfectly understood aspects of the new industry, which began as an adventure, a gamble with an uncertain pay-off, were: the nature of underground structures favorable to oil accumulation; the peculiar lithographic properties of subsurface structures favorable to oil accumulations; the high probability that dissipation of reservoir pressure

[5] Material for this and the following section is based on a wide variety of sources. An expanded version of this section and a complete list of references may be found in Williamson and Daum, *American Petroleum Industry, 1859–1899*, Appendix E. The best sources on the rule of capture for this period are: R. E. Hardwicke *et al.*, *Legal History of the Conservation of Oil and Gas, A Symposium*, Chicago, 1938; Northcut Ely, "The Conservation of Oil," *Harvard Law Review*, 1938; J. H. Marshall and N. L. Meyers, "Legal Basis of Petroleum Production in the United States," *Yale Law Review*, 1938. The generalizations made on the flush field phenomena are based on Andreano, "The Emergence of New Competition," Appendixes A and B. Technology in crude oil production is summarized in Williamson and Daum, *American Petroleum Industry, 1859–1899*. The most useful and authoritative survey of production techniques is *History of Petroleum Engineering*, API, Division of Production, Dallas, 1961. Isaiah Bowman, "Well Drilling Methods," *Water Supply Paper 257*, Dept. of Interior, Geological Survey, 1911, is also a classic work in oil field technology.

drives—water or gas—would result in trapping underground petroleum; and the many ways of producing underground faulting.

Geological uncertainties were reinforced by the institutional framework in which oil prospecting was carried on. Specifically, the common law "rule of capture," which held that subsurface mineral rights rested in the property owner (or lessee) who reduced such minerals to possession, created peculiar technical difficulties in locating and securing petroleum deposits. Petroleum is a fugaceous mineral; its resting place is not permanent but changes according to underground flow and movement. Two adjacent wells producing petroleum from a common pool may stabilize underground drainage, so that each property owner obtains an output equal to the size of the reserves surrounding his well and the strength of the underground pressure pushing the petroleum to the surface. If only one well is drilled, however, and if the two adjacent locations are separately owned (or leased), the one without a well will suffer a loss of underground oil through drainage to the other well. It is in the interest of the property owner without a well, therefore, to drill one in order to protect his petroleum from drainage and to recover his underground rights vested in his above-ground property right.

The historical effect of the rule of capture was to stimulate the drilling of additional wells to "offset" underground drainage. The rule also tended to favor well drilling in rough proportion to the number of property owners or lessees. A proliferation of wells, each drawing from a common source of underground pressure drives, resulted in underground faulting, quick dissipation of the pressure drive, geologically undesirable drainage and shifting of petroleum deposits, and loss of potentially producible petroleum, which could be recovered only by drilling new wells to relocate the shifts in the underground rocks.

The "rule of capture" and the randomness of locating well deposits were characteristic of the petroleum industry from its inception. They contributed to the phenomenon known as "flush fields" which dominated the pattern of crude petroleum production in the period under review. Strictly defined, a flush field is one where output as a fraction of producible underground reserves attains its peak rate over the life of the field in a relatively short time. Two pieces of evidence may be used to illustrate the occurrence of a flush field: actual production rates of individual pools within a field, and peak production rates and rates of decline over time for individual fields or pools. Data on actual production rates for individual pools are well understood, and virtually any set of pools in any of the major producing oil fields will show periods of from six months to two years of output expansion after the initial opening, a peak in output, and then a decline. Total output of the field will continue to expand and will peak later than an individual pool does as additional deposits within the field are discovered and exploited in the same pattern. Examples of the elapsed time from peak rates for three pools discovered between 1901 and 1910 are shown in Table 7.

The phenomenon of flush fields was not only a function of institutional factors but also had its economic influences. The relative ease of entry, the low marginal costs of production for individual wells, and the nominal total costs of above-ground storage were characteristic of crude petroleum production throughout this period. The combination of economic and

TABLE 7

PEAK PRODUCTION AND DECLINE, THREE OIL POOLS, 1902-11
(average daily production)

Pool	Date of Peak Production	Highest Production (barrels)	Per Cent Decline From Peak After: 1 Year	2 Years	3 Years
Spindletop	Oct. 1902	62,548	67	92	94
Humble	June 1905	93,272	84	92	90
Glenn	Mar. 1911	83,370	64	69	66

Source: Andreano, "Emergence of New Competition," p. 309.

institutional factors produced, in the short run, perverse supply elasticity for crude; declines in the price of crude oil would produce proportionately greater increases in the amount of crude produced from a given pool or field. In the short run, the supply curve of crude petroleum could be described as having a large horizontal segment; once a well was brought into production, the marginal cost was zero, or near it.

TECHNOLOGY

Until the development of the rotary drill in the late 1890's, the techniques of well drilling had remained essentially unchanged since the early 1870's. The technique known as cable-tool drilling was adapted to petroleum production from its earlier uses in water- and salt-well drilling. Though the principles of cable-tool drilling remained essentially the same, the quality of equipment improved over time. Application of power, improvements in drilling tools, use of casing, and development of the "torpedo" were the major kinds of technical improvement. Most of the changes resulted from particular problems encountered by oil producers in the fields. Others, such as improvement in metal strengths, use of explosive charges to accelerate the flow of oil, and application of machine operations, were adaptations of techniques developed in other areas of the economy. With one major exception, rotary drilling, the major technical changes in methods and equipment used in drilling and completing wells were developed during the first decade of the industry's history.

Cable-tool drilling is based on the percussion principle of boring. The drilling is generally slow except at shallow well depths and requires a high degree of art. Rotary drilling—a technique first used in drilling water wells in West Virginia, South Dakota, and northern Texas—consists of driving a bit through strata; water, or some other fluid, is passed through the cutter or drill bit under pressure in order to force the upbraided material through the side of a hole outside the bit casing. Rotary drilling was relatively faster than cable-tool drilling, gradually required less of the driller's art, and was specially suited to loose, unconsolidated strata of the type commonly found in the Gulf Coast areas. The later development of a hard rock bit, plus some modifications in derrick design and power systems, made rotary drilling well adapted for harder rock drilling. The method was first used in an oil well at Spindletop in 1901, and with a few minor exceptions its use was confined to wells drilled in Gulf Coast Texas and Louisiana until the 1920's.[6]

INPUTS

Strictly conceived, the final input for crude petroleum output is the drilled well. The geological and engineering peculiarities of crude oil production mentioned previously, however, make such a simplified notion of a production function impracticable and empirically unusable. The collection of inputs must be viewed, therefore, as the flow of land, labor, capital, and entrepreneurial skill in the exploration, drilling, completion, and operation of a well. There are no figures that show the aggregate structure of these separate inputs or of their relative contributions to the final output of crude petroleum. Except for a few Census figures, the aggregate mix of inputs can be discussed only in qualitative terms.

A precise measure of the magnitude of labor and capital employed in the exploration, drilling, completion, and operation of crude petroleum wells for the pre-1900 period is impossible within the present limits of data availability. Lease values were not reported; much of the work force in the early years was part time, floating, and otherwise uncountable;

[6] Williamson and Daum, *American Petroleum Industry, 1859–1899*, pp. 137–158; Williamson, Andreano, Daum, and Klose, *American Petroleum Industry, 1900–1959*, pp. 29–32.

TABLE 8

SELECTED CENSUS DATA ON CRUDE OIL PRODUCTION, 1870-1919
(dollars in millions)

Class	1870	1880	1889	1902	1909	1919
Number in work force[a]	4,488	11,477	29,223	50,107	59,085	125,110
Wage bill[b]	4.0	10.9	10.3	29.2	51.6	236.7
Capital (at book value)	--	--	--	330.9	683.3	2,421.5
Value of crude output	19.3	24.6	27.0	71.4	117.7	694.0

Source: Special Reports of the Census Office, *Mines and Quarries*, 1902, p. 721; *Fourteenth Census, 1920*, Vol. XI, *Mines and Quarries*, p. 311; *Thirteenth Census, 1910*, Vol. XI, *Mines and Quarries*, p. 263.

[a]Includes operators, salaried officers, and contract employees, 1902-19; no separation by type earlier.

[b]Includes salaries, wages, and contract payments; contract payments not available for 1870 and 1889.

while equipment in drilling and completing could be reused many times. In Table 8 is a summary of selected input data for the crude petroleum sector for 1870–1919 from the Census reports of those years. Because the pre-1902 data are most unreliable, they are presented only to give some impression of the general direction of expansion and the magnitudes involved.

DRILLING COSTS

The cost of equipment, labor, and materials used in drilling wells can be detailed a bit more than other input components can. But even these data are still only an indication of general trends. The standard list of items used in drilling during the early decades varied for each drilling location depending on the depth of the well, the art of the driller, the terrain, the lithographic properties of the strata being drilled, and other uncontrollable variables. Inability to clarify depreciation charges, to allocate costs of drilling equipment over multiple locations (or for pumping), and wide variability in fuel intake and completeness of materials needed must also be considered as deficiencies of the qualitative estimates of drilling costs presented below.

During the first decade of the industry, drilling costs declined in real terms. It seems most likely that, as a result of equipment improvements, the greater skill of the drillers, and the wider use of power systems in percussion drilling, the total unit cost of putting down a well was reduced appreciably by the early 1870's.

The trend in drilling costs in the Appalachian field after the early 1870's continued downward, although increases in well depths put absolute dollar costs successively higher. Well depths in the early 1870's were on the average from 700 to 900 feet, while for drilling costs, a total of $6,100 probably prevailed as an average.[7]

The pattern of drilling costs and well depths is somewhat clearer to trace after the early 1870's. The estimates of total drilling costs shown in Table 9 include: pipe, casing, tubing, sucker rods, and belting; derrick and rig; engine and boiler; contract drilling (driller plus four hands); torpedoes and storage tanks. Undeflated money values are shown. The modal well depth in the Appalachian field was 1,200 to 1,500 feet

TABLE 9

APPROXIMATE COST OF DRILLING, APPALACHIAN FIELD, 1877-98
(dollars)

Depth (feet)	1877-78	1886-88	1897-98
1,000	3,021	2,119	--
1,400	3,535	2,483	--
1,600	3,822	2,589	2,206
2,000	4,326	2,951	--
2,400	--	--	2,595
2,800	--	--	3,160
3,200	--	--	4,720

Source: Williamson and Daum, *The American Petroleum Industry, 1859-1899*, p. 768; Andreano, "Emergence of New Competition," p. 329. See also footnote 8.

in the late 1870's, 2,000 to 2,200 feet in the late 1880's, and 2,600 to 2,800 in the late 1890's.[8]

[7] This figure is based on a well depth of 900 feet and the use of a derrick, boiler and engine, casing, tubing, sucker rods, a contract driller, a tank, and two torpedoes. On the assumption of a 20-acre drilling location, a sum was added for lease contracts. Prices were obtained for each of the items; for example, a contract driller price of $2.00 per foot was used. Materials used in making the calculations—to be interpreted as only an approximation—are from Cone and Johns, *Petrolia*, p. 463; *Derrick's Hand-Book* I, pp. 153 and 278; and various parts of the Carll, Folger, and Wrigley Reports. The drilling locations developed up to 1875 varied considerably in stratigraphic characteristics, and many wells could be drilled for one-half the average cost presented here. Others, however, presented greater boring difficulties and required more time to drill, with much higher costs.

