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Demand for Platinum To Reduce Pollution From Automobile Exhausts

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DEMAND FOR PLATINUM TO REDUCE POLLUTION FROM AUTOMOBILE EXHAUSTS

by

David J. Kusler¹

ABSTRACT

This Bureau of Mines study is an appraisal of the demand for platinum, should this strategic metal be used as a catalyst in the National abatement of automobile exhaust pollution. The Clean Air Act of 1970, as amended, requires that automobiles produced in 1975 and thereafter be provided with antipollutive measures to control automotive exhaust emissions. The study considers the need for automobile pollution control, the methodology for such control, the annual primary (new) platinum demand for automobiles produced from 1975 to 1990, primary platinum availability, and supply-demand forecasts and outlook. The correlative demand for platinum for the production of the required unleaded gasoline is also considered.

Methodology for the study included a forecast of new automobile production from 1975 to 1990, development of automobile survival and retirement data, estimates of new platinum demand under various conditions of salvage, and data on recycling the precious metal from the catalytic converters of scrapped vehicles and existing vehicles when their spent converters are exchanged for replacement units.

The new platinum demand for automobile exhaust converters, based on a converter service life of 50,000 miles, is estimated to be 1.41 million troy ounces initially in 1975, rising to 1.68 million in 1980, and declining curvilinearly to 0.94 million in 1990. The platinum demand for converter longevities other than 50,000 miles can be derived from the tabular data presented. An appendix to the report presents a comparison between longevities of 50,000 miles and 25,000 miles. The petroleum industry's demand for new platinum for the production of lead-free gasolines could total as high as 1 million troy ounces between 1972 and 1981, just for expansion of isomerization and reforming capacity, and is in addition to normal operating demand for this metal.

¹Chemist.

INTRODUCTION

The study is an appraisal of the potential demand for platinum, should that metal be used in a catalytic converter for the purpose of reducing the amounts of hydrocarbons (HC), carbon monoxide (CO), and possibly nitrogen oxides (NO_x) to levels acceptable to the requirements of the Clean Air Act of 1970 as amended (Public Law 91-604). The act stipulates a 90-percent reduction based on 1970-71 model automobile HC and CO emission levels for light-duty vehicles produced in 1975. The same percentage reduction will be required for NO_x emission for the 1976 model year as compared with 1971 uncontrolled models.

This report is part of the Bureau of Mines continuing role in the estimation, conservation, and development of mineral resources and is concerned with platinum supply-demand relationships.

Earlier analyses of platinum supply and demand were mainly concerned with statistical evaluations for traditional use patterns and were published in the Bureau of Mines annual Minerals Yearbook series and in various bulletins. This study considers a potential platinum use estimated to be several times larger than the traditional demand in 1975 and likely to remain the largest single use in the post-1975 years.

Data for this study were compiled and developed from various sources: (1) published literature on platinum resources and reserves, supply-demand statistics, catalysts, pollution control systems and measures, and the petroleum refining industry; (2) recorded and forecast motor vehicle data issued by the U.S. Department of Transportation; (3) published automotive statistical data from the Automobile Manufacturers Association and other automobile trade associations; (4) published and unpublished information from the Environmental Protection Agency (EPA), U.S. Department of Health, Education, and Welfare; (5) interviews with representatives of major domestic suppliers of platinum metal and catalysts; (6) interviews with representatives of the major domestic automobile manufacturers; and (7) discussions with representatives of several large domestic petroleum refineries. In general, data were selected which enabled projections of possible platinum demand to 1990 for its use in automobile pollution abatement control systems and in the correlatively required production of lead-free gasoline.

If catalytic devices are adopted, not necessarily platinum-based, automotive fuel will need to be essentially lead-free gasoline. The change in petroleum refinery practice will also require additional platinum (as a reforming and isomerization catalyst) in excess of the current petroleum industry inventory; this additional demand has been considered.