[8] The calculations presented in Table 9 are a summary of much more detailed data contained in the sources to the table. The calculations are based on the prevailing practice of well drilling in western Pennsylvania for the respective dates. Pipe, casing, tubing, belting, packing, and sucker rods were computed at prices prevailing in each year, and the amounts for wells of various depths used were checked against contemporary practice in the White Sands and Bradford oil areas. Derrick, engine and boiler, and storage tanks were figured at the minimum prices. Only the cost of a 100-barrel storage tank and two torpedoes were included in the calculation; for some wells more

An impressionistic account of drilling costs, by fields other than the Appalachian area, for the years after 1888 follows.

Ohio-Indiana

The best contemporary estimates suggest that the total cost of bringing wells into production, with the common depth of 2,000 feet, ranged from $2,000 to $2,500.[9]

Gulf Coast

At Spindletop in 1901, the rotary drill was used for the first time successfully in a commercial oil well. Because the rotary was not used to any great extent in other fields, there is no real basis for comparison, and it is not possible to calculate the cost reduction, if any, produced by the innovation. A sample of several of the largest producing companies in the field which used the rotary and drilled thirty-two wells during the year 1906 showed an arithmetic average total cost of $6,331.41. There was a cluster of wells costing $4,000 and $8,000, and the range was from $1,250 to $11,000. Depths were approximately 2,000 feet for half the wells drilled.[10]

Mid-Continent Field

Modal well depths in Oklahoma, Kansas, and north Texas were close to 2,500 feet between 1906 and 1910. The only available estimates placed the total cost of putting down a well (1,900 foot depth) at $5,000. All drilling was done with cable tools.[11]

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torpedoes and larger storage tanks obviously would be required. Drilling contractors' prices were again checked against actual transactions: $1.00 a foot for 1877–78, $0.60 a foot for 1886–88, and $0.45 a foot for 1897–98 were the figures used. The basic data underlying Table 9 may be found in: *Mineral Resources*, 1888, pp. 316–17; *Engineering and Mining Journal*, Sept. 1, 1888, p. 179; *Derrick's Hand-Book*, II, pp. 177–183; *Peckham Report*, pp. 142–48. Modal well depths were calculated from well records in the Carll Report, pp. 147–323, and *Mineral Resources* for the respective years.

[9] These impressions are based on well records and scattered cost data in Edward Orton, First Annual Report, *Geological Survey of Ohio*, Columbus, 1890.

[10] Gulf Coast data are primarily from *Oil Investor's Journal*, an oil field paper issued from Beaumont, beginning in 1902. Three numbers of the *OIJ* (Nov. 3, 1906, Jan. 18, 1907, and July 6, 1908) contained extensive surveys of well depths and costs, drawn from company records of drilling operations. Also of value was Robert Hill, "The Beaumont Oil Field," *Transactions of the American Institute of Mechanical Engineers*, 1903.

[11] *The Oil Investor's Journal*, July 6, 1908; C. W. Shannon and L. E. Trout, *Petroleum and Natural Gas in Oklahoma*, Oklahoma Geological Survey, Bull. 19, Norman, 1915; *Oil and Gas in Oklahoma*, Oklahoma Geological Survey, Bull. 40, Norman, 1928.

California

The only data available on drilling costs in California are presented in Table 10. The modal well depth was between 2,000 and 2,500 feet. These data are somewhat misleading as they are an unweighted mix of the total costs for all oil pools in California. Consequently, the decline in total cost with increasing depths must not be taken literally.[12]

TABLE 10

TOTAL COST OF DRILLING WELLS, CALIFORNIA FIELD, 1913

Depth (feet)	Cost (dollars)
1,000	11,700
2,000	11,490
3,000	11,080

Source: Andreano, "Emergence of New Competition," p. 334; California State Mining Bureau, Bull. 69, p. 26.

TRANSPORTATION AND STORAGE OF CRUDE AND REFINED PRODUCTS

Early Storage and Transport Facilities

A highly inflammable and volatile liquid, petroleum from the outset posed difficult transport and storage problems. Producers in the oil region initially built wooden tanks or vats to receive the oil from individual wells, although it was not uncommon for the owner of a newly struck flowing well to store his oil in a hastily constructed earthen reservoir.

Even the best wooden storage facilities were more subject to loss through leakage and evaporation and fire than iron tanks introduced during the 1850's by coal oil refiners were. It was not until the wartime shortages of metal were relieved after 1865, though, that iron storage tanks became widely adopted in the region and at major shipping and receiving centers.[13]

Following a long-established practice for transportation of liquids, the industry originally packaged both crude and refined products in barrels for shipment to refining and marketing centers. Because of their cost, weight, and tendency to leak, wooden barrels were not, however, satisfactory or economical for transporting petroleum. One of the major

[12] Original data are from *Petroleum Industry of California*, California State Mining Bureau, Bull. 69, Sacramento, 1914. The FTC compiled drilling and completion cost data for 1914–19. See FTC, *Pacific Coast Petroleum Industry*, I, p. 137.

[13] Williamson and Daum, *American Petroleum Industry, 1859–1899*, pp. 183–194.

achievements of the industry during the 1865–1914 period was the gradual substitution of bulk handling methods for special packaging.

Gathering Lines

The first step in the evolution of bulk shipments came early in the 1860's when producers in the oil regions began experimenting with gathering lines. By 1865, the major technical problems had been solved, and the practice of linking producing wells by pipeline to storage facilities and shipping terminals several miles distant was firmly established.

Tank Cars

Until the mid-1860's, producers in the region had no choice but to barrel their product at storage tanks for shipment to market by one of two routes. One was to send the barrels by wagon over rough roads to the nearest railroad station some 25 miles to the north. The other and more popular route was to load the barrels on small craft for the journey down Oil Creek to the Allegheny River, where the cargoes were transferred to flat boats or rafts for transport down river to Pittsburgh.

The relative importance of the river system of transport began to decline when local railroads, closely linked with major truck lines, were extended into the region. Barreling of the crude at shipping terminals continued, however, until the advent of the railroad tank car about 1865. The early models consisted simply of wooden tanks mounted on flat cars and were subject to considerable leakage and the ever-present danger of fire. After 1868, that type of car was gradually replaced by the modern horizontal, boiler type of car, made of steel and equipped with a dome to allow the oil to expand without damaging the tank. Even the earliest tank car brought significant savings to shippers through reduction of losses from leakage and evaporation and, above all, through elimination of barrels costing several dollars each.[14]

Long-Distance Crude Oil Pipelines

By the early 1870's, the major technical bottlenecks in petroleum transportation appeared to have been broken. A system of gathering lines enabled most producers to run their crude from wells to railheads or riversides at one-tenth the cost formerly charged by teamsters. For longer hauls, three major trunk lines had more or less adequately linked the producing fields with refining centers. Even so, transportation costs were still among the industry's largest expense items. It was the possibility

[14] *Ibid.*, pp. 178–183.

of further reducing them that led to the development of the long-distance crude oil pipelines.

Preliminary attempts to construct such a line, beginning in 1874, revealed the difficulties involved. Capital requirements were large, and technical problems requiring solution involved pipelaying and the design of pumps which could provide sufficient pressure to boost the oil over hilly terrain. In addition, the early promoters encountered stubborn opposition from the railroads, which attempted to block pipeline construction in various ways, including purchase or lease of rights-of-way along proposed pipeline routes and the initiation of a variety of legal proceedings in court.

It remained for the Tidewater Pipe Company, backed by independent oil men who had good reason to think Standard Oil was receiving preferential rates from the railroads on its crude shipments, to overcome those obstacles. Five inches in diameter and built at an estimated cost of $750,000, the first crude oil line, stretching over the 100 miles from Corryville to Williamsport, Pennsylvania, began functioning in June, 1879.[15] Once its feasibility had been demonstrated, Standard Oil moved quickly into the construction of long-distance crude oil lines tapping the oil region, as did other independent producing and refining companies.

Pipelines were rapidly introduced into the new fields subsequently brought into production in Ohio, Indiana, the Gulf Coast, California, and the mid-continent region. There was also a trend toward increasing pipeline capacities by enlarging the diameter of pipe from the 5 to 6 inches typical of the 1880's. A growing number of new lines were constructed over the succeeding twenty-five years with 8-inch pipe and in some instances 12-inch pipe.[16] While some crude continued to move by tank car, the great bulk of oil produced from the 1880's on was shipped to refining centers by long-distance lines.

Ocean-Going Tankers

While a few sailing ships fitted with iron tanks began hauling crude oil across the Atlantic during the early 1860's, several factors long prevented bulk transportation from replacing barrels or tins in marine shipments. It was difficult, for example, to prevent movement of oil in tanks from throwing the ship out of balance, while vapor and leakage posed a serious fire hazard. Moreover, the volume of crude oil exports

[15] *Ibid.*, pp. 405–412, 440–444.

[16] *Ibid.*, pp. 443, 603; Williamson, Andreano, Daum, and Klose, *American Petroleum Industry, 1900–1959*, pp. 69–71 and 88–92.

was not large enough to attract serious attention of Americans to development of better tank ships for crude oil shipment, while barrels or tins were considered safer and more satisfactory for water-borne transport of refined products.

Actually, it was the attempt of the Russian industry to reduce the cost of transporting refined products to western Europe which led to the introduction of the modern type of ocean-going tankers. Following successful earlier experiments with wooden sailing tankers on the Caspian, the Nobel firm, located in Baku, put into service in 1885 two iron steam tankers, equipped with a multiple system of storage compartments.[17] It was not until after the discovery of the important Gulf Coast fields in 1900 that tankers became important carriers of crude oil to Atlantic coast refining centers. The adaptation of the construction features of the ocean-going tankers to barges also extended the bulk shipment of crude oil on the inland waterways of the United States.

Bulk Handling of Refined Products

All the objections to barreled shipments of crude—the weight and cost of the barrels, the tendency of the contents to leak or evaporate, and the problems associated with their return for reuse—also applied to shipment of refined products. The introduction of bulk shipments by railroad tank cars during the late 1860's was thus a major step in the evolution of a system which ultimately enabled marketers to move refined oil to final consumers without special packaging. Yet, for various reasons, barrels continued to play an important—if diminishing—role in the distribution of refined products throughout the 1865–1914 period.

The expansion of tank-car shipments, for example, necessitated a corresponding construction of storage facilities or bulk stations to receive the oil at major distributing points. Because barrels remained for some time the most convenient means of storing oil by retail outlets and retail customers, the initial effect of tank-car shipments was simply to transfer packaging or barreling operations from refineries to bulk stations. It was not until the 1880's that tank-wagon deliveries from major distributing centers began to extend bulk distribution to retail outlets and—by door-to-door deliveries—to retail customers. Tank-wagon deliveries, however, were economical only in relatively densely populated markets. In other areas, refined products continued to be distributed in barrels or drums.[18]

Overseas distribution of refined products followed much the same pattern. Initially the oil was either barreled or, if destined for shipment

[17] Williamson and Daum, *American Petroleum Industry, 1859–1899*, pp. 637–643.
[18] *Ibid.*, pp. 533–534.

to or through the tropics, put in five-gallon tins at the refineries. The initial effect of tank-car shipments, again, was largely to transfer packaging operations for export sales to the major ports. With the growing use of ocean-going tank steamers after the mid-1880's, bulk handling of refined products was increasingly extended to bulk storage facilities at the principal overseas receiving ports. As in the United States, the further extension of tank-wagon deliveries was primarily a function of the densities of the markets. By 1914, the method was quite widespread in western Europe, but for other parts of the world oil was packaged in barrels or tins at the ports for delivery to retail outlets and retail customers.[19]

In view of the growing significance of long-distance crude oil pipelines during that period, it is at first glance strange that there was no corresponding development of product pipelines before 1914, particularly since kerosene had been successfully transported several hundred miles from its source to Wilkes-Barre, Pennsylvania, through a line completed in 1893.[20] Several factors help explain the delay. One was a general feeling among oil men that piping refined oil over several hundred miles would damage the product. More important, however, were differences in the demography of the markets for crude and refined products. Since a large portion of the industry's refining capacity was located at major marketing centers, operators of crude oil pipelines terminating at such centers were assured of a demand for crude oil sufficiently large to cover operating costs. The fact that refining capacity was so concentrated tended to reduce the volume of refined products demanded at major marketing terminals below the amounts required for the economical operation of long-distance product pipelines.[21] It was not until the 1930's that the domestic demand for refined products was sufficiently large to make long-distance product pipelines economical.

Inputs

Lack of both data and of comparability of statistics make it impossible to provide more than a fragmentary analysis of the growth of inputs of capital and labor in the transport sector of the industry. It was reported, for example, that in 1865 there were "some 2,000 craft" engaged in the transport of crude down Oil Creek and the Allegheny River.[22]

While the size of their holdings is not known, railroads and their affiliated fast freight-forwarding companies apparently owned and operated

[19] *Ibid.*, pp. 653–657.
[20] *Ibid.*, pp. 572–573.
[21] *Ibid.*, pp. 532–533.
[22] *Ibid.*, p. 168.

most of the tank cars available for transport of petroleum for some two decades after the mid-1860's.[23] In 1890, when information on rolling stock was first collected, the number of railroad-owned tank cars—including those used to transport liquids other than petroleum—was 2,056.[24] Although the railroads added substantially to their holdings after 1890, in 1905 Standard Oil's tank-car fleet numbered approximately 10,000 and that of independents 3,000, compared with the 5,163 owned by railroads.[25] A rough estimate suggests that by 1914 there were between 20,000 and 25,000 tank cars available for the transport of petroleum—8,530 owned by railroads and the remainder by refiners and private carriers.[26]

TABLE 11

LENGTH OF GATHERING AND TRUNK PIPELINES, 1879-1910
(miles)

Year	Gathering Lines	Trunk Lines	Total
1879	372	322	694
1880	514	702	1,216
1890	2,457	2,933	8,390
1900	11,152	6,821	17,973
1910	23,804	16,226	40,090

Source: *Petroleum Facts and Figures*, API, 1959, p. 153.

Data on total pipeline mileage, first available in 1879, are shown in Table 11. The total capital investment in pipelines was roughly proportional to the increase in mileage, although construction costs varied considerably with the expense of obtaining rights-of-way, with the terrain, the size of pipe, and with pumping requirements. Estimates of the cost per mile of the early lines into the oil region ranged between $7,500 and $10,000; first lines in the Gulf Coast area cost between $5,400 and $6,500 per mile, compared with costs of approximately $10,000 per mile for lines into Ohio, Indiana, and the mid-continent.[27]

The growth of the world tanker fleet between 1900 and 1914 is shown

[23] *Ibid.*, p. 198.

[24] *Report on the Transportation Business in the United States*, Dept. of the Interior, *passim*; Eleventh Census of the U.S., 1890, Part I, *Transportation by Land*, 1895, p. 109.

[25] *Report of the Bureau of Corporations on the Transportation of Petroleum*, Washington, 1906, p. 78; *Statistics of Railways in the United States*, ICC, 1915, p. 25.

[26] *Statistics of Railways in the United States*, ICC, 1915, p. 25.

[27] Williamson and Daum, *American Petroleum Industry, 1859–1899*, pp. 443 and 603; Williamson, Andreano, Daum, and Klose, *American Petroleum Industry, 1900–1959*, pp. 88–92.

in Table 12. Note that in 1900 there were but three tankers under American registry, making up 2 per cent of the world tonnage, while in 1914 the American flag tankers accounted for only about 15 per cent of the total. As a measure of the actual number of tankers owned by American oil companies, these proportions are somewhat misleading. In 1909, for example, two of Standard Oil's European subsidiaries owned and operated 49 tankers.[28] This was a practice followed on a somewhat smaller scale by other American companies.

TABLE 12

PETROLEUM TANKER FLEET, OCEAN-GOING VESSELS OF 2,000 GROSS TONS AND OVER, 1900-14

	World Fleet		U. S. Registry		
Year	Number	Gross Tons (thousands)	Number	Gross Tons (thousands)	Percentage of Total
1900	109	356.5	3	7.6	2.0
1904	153	579.2	19	58.0	10.3
1909	194	778.3	31	108.9	14.5
1914	300	1,317.2	53	197.2	15.5

Source: *Petroleum Facts and Figures*, API, 1959, pp. 174-175.

Storage and Distribution Facilities

As already noted, increased bulk shipments of refined products by tank car or tanker necessitated a corresponding expansion of storage and distribution facilities at principal marketing centers. Standard Oil, for example, increased the number of bulk stations it owned and operated in the domestic market from 130 in 1882 to a reported 3,573 in 1906.[29] Further expansion by the Standard Oil companies and construction by independents must have brought the total to well over 5,000 by 1914. Because of differences in size, the growth of the number of bulk stations provides only a rough indication of capital investments in this sector of the distribution system. Apparently $20,000 was a representative figure during the late 1880's for investment in a metropolitan-area station which, in turn, distributed its products to outlying substations that might cost only a few hundred dollars.[30]

Transport Costs

Information on the relative costs of the various methods of transporting crude is no better than data on inputs. Rates for shipment down Oil

[28] Hidy and Hidy, *Pioneering in Big Business*, New York, 1955, p. 456.
[29] Williamson and Daum, *American Petroleum Industry, 1859–1899*, p. 690.
[30] *Ibid.*, p. 690.

Creek during the mid-1860's were reported to range "between $.15–$.75, and occasionally $1.00 a barrel," while the charge by river from Oil Creek to Pittsburgh varied "from $.40 to $1.00 a barrel." Depending on the distance and the condition of the roads, teamster charges for hauling to railroad or river shipping points might run as high as $4.00 per barrel. A fairly reliable estimate for 1862 suggests a total cost for delivering crude oil to New York from the oil region of $8.00 per barrel.[31]

Railroad tank-car shipments could undoubtedly be made at costs much below the combined water and rail costs in the early 1860's. Given the nature of the railroad competition particularly before 1887, however, there was no necessary connection between charges and costs. By the early 1870's the actual cost of rail shipments from the oil region to the Atlantic seaboard was close to 56 cents per barrel, although rates charged varied from 87 cents to $1.50 per barrel. Following the passage of the Interstate Commerce Acts in 1887, rail charges for bulk shipments of crude to the east coast apparently became stabilized at about 55 cents per barrel.[32]

Whatever the rail costs or charges, it is clear that tank-car shipments could not compete for shipments from areas served by pipelines. By the late 1880's, reasonably accurate estimates suggest a pipeline cost of shipping crude from the oil region to tidewater ranging between 21 cents and 25 cents per barrel; a decade later, it had dropped to 11–13 cents per barrel.[33]

How much tankers cut transport costs of refined products relative to barrels during that period is impossible to measure. According to estimates made in 1888, however, the port fees, inspection charges, loading, and other costs for a tanker carrying 20,000 barrels of petroleum products were some $2,300 less than shipping the same amount in barrels. Moreover, compared with a maximum number of three round trips across the Atlantic in one year for sailing ships, tankers by 1892 were averaging seven round trips.[34]

REFINING

Distillation and Treating

The two basic steps involved in converting crude petroleum into finished products during 1859–1914 were distillation and treating. Under the techniques developed by coal-oil refiners and adapted to petroleum, distillation was accomplished essentially by applying heat to crude oil in stills. As temperatures rose, the various fractions were drawn off in

[31] *Ibid.*, pp. 166, 169, 187.
[32] *Ibid.*, pp. 349–350, 436, 586.
[33] *Ibid.*, p. 586.
[34] *Ibid.*, p. 586.

the order of their relative volatility or density, starting with butane and pentane (to use modern terminology), followed in order by the naphtha fractions (gasoline, naphtha, benzine), then kerosene, light fuel oil (gas oil), lubricating stocks, and finally residuum and coke.[35]

The major objectives of refiners over the years after 1859 were to improve the distillation process, by reducing fuel consumption and costs and obtaining closer control over output of the various fractions. Among the highlights of this development were improvements in the design and firing of stills; successful experiments with the introduction of superheated steam into the stills as an alternative to direct firing; vacuum distillation; and, after 1900, introduction of continuous distillation to replace the long-established practice of "batch distillation."[36]

To prepare the distillate fractions for final consumption, it was necessary to subject them to further processing or treating—usually involving use of chemicals—in order to remove impurities and objectionable odors and to improve their appearance or color. By the mid-1860's, for example, the best quality illuminating oil was obtained by first mixing the kerosene fraction with small amounts of sulphuric acid in agitator tanks to rid the product of its bad odor. To eliminate most of the sulphuric acid, the mix was next put through a series of water washes, followed by the addition of caustic soda to further neutralize the acid. The final step was to run the mixture into bleaching tanks where, after several days, the caustic soda tended to settle to the bottom.[37] Naphtha distillates had to be treated by essentially the same processes.

Petroleum lubricants posed somewhat special treating problems. From the start of the industry, some heavy-duty lubricants were produced directly from crude without distillation. This was done by filtering selected types of crude through animal charcoal and bone black, a process long used to purify and improve the color and odor of all kinds of oils. Lighter lubricating oil suitable for use as cylinder oil, however, was produced from distilled lube stocks which had to be treated in much the same way as refined kerosene. Moreover, it was also necessary to remove the wax from the lube stocks by chilling and pressing.[38]

In contrast with the other major refined products, distilled fuel oil required virtually no additional treatment. Care had to be exercised to keep the light fuel oil fraction within acceptable limits of volatility and density, but residuum, also used as a fuel, required no such attention.

[35] *Ibid.*, p. 208.

[36] For a detailed description of these developments, see *ibid.*, Chaps. 9, 10, 18, and 23; and Williamson, Andreano, Daum, and Klose, *American Petroleum Industry, 1900–1959*, Chap. 4.

[37] Williamson and Daum, *American Petroleum Industry, 1859–1899*, pp. 222–223.

[38] *Ibid.*, pp. 242–246.

As with distillation, refiners attempted after 1859 to reduce costs and obtain better results from treating processes. Despite major advances, however, treating tended to remain more of an art than a science during that period—particularly with respect to lubricating oils.

Refining Technology

The state of technology and the improvements in refining techniques, which occurred after the major innovations of the first decade, cannot be discussed in the short compass of this paper. With the exception of the Frasch process and the early experience with continuous distillation, refining remained strictly a matter of separating the components of crude, with the result that product yields were dependent entirely on the characteristics of the available crude. The commercial success enjoyed by continuous distillation after the first decade of the twentieth century indicates that the method, if adopted in the pre-1900 years, would have brought about significant improvements in the size and efficiency of refining plants. The Frasch process, though still committed to a batchstill operation, was developed in direct response to the crude oil discovered at the Lima-Indiana field. This crude, known as "skunk oil" or sour crude, had exceptionally high sulphuric content and was not refinable into kerosene by the known technology used for eastern oils. Frasch, a German-born engineer, developed a refining process for the Standard Oil Company and implemented the management's earlier decision to become heavily engaged in the production and transport of Lima crude.[39]

In any case, refiners entered the new century with a refining system tied to the rigidities of batch operation and mere separation of the components of crude supplies as part of a formula which depended for flexibility primarily upon expansion of facilities and crude supplies. Most of their problems for two decades ahead were concerned with adapting that relatively inflexible refining system, not only to production of four instead of two major products, but also to processing a vast quantity of low-yield crudes from the Gulf Coast, California, and mid-continent crude oil producing areas.