Finally, the internal combustion engine has been the conventional form of propulsion for automobiles and trucks since its inception circa the turn of this century. In its effort to meet the 1975-76 and later years' standards, the automobile industry is concentrating its efforts on modifications of the conventional internal combustion engine. The Environmental Protection Agency questions the ability of the conventional engine to meet

long-term health and welfare needs of the Nation as now perceived. Accordingly, this Agency has embarked on a program of federally sponsored research and development of alternative engine systems that are inherently cleaner than the conventional engine. This development activity is embodied in the Advanced Automotive Power System Program (AAPSP).² The long-term solution to the vehicle pollution problem may be in the departure of the conventional internal combustion engine and its replacement by a power system specifically designed to minimize or eliminate atmospheric pollution.

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The cooperation and assistance of the major domestic automobile manufacturers and automotive trade associations, and Government Agencies are hereby gratefully acknowledged. The author is especially indebted to the following: Representatives of the U.S. Department of Transportation and the Environmental Protection Agency; Engelhard Industries, a division of Engelhard Minerals and Chemicals Corp.; Universal Oil Products Co., Process Division; Gulf Research and Development Co., Process Research; and PPG Industries, Inc.

GENERAL DISCUSSION

Secondary Treatment of Automotive Emissions

While considerable reduction in HC, CO, and NO_x emission levels may be accomplished by engine modification alone, it is almost certain that automobiles produced in 1975 and later model years will require secondary treatment of the exhaust gas to achieve the required reduction in emission levels. Such secondary treatment may be accomplished by catalytic oxidation of HC and CO to carbon dioxide (CO₂) and water (H₂O), and catalytic reduction of NO_x to nitrogen (N₂) and oxygen (O₂). If platinum is the catalyst selected, it is considered as used primarily in the oxidation phase (HC and CO control). While platinum may also be used in the reducing phase, catalysts for NO_x control are still in the developmental stage. As of January 1971, a commercial NO_x catalyst was not available.

A recent study has shown that certain oxidation catalysts can tolerate low-lead fuel.³ In contrast, a platinum-based catalyst system will require virtually lead-free fuel. Platinum, however, has certain advantages, such as its proven effectiveness as a catalyst, its relatively low threshold activation temperature or "light-off," its fast "warmup," and its ability to withstand thermal stresses.

²U.S. Environmental Protection Agency. Annual Report of the Environmental Protection Agency to the Congress of the United States in Compliance With Section 202(b)(4) Public Law 90-148--The Clean Air Act as amended, July 1, 1971, Section G of Chapter 3, 43 pp.

³Jagel, K. I., and F. G. Dwyer. HC/CO Oxidation Catalysts for Vehicle Exhaust Emission Control. Pres. before the Automotive Engineering Congress, Detroit, Mich., Jan. 11-15, 1971, Soc. Automotive Eng. Paper No. 710290, 1971, 17 pp.

An alternative to catalytic conversion systems is the thermal reactor, a noncatalytic system not necessarily requiring unleaded fuel. It can oxidize HC and CO to meet the EPA emission standards. However, it currently requires exhaust gas recirculation (EGR) to control NO_x .⁴ Presently, automakers favor a catalytic over a thermal converter system, although the latter device is claimed to have certain advantages over a purely catalytic system.⁵ A summary of EPA activities in automobile emission control is given in a recent report to Congress.⁶ Tables and figures in appendix A show the sources of emissions contributing to air pollution and EPA's proposed reductions in automobile exhaust emissions. The following sections of this study present the estimated platinum supply-demand relationship, assuming that a catalytic system using this metal primarily as an oxidation catalyst is adopted.

Vehicle Classifications

Vehicles powered by internal combustion engines are classified by EPA in two categories--light duty and heavy duty--and this classification is followed in this study. Light-duty vehicles (LDV) are defined by EPA generally as those gasoline-fueled vehicles under 6,000 pounds gross vehicle weight (GVW). This includes passenger cars, light trucks, light vans, limousines, and other vehicles under the weight limitation. This vehicle category comprises 93 percent of the projected total vehicle annual production from 1975 to 1990 for all weight classifications. The platinum demand for light-duty vehicles is analyzed in depth in this study.

Heavy-duty vehicles (HDV) over 6,000 pounds GVW (gasoline- and diesel-fuel-powered trucks and buses) comprise only 7 percent of the projected total vehicle annual production from 1975 to 1990. Less than 10 percent of total road fuel (gasoline, diesel, and liquefied petroleum gases) is used by these vehicles, and the fraction is even smaller considering urban areas only. Because of survival data limitations and uncertainty as to the nature of control systems that may be adopted, a platinum demand for this vehicle category is an assumed percentage of the estimated platinum demand for light-duty vehicles.

Lead-Free Gasoline

As a consequence of the almost certain removal of lead from gasoline in the ensuing years, the additional demand for platinum as a petroleum-refining catalyst will be appreciable and is considered in this report. Lead, which in past years has been added to gasoline in the form of alkyl lead derivatives, such as tetraethyl lead (TEL) and tetramethyl lead (TML), to increase the

⁴Cantwell, E. N. A Total Exhaust Emission Control System. Paper pres. at the Joint Meeting of the Ontario and Quebec Chapters of the Air Pollution Control Association, Sept. 20-22, 1970, Montebello, Quebec, Canada, 15 pp.

⁵Chemical and Engineering News. DuPont Still in Running. V. 48, No. 26, June 22, 1970, p. 15.

⁶Work cited in footnote 2.

octane number of gasoline most economically,⁷ is inimical in varying degree to catalysts. It is a particularly inhibitory "poison" in the case of platinum,⁸ and is undesirable from the standpoint of this catalyst's longevity even in trace concentrations as low as 0.05 gram per gallon. Thus, if catalytic converters are to be used, virtually lead-free gasoline will be required. Ecological considerations will be an additional stimulus encouraging the ultimate removal of all lead from gasoline. However, lead probably will continue in limited use as an additive in one grade of gasoline until automobiles requiring leaded fuel are off the road. Complete removal of lead from motor fuel probably will not occur until near the end of this century, when virtually all pre-1975 vehicles requiring leaded gasoline will have been retired. The lowering of the octane level of gasolines as a result of the elimination of lead additives will require at least a partial restoration of the octane level by increasing the high-octane hydrocarbon components.

The EPA goal is that at least one grade of lead-free gasoline will be available nationwide before 1975, the year that installation of converters will be initially required on new automobiles. The choice of converter type is left entirely to the automaker; EPA concern is only that the device enables the emission standards to be met.

PLATINUM DEMAND FOR VEHICLE EMISSION CONTROL CONVERTERS

General Discussion

The demand for platinum as an oxidation catalyst for the control of HC and CO automotive exhaust emissions was considered by estimating the quantity of new platinum that would be required under various percentages of platinum salvaged and recycled. The recycled platinum will come from the converters of 1975 and later model-year vehicles that are retired and scrapped, plus the platinum from converter "trade-ins" of surviving vehicles produced in 1975 and after.

Table 1 shows the rate at which milage is accumulated by a late model automobile. Figure 1 is a simplified flow sheet showing the relationship between the supply of new and recycled platinum and the demand for new vehicle and replacement converters. Table 2 is a forecast of new automobile production from 1975 to 1990. Column 4 represents the production of light-duty vehicles that will be equipped with automobile exhaust converters using platinum as the oxidation catalyst for control of HC and CO emissions in conformance with the EPA 1975 and later year standards.

⁷Lane, John C. Gasoline and Other Motor Fuels. Ch. in Encyclopedia of Chemical Technology, ed. by R. E. Kirk and D. F. Othmer. Intersci. Encyclopedia, Inc., New York, v. 10, 1966, pp. 475-476.

⁸Yolles, R. S., and H. Wise. Catalytic Control of Automobile Exhaust Emissions. Critical Reviews in Environmental Control. V. 2, No. 1, April 1971, pp. 135-140.

TABLE 1. - Estimated milage accumulated by a late model automobile

Time	Miles driven per year	Accumulative average
1st year.....	14,500	14,500
2d year.....	13,000	27,500
3d year.....	11,500	39,000
4th year.....	10,000	¹ 49,000
5th year.....	9,900	58,900
6th year.....	9,900	68,800
7th year.....	9,500	78,300
8th year.....	8,500	86,800
9th year.....	7,500	94,300
10th year ²	5,700	100,000
Total.....	100,000	-

¹Considered as 50,000 miles accumulated in 4 years. The remaining milage (100,000 minus 49,000) considered as 50,000 miles accumulated in 6 years.

²Assumed life span: 10 years, 100,000 miles.

Data source: U.S. Department of Transportation, Federal Highway Administration. Cost of operating an Automobile. February 1970.