Output Record

While much better than the evidence for other sectors of the industry, the data covering refining are far from complete. The only growth indicators covering the entire 1865–1914 period are estimated rates of refining capacity and outputs of major refined products. Beginning with the Census of 1880, data are also available for the number of plants, average annual employment, book value of capital invested, and gross

[39] *Ibid.*, pp. 475–582, 616–618.

TABLE 13

PETROLEUM REFINING: WORKING CAPACITY AND RATE OF UTILIZATION, SELECTED YEARS, 1864–1911

	1864-65	1872-73	1881	1884	1888	1895-97	1906	1911
Rated capacity, per day (hundred barrels)	11.7	47.6	97.8	124.9	140.3	220.8	331.5	482.3
Rate of capacity utilization (per cent)	—	88	90	78	85	94	104	93

Source: Williamson and Daum, pp. 291, 473, 486; Andreano, pp. 20, 61, 350.

Note: Rated capacity was what the industry claimed as its daily limits of crude intake. The resulting rated capacity was tied to an annual basis (300 days). A deduction of 25 per cent from annual capacity was then made to allow for stills under repair, cleaning operations, and stand-by capacity. That figure was called working capacity. The amount of working capacity above or below annual refining receipts of crude was then taken as a percentage of working capacity.

and net value added by refining. Data on rated refining capacity and rate of utilization for selected years between 1864–65 and 1911 are shown in Table 13. Two summary conclusions may be drawn from this material.

1. Total rated refining capacity doubled about every ten years. Peaks in construction followed, with a short time lag, peaks in crude oil production. This was especially true between 1878 and 1884, with the prolific crude discoveries in Bradford; between 1888 and 1895, as a result of Lima-Indiana; and after 1901 and until 1911, coinciding with the output expansion of petroleum from the Gulf Coast, mid-continent, and California fields.

2. The rate of utilization of capacity, after allowances for stand-by capacity and other technical adjustments, calculated for selected dates from 1873 to 1911, exceeded 94 per cent only in 1906 when the rate was very close to the limits of working capacity.

Total output of major refined products, as already indicated, expanded from 1.33 million barrels in 1865 to 188.88 million barrels in 1914 (see Table A-3). The gross value added by refining, as a percentage of the total value of the products at retail (see Table A-1), ranged roughly between 18 and 25 per cent, while net values varied between approximately 8 and 11 per cent.

Inputs

Data on the capital and labor employed in the refining sector of the industry are shown in Table 14. It should be noted that the data on capital refer to book value as reported in the Census and are not a very satisfactory measure of capital inputs. Similarly, the labor force data refer to the average number of workers employed during the year and therefore correspond only approximately to a total labor input.

Despite these limitations, it is clear from the following tabulation that

TABLE 14

CAPITAL AND LABOR IN REFINING SECTOR OF PETROLEUM INDUSTRY, 1880–1914

	1880	1889	1899	1904	1909	1914
Book value of capital ($ million)	27.3	77.4	95.3	136.3	181.9	325.6
Wage earners	9,869	11,403	12,199	18,768	16,640	31,097

Source: *Census of Manufactures: 1900*, p. 363; 1919, p. 757.

refining tended to become much more capital intensive from 1880 through 1914, with a roughly corresponding increase in physical output per worker.

	1880	*1889*	*1899*	*1904*	*1909*	*1914*
Capital, per worker (dollars)	2,766	6,788	7,812	7,262	10,931	10,470
Output, per worker (annual, in barrels)	1,282	2,420	3,950	2,964	6,449	5,878

Costs

The cost of physical inputs in the refining sector is a function of prices of inputs, product mix, and size of plant. While precise input costs cannot be found, it is possible to trace unit refining or manufacturing costs for plants of known size. The manufacturing costs were probably equivalent to variable costs, although clearly in some instances the estimates also included contributions to overhead.

From the early 1870's until the late 1890's, manufacturing costs declined by at least 20 to 25 per cent in real terms. After the mid-1880's, data are available for plant size and the mix of crudes as well. While no fundamental change in refining techniques occurred, variations in the quality of the crude changed the mix of inputs for treating and distillation. Manufacturing costs for Standard Oil of 0.534 of a cent per gallon of crude input in 1884 had declined to 0.39 of a cent by the mid-1890's. Greater use of Lima crude subsequently forced Standard's manufacturing costs up to 0.47 of a cent per gallon in 1900. Standard's costs for all plants, sizes, and product mixes declined again to 0.42 of a cent per gallon of crude input by 1911. These cost variations were principally a function of lower material prices, the relative ease in obtaining acceptable quality of refined products from eastern crudes, and the accumulated skill of the refiner's art.[40]

Manufacturing costs for the newer grades of crude other than eastern or Appalachian oil were somewhat higher, on the average, than those noted above. Estimates for 1906 show manufacturing costs of 1.5 cents per gallon of crude input for Gulf Texas crude, 1.8 for Lima crude, 0.8 for mid-continent, and 1.7 for California crude. These higher estimates reflect both increases in raw materials prices and, more importantly, the greater difficulty in obtaining acceptable quality of refined products because of the many technical problems encountered with crude qualities, radically different from the known refining practices used for eastern oils.

[40] These data and succeeding figures on manufacturing costs computed from U.S. *v.* SONJ, *Brief of Facts and Arguments for Petitioners*, I, p. 199; Report of the Commission of Corporations on the Petroleum Industry, Part 2, *Prices and Profits*, p. 54; *Report of the Industrial Commission*, I (testimony of Davis, Westgate, Lee, Emery, and Riu).

The median plant size in the industry increased several times over from the mid-1880's to the midpoint of the first decade after 1900, although wide variation in plant size persisted throughout the period. In the mid-1880's the range of plant capacities was from 40 barrels to 6,500–7,500 barrels per day of crude input. An informed guess of median plant capacities in 1880 put Standard's plants at 4,500 barrels per day and non-Standard at about 1,000 barrels per day.[41]

Economies of scale did not appear to be very extensive despite the highly skewed distribution of plant capacities. The manufacturing cost disadvantage of a non-Standard plant in the pre- and post-1900 periods could not have exceeded the range of 0.12 to 0.25 of a cent per gallon of crude input for crudes of similar grades. The comparison is somewhat misleading, of course, because the persistence of such a wide range of plant sizes can be better explained by the ability of firms to find market niches relatively safe from Standard Oil competition.

Greater refining efficiency was no doubt in part responsible for the drop, shown in the following tabulation, in the value added by materials (chiefly chemicals) other than crude used in the refining process. Most of the decline between 1880 and 1899, however, was apparently a reflection of lower costs of these materials.

Percentage Value Added by Materials (Other than Crude) to Total Retail Value of Refined Products

1880	*1889*	*1899*	*1904*	*1909*	*1914*
20.6	13.4	9.2	9.7	9.9	9.5

(Source: Table A-1.)

Construction Costs

In the mid-1880's, the construction costs for a refinery of the most efficient design, using Appalachian crude, were about $100 per barrel of rated daily crude capacity, in current prices. In the late 1880's, construction costs for a plant using Lima crude approximated $141 per barrel of capacity, at current prices. In the 1900–10 period, the only data available refer to the experience of the Standard Oil Company, Gulf Oil Corporation, and the Texas Company. For a refinery using mid-continent crude, the cost per barrel of capacity in 1906 at current prices ranged between $73 and $80; for California crude, $74; for Gulf Coast crude, about $260; for Illinois (about 1910), $176. By multiplying per barrel of capacity cost by median plant sizes of Standard and non-Standard refineries

[41] Williamson and Daum, *American Petroleum Industry, 1859–1899*, pp. 282–283, 482–484; Andreano, "Emergence of New Competition," pp. 336–344.

for 1906, it is possible to give rough estimates, shown in Table 15, of the construction costs of refineries of the most efficient design with differing crude mixes.[42]

Construction costs in the present context may also be considered as a first approximation of the total capital requirements a new firm would face at the refining level. Average capital investment at book value per refinery in 1904 was \$1.4 million. A sample of 336 firms from a population of 1,344 firms, in *Moody's Investment Manual* for 1906, showed a mean

TABLE 15

ESTIMATES OF CONSTRUCTION COSTS OF REFINERIES, BY CRUDE MIX AND PLANT SIZE, 1906

Plant Size (barrels per day)	Construction Costs, by Type of Crude (thousand dollars)			
	California	Mid-Continent	Gulf Coast	Illinois[a]
1,800	133.2	131.4	468.0	316.0
2,400	177.6	175.2	624.0	422.0
6,500	481.0	474.5	1,690.0	1,114.0
7,500	552.0	547.5	1,950.0	1,320.0

[a]For 1910.

capital investment (total dollar face value of outstanding stocks and bonds) of \$1.5 million and a mode of \$1.10 million. This comparison suggests that to build *de novo* a plant of median size, total capital requirements were relatively close to the average investment of American manufacturing and industrial firms in general.[43]

III

Demand Structure for Final Products

OVER-ALL DOMESTIC AND FOREIGN DISTRIBUTION

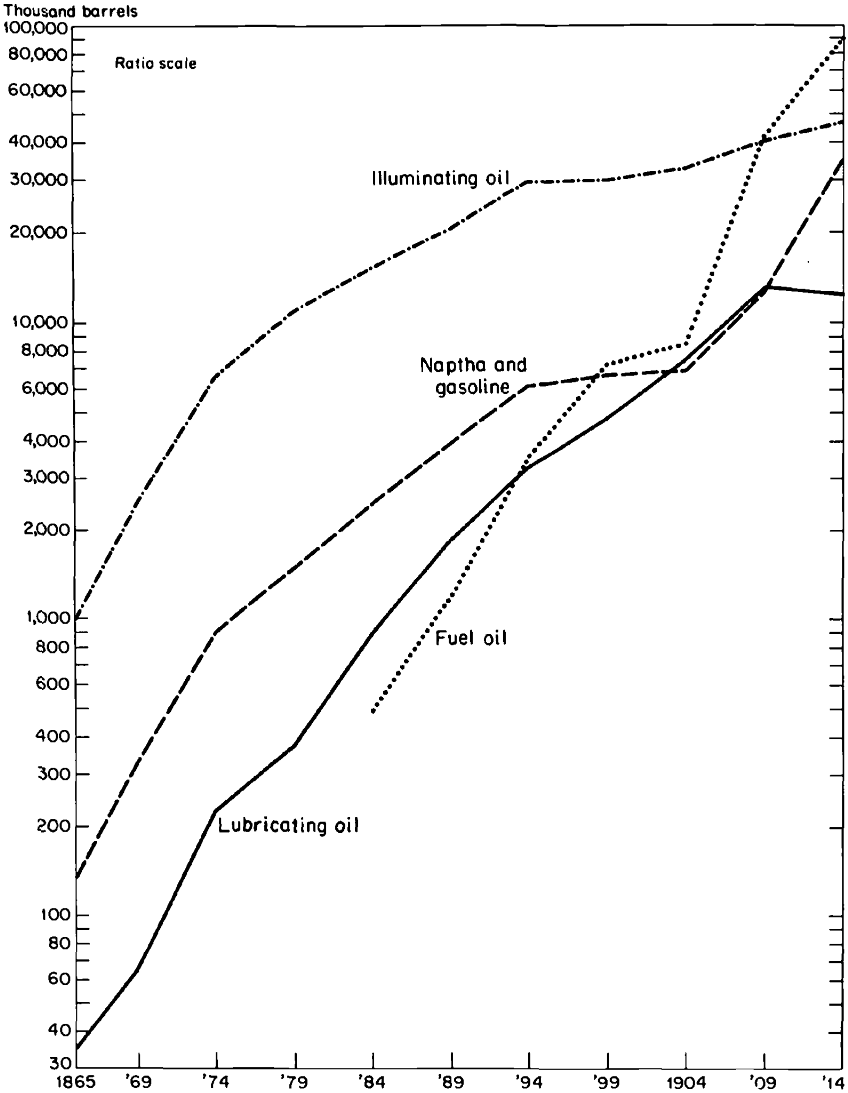
The broad trends in demand for the major refined products of the American petroleum industry between 1865 and 1914 are shown in Chart 3. Illuminating oil was by far the most important refined product marketed by

[42] The capacity construction per-barrel costs were computed by dividing rated capacity into the published construction costs of new refineries. Data were found on contemporary costs of refineries in *Report of the Industrial Commission*, I, pp. 268–69, 278, 355–56, 570–72; *Petroleum Age*, May 1886; *Oil Paint and Drug Reporter*, July 24, 1888; *Moody's Investment Manual*, 1901–1909.