TABLE 2. - Forecast of U.S. motor vehicle production (for domestic use plus imports), 1975-90, million units

Year	New passenger cars, total ¹	New trucks and buses, total ¹	Light-duty trucks under 6,000 pounds GVW, 58 percent of column 2 ²	Light-duty, vehicles, column 1 plus column 3	Light-duty vehicles, percent
	(1)	(2)	(3)	(4)	(5)
1975.....	10.9	2.4	1.4	12.3	92
1976.....	11.2	2.4	1.4	12.6	93
1977.....	11.5	2.4	1.4	12.9	93
1978.....	11.7	2.5	1.5	13.2	93
1979.....	12.0	2.5	1.5	13.5	93
1980.....	12.2	2.5	1.5	13.7	93
1981.....	12.4	2.5	1.5	13.9	93
1982.....	12.5	2.6	1.5	14.0	93
1983.....	12.7	2.6	1.5	14.2	93
1984.....	12.9	2.6	1.5	14.4	93
1985.....	13.1	2.6	1.5	14.6	93
1986.....	13.3	2.6	1.5	14.8	93
1987.....	13.5	2.7	1.6	15.1	93
1988.....	13.8	2.7	1.6	15.4	93
1989.....	13.9	2.8	1.6	15.5	93
1990.....	14.0	2.9	1.7	15.7	93

¹U.S. Department of Transportation, Federal Highway Administration. Forecast of Motor Vehicle Distribution, Production, and Scrappage. October 1971.

²Estimated from data in the table "Truck and Bus Factory Sales by Vehicle Weight," Motor Truck Facts, 1971, published by Automobile Manufacturers Association, Inc.