[43] Andreano, "Emergence of New Competition," pp. 346–348.

CHART 3

Sales of Major Refined Petroleum Products, 1865–1914



Source: Table A-3.

the industry throughout most of the period. Indeed, it was not until 1909 that the volume of fuel oil—output of which before that date had been relatively small—began to exceed the volume of illuminating oil distributed. Sales of naphtha and gasoline ranked second to illuminating oil until 1904 when, after being temporarily exceeded by lubricating oil, they began to move up rapidly during the succeeding decade. The volume of lubricating oil distributed moved up in an almost unbroken trend before leveling off between 1909 and 1914.

By 1872-73, as shown in Table 16, the export market absorbed approximately two-thirds of the output of American refineries. Thereafter, the proportion of refined output shipped abroad declined steadily and, in

TABLE 16

PERCENTAGE OF MAJOR REFINED PRODUCTS EXPORTED, 1865-1914

Year	Illuminating Oil	Naphtha-Gasoline	Lubricating Oil	Fuel Oil	Total Refined Products
1865					45.6
1869					66.7
1873-75	75.1	30.9	12.1		68.1
1878-80	70.4	25.7	23.9		63.8
1883-85	69.1	12.5	31.5		60.1
1889	65.1	8.4	36.2		51.2
1894	59.0	5.0	29.1		42.3
1899	58.5	4.1	34.7	6.9	41.2
1904	54.3	5.8	27.3	9.8	37.8
1909	64.2	11.6	26.5	10.3	33.0
1914	59.3	13.2	37.5	12.7	24.7

Source: Table A-3.

1914, accounted for just under one-quarter of total sales. Two factors largely account for the decline in relative importance of the export market after the early 1870's. One was the rapid growth of the petroleum industry abroad, particularly in Russia. The second was the increase in domestic demand for petroleum products associated with the expansion of the American economy.

Despite the general decline in relative importance of foreign markets for the American industry, exports continued to absorb the bulk of illuminating oil produced domestically during that period. Foreign markets after 1873–75 also provided an outlet for one-quarter to over one-third of the domestic output of lubricating oil. From a high point of almost 31 per cent during 1873–75, the proportion of naphtha and gasoline sold abroad, after dropping to 4 per cent in 1899, moved up to just over 13 per cent in 1914. Fuel oil exports, practically nonexistent before 1899, also accounted for almost 13 per cent of total fuel oil sales by 1914.

MAJOR FACTORS AFFECTING THE DEMAND FOR REFINED PRODUCTS

Illuminating Oil

The rapid growth and relative importance of illuminating oil production for the American petroleum industry reflected a virtually worldwide demand for a safe, efficient, and comparatively cheap source of artificial illumination. Early developments in the coal oil industry during the 1850's paved the way for kerosene, the petroleum illuminant, to meet that demand. Using processes pioneered in the manufacture of gas from coal, American and British coal oil producers by the end of the decade were turning out a lamp oil less expensive than sperm whale or lard oils, and much safer to use than the cheaper but highly volatile camphene—made from turpentine and alcohol—which had been quite widely adopted in the United States.[44]

Largely because of the necessity of reducing coal under pressure to produce crude coal oil for further processing, refined coal oil (averaging about 75 cents per gallon at wholesale during 1860) was still relatively expensive. Because of the report by Benjamin Silliman that crude petroleum was the approximate equivalent of crude coal oil, George H. Bissell and J. G. Evelyth initiated the series of events which led to the completion of the Drake well in 1859 and marked the birth of the petroleum industry in the United States.[45]

Once the difficult problem of storage and transport from the remote oil region of northwestern Pennsylvania had been solved, a rapid expansion of crude oil production in the area provided an abundant source of raw material for petroleum refineries. Despite various technical obstacles in adapting coal oil refining processes to petroleum, petroleum refining had emerged by 1862 as a firmly established branch of the industry. In that year, the average wholesale price (in gold) of kerosene in New York was approximately 32 cents per gallon.[46]

Because of its excellent illuminating qualities and because it was either cheaper or safer than other liquid illuminants, kerosene found a ready market among the owners of some 4 to 5 million lamps, already in use in the United States in 1862. The demand in the European market, which absorbed some 80–85 per cent of the illuminating oil shipped abroad

[44] Williamson and Daum, *American Petroleum Industry, 1859–1899*, pp. 33–34, 43–60.
[45] *Ibid.*, pp. 59, 63–81.
[46] *Ibid.*, pp. 202, 326.

during the 1860's, also reflected a familiarity with lamps, particularly among the more industrialized and urbanized areas of Great Britain and western Europe.

Several factors account for a subsequent increase in the total distribution of American-made kerosene from just under 1 million barrels in 1865 to 46.5 million barrels in 1914 (see Table A-3). A major contribution to the expansion was an approximate 75 per cent decline between 1865–69 and 1890–94 in the average price of kerosene, as reflected in New York wholesale quotations (Table 17). That decline was in part the result of

TABLE 17

AVERAGE NEW YORK WHOLESALE PRICE OF ILLUMINATING OIL AND NAPTHA-GASOLINE, 1865-1914
(cents per gallon)

Year	Price of Illuminating Oil	Price of Naptha-Gasoline
1865-69	26.6[a]	
1870-74	18.1[a]	
1875-79	13.3	
1880-84	8.1	6.0 (1884)
1885-89	7.3	6.0
1890-94	6.1	6.3
1895-99	6.9	7.5
1900-04	9.4	14.0 (1904)
1905-09	9.1	13.4 (1909)
1910-14	8.1	16.4

Source: Williamson and Daum, *American Petroleum Industry, 1859-1899*, pp. 326, 524, 680; Williamson, Andreano, Daum and Klose, *American Petroleum Industry, 1900-1959*, p. 172.

[a]Price in gold.

lower refining costs and improved handling and storage facilities. More important, however, in affecting delivered prices was the introduction of bulk shipments of crude and refined products.

The adoption of mass-production methods by domestic lamp manufacturers also contributed significantly to the expanding demand for kerosene by making cheap, efficient lamps available to low-income groups both at home and abroad. The evolution of a distribution system and aggressive marketing tactics, which extended kerosene deliveries to thousands of retail outlets throughout the world, provided an additional stimulus to the growing use of kerosene. These forces continued to increase the over-all demand for American-produced kerosene after 1890–94, despite an upward trend in wholesale prices, an expansion of the petroleum industry outside the United States, and growing competition from other sources of artificial illumination, notably manufactured gas and electricity.

Although electricity was eventually to capture the bulk of the illumination markets in the more economically advanced areas of the world, it initially competed with kerosene, as manufactured gas did, chiefly in urban communities in the United States and western Europe. Even in urban centers kerosene remained the "poor man's" illuminant long after 1914, as well as the major source of artificial illumination for a growing proportion of rural populations throughout the world. In other words, kerosene's illuminating qualities plus the requirement of special equipment for its use (lamps) tended to make the demand for the petroleum illuminant relatively inelastic in the short run, but both price and income elastic in the long run.

Naphtha and Gasoline

With the refining techniques available to the industry before 1914, there was relatively little flexibility in the proportion of yields of particular products from inputs of crude oil. As a result, the output of naphtha and gasoline, which grew from 133,000 barrels in 1865 to nearly 35 million barrels in 1914, was primarily a function of the expanding volume of illuminating oil production.

TABLE 18

DOMESTIC DISTRIBUTION OF PETROLEUM FUEL
(million barrels)

	1899	1904	1909	1914
Residuum and gas oil	6.75	7.67	37.21	77.7
Crude[a]	5.16	28.36	50.72	77.0
Total	11.91	36.03	87.93	154.7

Source: Williamson, Andreano, Daum, Klose, *American Petroleum Industry, 1900–1959*, p. 176.

[a]Skimmed or topped.

Initially a "waste" product, either thrown away or used by unscrupulous refineries or distributors to adulterate kerosene, naphtha and gasoline soon found an outlet for use as a solvent and as a cleaning fluid, but before the early 1890's only at prices ranging well below illuminating oil prices, as shown in Table 18. The rise in prices of naphtha-gasoline relative to kerosene between 1895–99 and 1900–04 appears to have reflected the extra refining costs of preparing naphtha-gasoline for special uses.

Until foreign sources were developed, based largely on the Russian industry, exports absorbed nearly one-third of the American output during 1873–75 and about one-quarter during 1878–80 (see Table 16). A further expansion in the domestic demand for solvents and cleaning fluids did much to improve the relative price position of naphtha and gasoline after the early 1890's—a demand further strengthened by the growing popularity of gasoline-burning cook stoves and portable space heaters. It remained for the development of the automobile after 1900, however, to make gasoline rather than kerosene the major product of the American petroleum industry. By 1909, the automotive demand absorbed an estimated 25 per cent of the total domestic distribution of gasoline; by 1914 the proportion was almost 40 per cent.[47]

Lubricating Oil

From the beginning of the industry, the lubricating potentials of petroleum attracted the attention of refiners. By the late 1860's crude petroleum—treated to reduce impurities—was already being used in limited quantities as a lubricant. More important for the future acceptance of petroleum lubricants, however, were Josiah Merrill's refining processes developed during the decade, which rid the petroleum product of its bad odor and improved its lubricating qualities.[48] Initially a high proportion of petroleum lubricants was blended with other oils to meet the requirements of users. This practice continued to be important, although further improvements in refining and treating during the succeeding half-century enabled petroleum lubricants to capture an increasing share of that market.

Petroleum lubricants unquestionably made a significant contribution to general economic growth during this period. There is considerable reason to doubt whether vegetable and animal oils, long used for the purpose, could have met the growing demand for lubricants which accompanied the rapid industrial and commercial expansion, particularly in the United States and western Europe, during those years. The general nature of that demand is reflected in total sales of lubricants, which grew from 35,000 barrels in 1865 to almost 12.5 million barrels in 1914, and in exports (principally to Europe) which, after 1878–80, as already noted, ranged between one-quarter and one-third of the total.