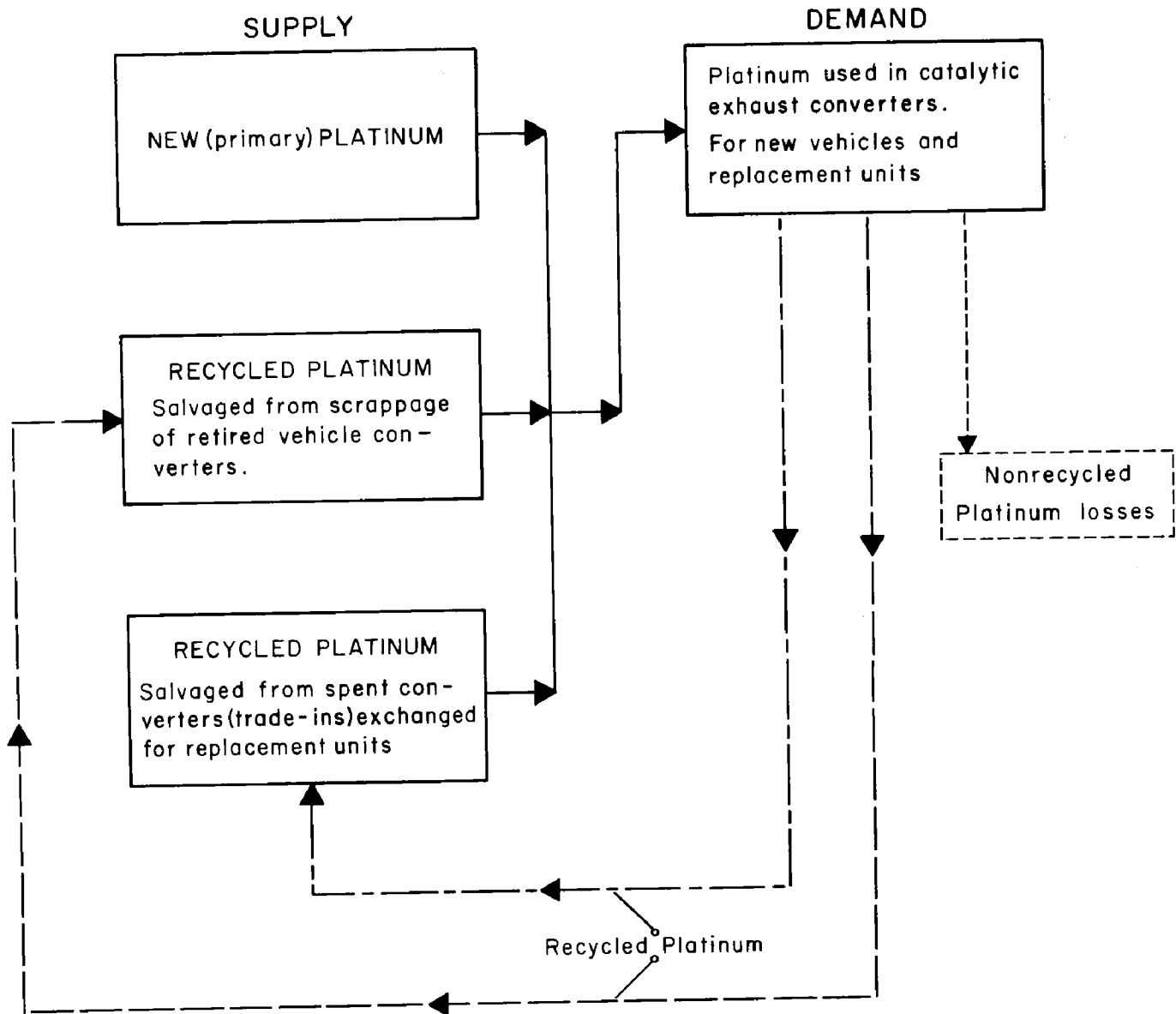


FIGURE 1. - Platinum Supply-Demand Relationship Assuming Use of a Platinum Catalyst in Automobile Exhaust Converters.

Platinum Required per Converter

A platinum-based catalyst is essentially composed of a ceramic support or substrate and platinum. The platinum is deposited on the support, which may be a monolithic honeycomb structure or pelleted forms. The catalyst is protected from shock, vibration, and other external effects by enclosure in a suitable metal housing. The complete assembly constitutes the catalytic converter. Glogau estimates that the quantity of platinum required will range from 0.06 to 0.10 troy ounce per automobile.⁹ For simplicity, the assumption

⁹Testimony of Richard C. Glogau, president, Engelhard Industries Division, Engelhard Minerals and Chemicals Corp., before the California Air Resources Board, July 21, 1971, p. 4. Available from the State of California Air Resources Board, 1108 14th St., Sacramento, Calif. 95814.

is made in this study that, on the average, each light-duty vehicle will require a total platinum demand of 0.10 troy ounce. This quantity is predicated on the use of platinum primarily as an oxidation catalyst. If additional platinum be required for NO_x control or should the base quantity of platinum per vehicle prove to be other than 0.10 troy ounce, the tabular data can be adjusted easily to the new base, and new projections made from the amended data.

Platinum Recycled From Scrapped Vehicles

To determine platinum recycled from the converters of scrapped vehicles, a method of estimating the retirement rate of post-1975 automobiles was