The demand for lubricants was primarily a function of (1) an increase in the use of machines and equipment with moving parts in industry,

[47] Williamson, Andreano, Daum, and Klose, *American Petroleum Industry, 1900–1959*, p. 198.

[48] Williamson and Daum, *American Petroleum Industry, 1859–1899*, pp. 245–246.

agriculture, and transportation and (2) cyclical fluctuation in industrial and commercial activity. Because lubricating costs were relatively small, compared with total operating costs, it is unlikely that price had any significant influence on the quantities of lubricating oil demanded.

Fuel Oil

There were persistent efforts during the decade of the 1860's to promote the use of partially refined crude oil, or the heavier fractions resulting from the distillation processes, as a source of energy to compete with wood and coal. The industry had high hopes that experiments by the United States Navy with petroleum-fueled boilers would establish the greater efficiency of their product. Despite advantages in storage and reductions in labor needed to tend the boilers, the Navy tests revealed that, with the equipment available, operating costs were some eight times greater for petroleum than for coal. Similar results from attempts to utilize petroleum on river steam boats and for industrial plants during that period indicated that cost factors weighed heavily against its use.[49]

An important market did develop for "gas oil," the distillate fraction obtained after the kerosene fraction in the refining process. As the name suggests, gas oil was used an an "enricher" in the production of manufactured gas. While gas oil continued to account for a substantial portion of distilled fuel oil sales, the market for the heavier fuel oils was slow to develop before the late 1880's.

Discovery and development of the Lima field in Ohio and Indiana starting in the mid-1880's marked the beginning of a growing use of petroleum as a fuel in the United States. Heavily laden with sulphur, Lima crude oil proved initially very difficult to refine. Selling (at the well) at prices ranging between 15 and 48 cents a barrel during 1887–94, crude oil "skimmed" or "topped" to evaporate or recover the light ends (gasoline and naphtha) found a ready market among industrial users in the upper Middle West.[50]

The rapid growth of production in California during the late 1890's gave further stimulus to use of petroleum as fuel. California oil, an asphaltic-based crude which was difficult to refine under available techniques and was also skimmed or partially refined, captured an increasing share of the West Coast fuel market, previously largely dependent on expensive imported coal.[51]

[49] *Ibid.*, pp. 240–242.
[50] *Ibid.*, pp. 601–603.
[51] Williamson, Andreano, Daum, and Klose, *American Petroleum Industry, 1900–1959*, p. 175.

By the early 1890's, advances in refining technology—particularly the processes developed by Herman Frasch—made possible more satisfactory yields of illuminating oil from Lima crude. Because of their sulphur content, the heavier fractions could not be used to produce lube stocks, with the result that approximately one-half the output of refineries processing Lima crude was distilled fuel oil.[52] This output contributed substantially to the total domestic distribution of distilled fuel oils, which grew from about 483,000 barrels in 1883–85 to 6.75 million barrels in 1899 (see Table A-3).

Discovery of the prolific field in the Gulf Coast area in 1900 marked a third major impetus to a growing use of petroleum as fuel. Gulf Coast crudes, like those in California, had an asphaltic base initially difficult to refine. Selling at well-head prices ranging between 18 cents and 94 cents a barrel during 1900–14, a high proportion of Gulf crude production, skimmed or partially refined, was also distributed to fuel oil users.[53] As indicated in Table 18, the quantities of unprocessed or skimmed crude oil sold as fuel exceeded residuum or gas-oil sales by substantial margins between 1904 and 1909. By 1914, improvements in refining technology and expansion of refining facilities, particularly in the Gulf Coast area, had combined to reduce the proportion of the domestic fuel oil market supplied by skimmed or partially refined crude.

Aside from its use as a gas enricher, petroleum fuel oil was primarily sold in competition with coal or as an alternative or substitute for boiler fuel to produce heat and energy. Petroleum's ability to compete with coal on a price basis in the domestic market was much greater in certain areas than in others, as already suggested. In 1909, for example, total fuel oil sales were divided by major geographic areas as follows: Pacific Coast, 41 per cent; Southwest, 27 per cent; Atlantic Coast, 16 per cent; Upper Mississippi, 9 per cent; and all other, 7 per cent.[54]

A division of total fuel oil sales by types of major user in 1914 shows the following: industry and commercial, 50 per cent; railroads, 33 per cent; manufactured gas, 10 per cent; Merchant Marine and Navy, 7 per cent.[55] In large part, the high proportion of sales to industrial and commercial users reflected the ready adaptability of their burning equipment to fuel oil in response to a relatively small price differential. While the conversion of coal-burning locomotives to fuel oil was more expensive, the relatively low price of fuel oil, plus greater operational flexibility, prompted the railroads operating west of the Mississippi to make an early switch to

[52] Williamson and Daum, *American Petroleum Industry, 1859–1899*, p. 619.

[53] Williamson, Andreano, Daum, and Klose, *American Petroleum Industry, 1900–1959* pp. 39, 176.

[54] *Ibid.*, p. 177.

[55] *Ibid.*, p. 178.

TABLE 19

ANNUAL ENERGY SUPPLY FROM MINERAL FUELS AND WATER POWER, SELECTED YEARS, 1899-1914
(trillion British thermal units)

	Total	Water Power	Coal	Petroleum	Natural Gas
1899	7,529	238	6,708	342	240
Per cent	100	3.2	89.1	4.5	3.2
1904	10,680	354	9,291	702	333
Per cent	100	3.3	87.0	6.6	3.1
1909	14,284	513	12,155	1,099	517
Per cent	100	3.6	85.1	7.7	5.6
1914	16,513	636	13,545	1,595	636
Per cent	100	3.9	82.0	9.7	3.9

Source: *Historical Statistics*, 1960, p. 355.

petroleum fuel. Of particular interest was the growing use of petroleum fuel in marine transportation. Experiments beginning in the 1890's had demonstrated the economy of substituting petroleum for coal in modern ocean-going vessels. By 1914, conversion from coal to fuel oil by the American and British navies was already well under way.[56]

Fuel oil sales were the major factor in the growing importance of petroleum as a source of energy for American industry. As shown in Table 19, petroleum's share in the total energy generated from mineral combustion and water power in the United States more than doubled between 1899 and 1914.

CHANGES IN THE RELATIVE VALUE OF MAJOR REFINED PRODUCTS

There was a marked shift in the relative contributions to total value at refineries of each of the major refined products between 1879 and 1914 (Table 20). The relative position of illuminating oil declined from over

TABLE 20

VALUE AT REFINERIES OF MAJOR REFINED PRODUCTS AS A PERCENTAGE OF TOTAL VALUE, 1879-1914

	1879	1889	1899	1904	1909	1914
Illuminating oil	86.2	74.3	66.9	62.2	44.7	26.5
Gasoline and naphtha	6.8	11.1	14.4	14.5	18.8	33.8
Lubricating oil	7.3	12.7	12.1	17.0	19.2	16.3
Fuel oil	0.7	1.9	6.5	6.3	17.3	23.4

Source: See notes to Table A-1.

[56] *Ibid.*, pp. 181–183.

86 per cent of the total to less than 27 per cent during those years, in contrast to gasoline, which by 1914 contributed nearly 34 per cent, and fuel oil, which contributed over 23 per cent of the total.

IV

Changes in Industry Structure

In 1878, the Standard Oil group achieved the peak of its control over each sector of the industry as it was then structured. At that time, the center of crude oil production was in the western regions of Pennsylvania. To a limited extent, crude was produced elsewhere but some 99 per cent of the crude supplies used to make the major petroleum product—kerosene—came from Pennsylvania. In the mid-1880's, with the discoveries in Ohio and Indiana, the locus of crude oil production moved successively farther west, into mid-continent, California, Gulf Coast, and then Illinois. By 1911, total crude oil production was divided among the major producing areas as follows: Appalachian, 11 per cent; Lima-Indiana, 3 per cent; Gulf Coast, 5 per cent; California, 37 per cent; mid-continent, 30 per cent; and Illinois, 14 per cent.[57] These shifts in the sources of crude production were caused by the dynamic pattern of flush field development, noted earlier, and constituted one of the major factors affecting the structure of the industry.

Quite aside from changes in industry structure attributable to general economic growth, the circumstances leading to entrance of new firms into the industry may be put in three main groups:

1. Growth in the number and location of new flush fields that, because of minimal barriers to entry posed by absolute capital requirements and economies of scale in production and refining, enabled established firms to expand and new firms to obtain crude supplies necessary to begin operations.
2. The quality and quantity of crude oil discoveries, which played an important role in types of product made and sold and, in turn, facilitated entry through the process of market segmentation.
3. Incorrect, or insufficiently rapid, market response on the part of the dominant firm (Standard Oil), which left market opportunities or market space, not only for the exploitation of crude deposits, but also for the distribution of "old" and "new" products.

Changes in Standard Oil's relative position in the industry between 1880 and 1911 are summarized in Table 21. In crude oil, for example,

[57] Arnold and Kemnitzer, *Petroleum in the United States*, p. 33.

TABLE 21

SUMMARY OF STANDARD OIL'S POSITION
IN THE AMERICAN PETROLEUM INDUSTRY,
1880-1911

	1880	1899	1906	1911
	PERCENTAGE CONTROL OVER CRUDE OIL SUPPLIES			
Appalachian[a]	92	88	72	78
Lima-Indiana[a]	--	85	95	90
Gulf coast[b]	--	--	10	10
Mid-continent[c]	--	--	45	44
Illinois[d]	--	--	100	83
California[e]	--	--	29	29
	PERCENTAGE CONTROL OVER REFINERY CAPACITY			
Share of rated daily crude capacity	90-95	82	70	64
	PERCENTAGE OF MAJOR PRODUCTS SOLD			
	1880	1899	1906-1911[f]	
Kerosene	90-95	85	75	
Lubes	--	40	55	
Waxes	--	50	67	
Fuel oil[g]	--	85	31	
Gasoline	--	85	66	

Source: Harold F. Williamson and Ralph L. Andreano, "Competitive Structure of the American Petroleum Industry, 1880-1911," *Oil's First Century*, 1960, p. 74.

[a]Share of pipeline run.

[b]Consumption at portside.

[c]Prairie Oil and Gas Company share of crude available (current production plus stock).

[d]Ohio Oil Company pipeline runs, as per cent of total field production.

[e]Standard did not enter the California sector until 1900. Figures are company output as per cent of total field production.

[f]Data available for Standard are 1906 and 1910; all other firms, 1908. Both the lube and wax estimates may thus be overstated.

[g]Include residual fuel oil and unrefined crude sold as fuel.

Standard maintained its predominant control over production in the Appalachian, Lima-Indiana, and Illinois fields between 1880 and 1911. The proportion of crude from California, mid-continent, and Gulf Coast fields going to independents had, by 1911, reduced Standard's share of total domestic production during the period from over 90 per cent to approximately 60–65 per cent. This decline in the company's relative share of domestic crude production was closely matched by a decrease in the proportion of total refining capacity under Standard's control from approximately 90–95 per cent in 1880 to 60–65 per cent in 1911. The impact of these shifts on Standard's general marketing position was varied. By 1911, however, the independents were supplying nearly 70 per cent of the fuel oil, some 45 per cent of the lubricants, one-third of the gasoline and waxes, and about one-quarter of the kerosene distributed by the American petroleum industry.

These changes, coupled with the emergence of a dozen or more integrated companies, plus a large number of smaller ones specializing in one or more phases of the oil business, suggest a competitive structure in 1911 which was a far cry from that of the late 1870's, when Standard Oil and the American petroleum industry were practically synonymous. The circumstances and processes by which new companies entered the industry during the period before 1911 may be illustrated by developments associated with the opening of the major new crude producing areas.

APPALACHIAN

Standard Oil's position in the American industry in the late 1870's was based essentially on ownership (or lease) of some 90 per cent of domestic refining capacity, plus virtually a monopoly control of facilities for gathering and transporting crude oil. But even Standard found it impossible between 1876 and 1882 to expand its gathering lines, storage, and transport facilities rapidly enough to accommodate an approximate trebling of output of crude, largely from Bradford, the first modern flush field, in the Appalachian oil region.

The result was a sufficient supply of crude outside Standard's control to provide the basis for the emergence of two types of firm: (1) fully integrated companies producing a complete line of refinery products, such as the Tidewater Oil Company and a group subsequently merged to form the Pure Oil Company; and (2) companies partially or fully integrated including the Union Petroleum, Crew-Levick, and Pennzoil companies, which specialized in producing lubricating oils and wax.

The immediate impact of Bradford on Standard's position in the industry is reflected in Standard's share of total refining capacity, which fell from about 90 per cent in the late 1870's to approximately 75 per cent by 1884. Some of the loss was subsequently regained and, for the entire 1880–99 period, Standard's share of total refining capacity declined about 10 percentage points; its share of Appalachian crude production over the same period dropped from 92 to 88 per cent. The most important effect of Bradford (supplemented by the growth of production in Lima-Indiana), however, was to reduce Standard's share of the production of lubricants and waxes from 75 per cent or more in 1880 to approximately 40 per cent of lubricants and 50 per cent of waxes by 1899.

LIMA-INDIANA

Production in the Lima-Indiana fields, which began to expand in the mid-1880's and reached a peak in 1896, prompted Standard Oil to move quickly into the area with an extensive system of gathering lines, storage facilities, and crude trunk lines. Even so, Standard's control over output which, measured by pipeline runs, was approximately 93 per cent in 1894, declined to about 85 per cent by 1899. Chiefly because of the quality of the crude (sold largely as fuel oil until the development by Standard of the Frasch process) and the costs of entry, Standard Oil was the only established company to move into the Lima-Indiana fields.

The Lima-Indiana fields did, however, provide an opportunity for new entrants, including the Sun Oil Company, the National Refining Company, and the Paragon Oil Company. These companies were fully integrated, with their own production, pipelines, and refining and marketing facilities. While fuel oil was their major product, adoption of refining techniques similar to the Frasch process enabled them all to produce a full product line by 1899.

While the independents' share of the market was relatively modest—probably no more than 15 per cent of fuel oil and much less of other products—the experience gained in exploiting the industrial demand for petroleum fuel oil was an important factor in subsequent decisions to move into the Gulf area after the turn of the century.

GULF COAST

In contrast to its action in Lima-Indiana, Standard Oil did not formally enter the Gulf Coast region, where crude production reached its peak about 1905. Three reasons have generally been cited in explaining Standard's response: (1) the legal climate in Texas, where an antitrust action had been instituted against the Waters-Pierce Company, Standard's major marketing affiliate in the state; (2) the refining quality of the Texas crude, which yielded relatively small amounts of kerosene, the product Standard was primarily interested in refining; and (3) the feeling on the part of Standard officials that mid-continent and California offered better investment opportunities than Gulf, both in quantity and quality of crudes needed for their operations. Standard's role in the Gulf Coast development was thus limited to the purchase of an estimated 10 per cent of the output from the region.

With some 90 per cent of Gulf Coast crude output available for "outsiders," the impact on the structure of the industry—and on Standard's position—was quite significant. Of the already established firms in the Appalachian and Lima-Indiana regions, Sun Oil Company moved most rapidly to use Gulf crude as a springboard for a highly successful program of expansion, which made the company one of the leading factors in the industry, particularly in the production and distribution of fuel oil and lubricants. Pure Oil was also able to acquire a modest interest in the Gulf fields.

The most significant structural changes stimulated by Gulf Coast developments, however, were attributable to *de novo* entrants into the industry. These were of two types. First, there were fully integrated companies, such as Gulf Oil and the Texas Company, which attempted to produce a full product line but were more successful for several years as distributors of fuel oil. Second, there were the fuel oil companies—about twenty in all—which did not operate refineries (because the crude oil could be sold as fuel after exposure to the sun had evaporated the light ends) but were integrated from production to marketing facilities. The increasing importance of independents in the expanding fuel market was reflected by a decline in Standard's relative market share from about 85 per cent in 1899 to 31 per cent in 1906–11.

MID-CONTINENT

The mid-continent region provided the basis for an even more significant expansion of established independents and the entry of new firms. Not only did the strike at Glenn Pool in 1905 establish the region as a major producing area in the United States, but also the crude was an Appalachian type yielding relatively large proportions of gasoline and kerosene as well as high-quality lube stocks.

Standard Oil understandably was quick to acquire leases and to build gathering lines, storage facilities, and trunk pipelines in mid-continent. Other companies were also quick to move in. Among the leaders were the firms already operating in the Gulf region: notably, Gulf Oil and the Texas Company; National Petroleum and Sun Oil, which had started in Lima-Indiana; Associated Oil Company, a California concern; Union

TABLE 22

SIZE CHARACTERISTICS OF OKLAHOMA-KANSAS INDEPENDENTS, 1906-11

Name of Company	In Production	Daily Crude Oil Capacity of Refineries (42-gallon barrels)	Pipeline Mileage	Number of Railroad Tankers	Number of Distribution Stations
American Refining		1,500			
Chanute Refining	Yes	1,750	60	290	33
Cudahy Refining	Yes	6,000	128	335	610
Great Western Refining	Yes	2,000	24	40	1
Indiahoma Refining	Yes	1,200	43	83	3
Kansas City Refining	No	1,000	—	42	—
Kansas Oil Refining		1,800	60	52	—
Kansas Co-operative Refining	Yes	500	6	30	20
Kanotex Refining	Yes	1,000	33	41	31
Milliken Refining		4,000	65	370	—
Muskogee Refining	Yes	1,440	18	49	8
National Refining	Yes	3,000	110	315	50
Oklahoma Refining		600	7	40	50
Petroleum Producing	Yes	3,500	170	182	—
Paola Refining	Yes	150	40	—	—
Sapulpa Refining	No	3,000	35	69	—
Uncle Sam Oil	Yes	1,400	—	88	7

Source: Williamson and Andreano, *Oil's First Century*, p. 78. Basic data compiled from *Oil Investor Journal*; 1906 (Nov. 18, p. 2), 1907 (May 5, p. 4), 1908 (Jan. 14, p. 19, Feb. 5, pp. 3, 4, March 19, p. 12, and April 5, p. 6); and *Oil and Gas Journal*, 1910 (June 16, pp. 23, 24, and July 14, p. 18).

Petroleum; Crew-Levick; and Pure Oil and Tidewater, pioneer processors of Appalachian crudes. In addition, the mid-continent provided the basis for the emergence of almost a score of partially or fully integrated firms (see Table 22).

With Standard's control over mid-continent crude production limited to about 45 per cent during 1905–11, the effect of the growth of independents was to extend competition beyond the fuel oil market into the sale and distribution of kerosene, gasoline, and lubricants. The results of that expansion were most noticeable in the reduction between 1899 and 1906–11 of Standard's share of kerosene distribution from about 85 per cent to 75 per cent and of gasoline from about 85 per cent to approximately 66 per cent.

ILLINOIS

Standard's relative position in the industry would no doubt have deteriorated even more by 1906–11, if the organization had not succeeded in controlling some 85 per cent of the Appalachian-type crude produced in the Illinois fields, which reached their peak during 1907–11. Yet the remaining 15 per cent of the Illinois output was sufficient to make worthwhile Tidewater's acquisition of production in the area and extension of its trunk pipeline from Pennsylvania to southeastern Illinois. That output also enabled the Indian Refining Company (later absorbed by the Texas Company) to emerge by 1911 as a fully integrated concern.

CALIFORNIA

The structure of the petroleum industry in California up to 1911 followed a pattern of development radically different from the evolution of the industry east of the Rockies. It is true that, by extending its marketing organization into California during the 1880's, Standard Oil remained the dominant distributor of kerosene on the west coast until 1911. But the asphaltic-based California crude, ill-suited for production of kerosene or lube stocks, had little attraction for Standard, which acquired no producing properties, pipelines, or refineries in California until 1900. By that date, production in California—which by 1906 was as important quantitatively as output from mid-continent—was already split more or less equally among some seven integrated companies engaged primarily in the production and distribution of fuel oil.

Size Distribution of Firms[58]

Against that broader background of entry of new firms and changes in industry structure, it is possible to give a qualitative assessment of industry

[58] Data in this section from Andreano, "Emergence of New Competition," pp. 280–294.

concentration, by product and function, and to appraise the size of firms in the industry. This impression relates to the situation as it existed just before 1911.

Illuminating Oil. The largest three firms—Standard, Gulf, and the Texas Company—accounted for close to 90 per cent of industry output. The combined output of the largest seven firms—top three, plus Tidewater, National Refining, Crew-Levick Refining, Union Petroleum, and Cudahy Oil and Refining—was approximately 99 per cent. A fringe of twenty-five to thirty-five firms accounted for the remainder.

Lubricants. In all classes and grades of lubricants, the largest three firms—Standard, Sun Oil, and Texas—produced about 75 per cent of total industry output. The seven largest—top three, plus Gulf, Crew-Levick, Union Petroleum, and National—accounted for perhaps 90 per cent, with the remaining 10 per cent divided among thirty or forty firms.

Waxes. Three firms—Standard, Union Petroleum, Crew-Levick—produced 75 per cent of the total output. The national market share of no other firm exceeded 3-4 per cent, while the remainder of the industry output was accounted for by some fifty to sixty firms.

Gasoline. The largest firms—Standard, Gulf, Texas—produced 85–95 per cent of total industry output. The largest seven—top three, plus Cudahy, National, Union Petroleum, and Indian Refining—accounted for 90–98 per cent and thirty to forty firms for the remainder.

Fuel Oil. The top three—Standard, Union Oil of California, and Associated Oil of California—accounted for 50–60 per cent of total industry output. The largest seven firms—top three, plus Sun, Gulf, Texas, Higgins Oil and Fuel of Beaumont—produced 70–90 per cent of the total and a fringe of about fifty firms the remainder.

Crude Oil. The largest three companies—Standard, Gulf, and Union Oil of California—probably produced no more than 20 per cent of total U.S. output of crude in 1911. The largest seven—top three, plus Texas, Southern Pacific Railroad, Sun, and Tidewater—produced 25–30 per cent, and the remaining crude output was accounted for by several thousand separate firms.

Transportation Capacity. Gathering and trunk pipelines, railroad tank cars, river barges, and ocean and coastal tank steamers comprised the bulk of transportation facilities for crude oil and products. Only in trunk pipelines, however, is any impression of firm concentration possible. Nine firms—Standard, Gulf, Texas, Union of California, Associated of California, Tidewater, Cudahy, Sun, and National—owned virtually the total national trunk pipeline mileage.

Refining Capacity. The top three—Standard, Gulf, and Texas—operated or owned 80–85 per cent of total industry-rated daily crude oil capacity.

The largest seven firms—top three, plus Sun, Union Oil of California, National, and Cudahy—accounted for 90–95 per cent of total industry capacity. About forty firms—one of them Indian Refining, only slightly smaller than the smallest of the top seven—owned or operated the remaining capacity.

Over-All Firm Size. Except in a few instances, there are no specific data on the extent of vertical integration by individual firms. It is certain, however, that no refining company could successfully compete in national or regional markets without a minimum degree of vertical depth, backward at least to the extent of owning its own transportation capacity and forward to the ownership of bulk stations. An examination of the total crude inputs supplied from internal sources as a measure of vertical integration would show that the largest firms, ranked by assets, all had high crude-sufficiency ratios. Some, of course, had much higher ratios than others. Of the top four—Standard, Gulf, Texas, and Union Oil of California—for example, the firm with perhaps the least crude oil sufficiency ratio was Standard. The next four—Southern Pacific, Sun, Tidewater, and Union Petroleum—all had relatively high crude oil sufficiency ratios. The next largest five firms were all vertically integrated, although, as shown earlier, the extent of their integration is somewhat uncertain. These were National Refining, Cudahy, Crew-Levick, Higgins Oil and Fuel, and Indian Oil and Refining.

Appendix

TABLE A-1

AMERICAN PETROLEUM INDUSTRY: VALUE ADDED BY SECTORS, 1879-1914
(thousand dollars)

Sector	1879	1889	1899	1904	1909	1914
Value of crude at well, shipped to refineries	16,198	23,579	58,772	57,605	84,543	154,923
Gross value added by refining	27,364	40,122	43,505	67,518	85,690	146,633
Value added by transportation and storage of crude and refined products	37,337	56,751	69,319	115,942	184,310	284,629
Marketing, wholesale	14,378	27,169	36,598	56,695	79,234	118,870
Retail	10,037	22,338	34,464	48,389	73,603	124,597
Total	105,314	169,959	242,658	345,149	507,380	829,652
Value of crude at well,						
Exports	814	1,770	3,666	2,277	2,839	2,405
Fuel	—	—	6,330	24,380	35,510	62,370
Final value of industry output	106,128	171,729	252,154	372,806	545,729	894,427

Source: Data on crude and refining sectors are from *Census of Manufactures*, 1914, Vol. 11, pp. 582-583. Data on marketing and transport are estimated. See Table A-2.

TABLE A-2

AMERICAN PETROLEUM INDUSTRY: AVERAGE COST OF STORAGE AND TRANSPORT OF CRUDE AND REFINED PRODUCTS, 1879-1914
(dollars)

Average Cost of Storage and Transport Per 50-Gallon Barrel	1879	1889	1899	1904	1909	1914
Crude, well to refinery[a]	(1.09)	0.82	0.51	0.88	0.67	0.58
Refined products, refinery to wholesaler[b]	1.25	1.00	0.80	0.80	0.80	0.80
Refined products, wholesaler to retailer[b]	0.60	0.50	0.40	0.40	0.40	0.40

[a]Computed from data in *Census of Manufactures*, 1949. Average costs for 1879 were computed (see explanation in text).

[b]These costs are assumed.

TABLE A-3

PRODUCTION, EXPORTS, AND DOMESTIC DISTRIBUTION OF MAJOR REFINED PRODUCTS, 1865-1914
(thousand barrels)

Product	1865	1869	1873-75	1878-80	1883-85	1889	1894	1899	1904	1909	1914
Illuminating oil											
Production	992	2,450	6,530	10,800	15,171	20,191	29,458	29,500	32,500	40,000	46,500
Domestic			1,626	3,197	4,696	7,054	12,068	12,250	14,842	14,319	18,946
Export			4,903	7,603	10,475	13,137	17,390	17,250	17,658	25,681	27,554
Per cent exported			75.1	70.4	69.1	65.1	59.0	58.5	54.3	64.2	59.3
Naphthas and gasoline											
Production	133	326	895	1,483	2,442	3,916	6,114	6,650	6,900	12,850	34,800
Domestic			618	1,101	2,079	3,583	5,744	6,224	6,498	11,357	30,218
Export			277	382	363	333	370	426	402	1,493	4,582
Per cent exported			30.9	25.7	12.5	8.4	5.0	6.4	5.8	11.6	13.2
Lubricating oil											
Production	35	65	226	376	884	1,835	3,288	4,781	7,470	12,964	12,488
Domestic			199	286	606	1,170	2,332	3,124	5,626	9,531	8,800
Export			27	90	278	665	956	1,657	2,114	3,433	4,688
Per cent exported			12.1	23.7	31.5	36.2	29.1	34.7	27.3	26.5	37.5
Fuel oil											
Production					483	1,195	3,522	7,250	8,500	41,500	89,000
Domestic					483	1,195	3,522	6,750	7,669	37,211	77,687
Export								500	831	4,281	11,313
Per cent exported								6.9	9.4	10.4	12.7
Total production	1,336	3,267	7,650	12,656	18,498	27,600	44,300	48,181	55,640	107,314	182,880
Total domestic	727	2,279	2,442	4,582	7,381	13,465	25,583	28,336	34,635	71,907	137,743
Total exports	609	1,089	5,209	8,074	11,117	14,135	18,717	19,845	21,005	35,407	45,137
Total per cent exported	45.6	66.7	68.1	63.8	60.1	51.2	42.3	41.2	37.2	33.0	24.7

Source: *Williamson and Daum, American Petroleum Industry, 1859-1899*, pp. 489, 633, 678, 737-739; Williamson, Andreano, Daum and Klose, *American Petroleum Industry, 1900-1959*, p. 169.

METHODOLOGICAL NOTE

Although the basic framework underlying the computations is algebraic, a major obstacle to algebraic presentation is the somewhat difficult notation that results from the spatial and multiproduct characteristics of the American petroleum industry.

Value of Output of the Crude Oil Sector

Volume of crude oil shipped to refineries, shipped directly to wholesalers as fuel, and exported were obtained from *Census of Manufactures*, *Historical Statistics*, 1960, and Williamson, Andreano, Daum, and Klose, *American Petroleum Industry, 1900–1959*. These quantities were added and their sum multiplied by the price (average value) of crude at wells to obtain the contribution of the crude oil sector to the industry.

Value Added by Storage and Transport of Crude from Wells to Refineries

The difference between the delivered cost of crude to refineries and the value (at wells) of crude shipped to refineries was used as a substitute for value added by storage and transport. This formula was not used to compute the value added for 1879. In that year, 17.4 million (42-gallon) barrels of crude were shipped to refineries, but value added provided by the formula amounted to only $145,000, or an average cost of storage and transport of less than 1 cent per barrel. To avoid this difficulty, value added for 1879 was assumed to be $16 million. This assumption provided average costs of shipment per barrel (50 gallons) of $1.09. Table A-2 indicates that the average costs for 1879 seem reasonable when compared with similar shipment costs for other years.

Gross Value Added by Refining

This value was obtained by subtracting the cost of crude delivered to refineries from the value of refined products.

Net Value Added by Refining

Costs of materials (other than crude) used in refining were subtracted from gross value added by refining. Data required to obtain both gross and net value added by refining were taken from *Census of Manufactures*.

Value Added by Storage and Transport of Refined Products from Refineries to Wholesalers

Average assumed costs of storage and transport per barrel for shipments from refineries to wholesalers are indicated in Table A-2. The assumption is that these costs, in any particular year, apply to all categories of refined products. The total quantity of refined products multiplied by average shipment costs per barrel was used as a substitute for value added by this sector.

Value Added by Wholesalers

The cost of refined products delivered to wholesalers is assumed to equal the value of refined products at the refinery plus the cost of shipping them to wholesalers. The wholesale value of refined product was then obtained by applying wholesale margins of 18 per cent for all relevant Census years, except 1914 for which a margin of 17 per cent was used. Value added by wholesalers was obtained by subtracting the delivered cost from the wholesale value of refined products.[59]

Value Added by Storage and Transport of Refined Products from Wholesale to Retail Outlets

The quantity of refined exports was subtracted from the total quantity of refined products to obtain an estimate of the volume of refined products shipped to retailers. This amount was multiplied by the average shipment cost per barrel, shown in Table A-2, to determine the value added by storage and transport of refined products from wholesale to retail outlets.

Value Added by Retailers

Value of refined exports was subtracted from the wholesale value of refined products. The value added by storage and transport from wholesalers to retailers was added to this difference to obtain an estimate of the delivered cost of refined products for retail outlets. Retail margins for independent retail stores of 18.5 and 19.0 per cent for 1879 and 1889 and 19.5 for other Census years were applied to obtain the retail value of refined products. The difference between the delivered cost and retail value of refined products[60] was taken to be the value added by retail outlets.

Crude Oil Used Directly as Fuel

A similar procedure was used to derive the wholesale value of crude directly consumed as fuel. Storage and transport charges per barrel were assumed to be: 22 and 36 cents for 1899 and 1904, respectively; 28 and 25 cents for the other Census years.

[59] Harold Barger (*Distribution's Place in the American Economy Since 1869*, Princeton for NBER, 1955, p. 84) reports wholesale margins for gasoline and oil of 18 and 16 per cent for 1909 and 1919, respectively.

[60] *Ibid.*, p. 81.

Crude Exports

The difference between the average value of crude exports and average value at wells was regarded as a measure of the value added per barrel by both transport and marketing sectors. From this amount, 90 cents was assigned to the transport sector as the cost of storage and transport per barrel of crude, while the remainder was assigned to the marketing sector. This procedure was amended for 1909, since in that year the difference between the average value of exports and the average value of crude amounted to less than 90 cents. In that year, the entire difference, or 72 cents, was assigned to the transport sector.

Production, Export, and Domestic Distribution

Production, export, and domestic distribution of illuminating oil, naphthas and gasoline, lubricating oil, fuel oil, and totals of each are shown in barrels and percentages in Table A-3.

COMMENT

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When a qualitative business historian is asked to comment on a quantitative review of an industry, he is faced with a difficult problem. The approaches that suggest themselves range from challenging the whole concept which underlies the collection of data to questioning the accuracy of specific figures. On the more positive side it might be desirable to suggest that additional categories of data would be helpful, call attention to additional sources of information, and so on. In the present instance, however, none of these approaches would be particularly rewarding in terms of what the authors have set out to do and their competence in executing it.

One function that a qualitative commentator on a quantitative paper can perform is to remind the authors of the authority attributed by qualitatively oriented scholars to studies such as this one. This point is particularly relevant here both because of the authors' stature as historians of the American petroleum industry and because they have distilled in this paper the product of long years of research. In no other place is there such a compact yet comprehensive set of statistics on the American petroleum industry from its birth down to World War I. For this reason it is likely to become a standard reference, and the authors have a special obligation to combine caution in their statements with the greatest possible accuracy in their figures.

While perfection may be unobtainable, the perfectibility of data and their interpretation are constant challenges to both qualitative and quantitative scholars. Certainly, no students of the American petroleum industry are better equipped to meet them than Williamson, Andreano, and Menezes. As prepared for the Chapel Hill meeting in September 1963, however, their preliminary draft of the present paper contained a few sections that needed further refinement, at least as they were interpreted by this qualitative historian. For the most part, therefore, my commentary was addressed to certain sweeping statements and to the need for more clarification and documentation, as well as reference to a wider range of sources.

Without claiming anything for the helpfulness of that commentary, it is clear from a reading of the revised paper that the authors have now made my earlier remarks largely irrelevant. I am delighted that I have been deprived of an opportunity to reiterate them here, and I commend this paper to other students of the American petroleum industry who, like myself, are sure to find it a significant contribution to the literature.