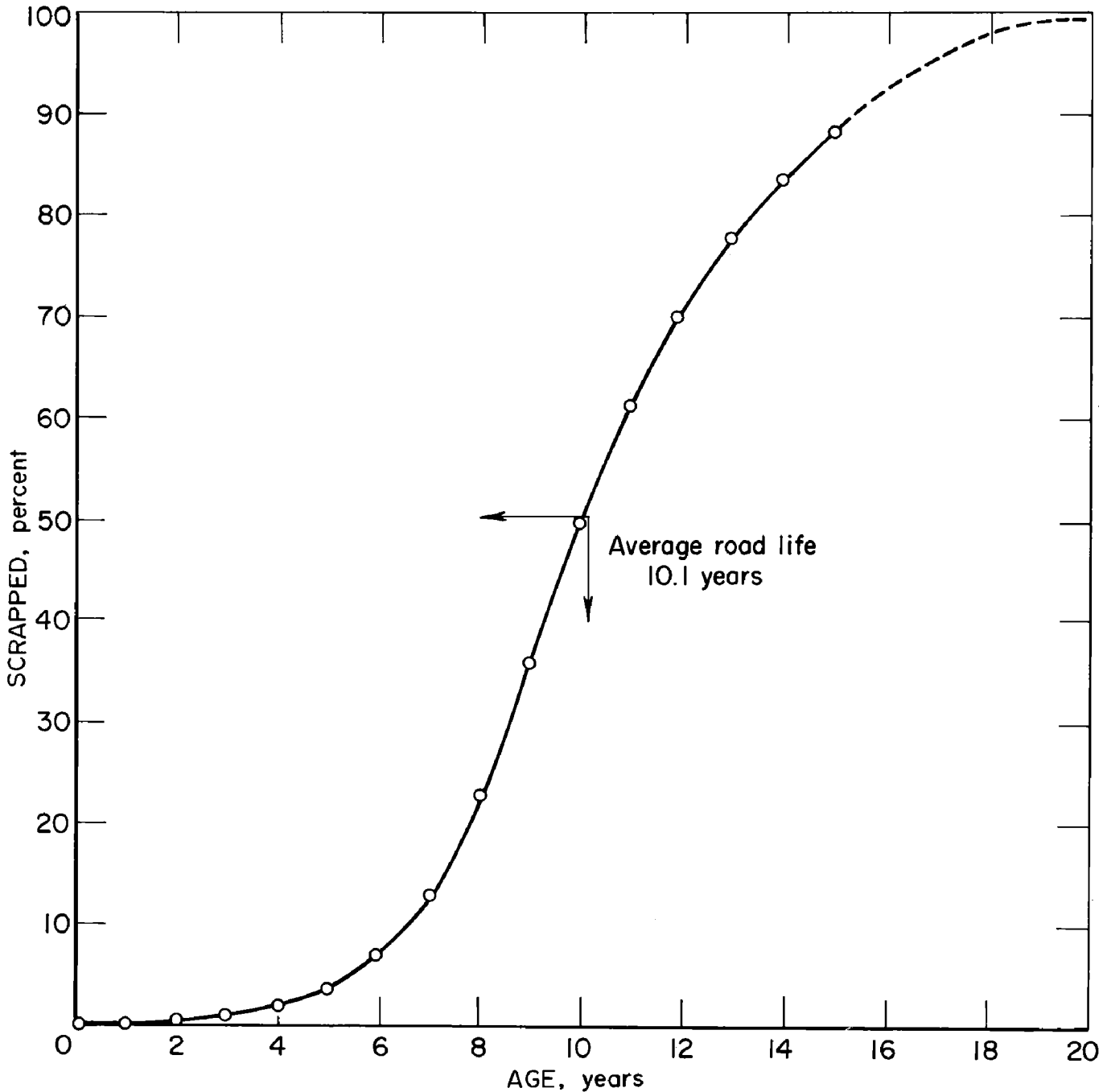


FIGURE 2. - Estimated Automobiles Scrapped Versus Age.

required. The longevity of future production-model cars most likely will be similar to that of cars previously produced for which predictive data (model year registration data) were available. The method used in this study involved determining the number of passenger cars surviving from 1950 to 1970, beginning with the 1950 models. By dividing each successive year's registration for any particular model year by the peak registration year for that model (generally 2 to 3 years after model introduction), the percentage of survival for that year model was obtained for each successive year of registration to the last year for which such data were given. It is assumed that the drop in registrations reported from one year to the next represents the retirement of any particular year model. In order to minimize differences in longevity of any one model year car over another, the data shown in table 3 and figure 2 were obtained by averaging the percentage survival of all model-year cars produced from 1950 to 1967 (1967 was the last year for which sufficient registration data was available). The longest data period was 15 years and the shortest was 4 years.

TABLE 3. - Estimated automobiles scrapped versus age, percent

Interval years	Survival	Retirement	Incremental retirement ¹
	(1)	(2)	(3)
0.....	100.0	0.0	0.0
1.....	² 99.9	.1	.1
2.....	99.5	.5	.4
3.....	99.0	1.0	.5
4.....	98.4	1.6	.6
5.....	96.6	3.4	1.8
6.....	93.2	6.8	3.4
7.....	87.0	13.0	6.2
8.....	77.1	22.9	9.9
9.....	64.2	35.8	12.9
10.....	50.8	49.2	13.4
11.....	38.6	61.4	12.2
12.....	30.2	69.8	8.4
13.....	22.1	77.9	8.1
14.....	16.3	83.7	5.8
15.....	12.0	88.0	4.3
16.....	³ 8.0	92.0	4.0
17.....	³ 4.5	95.5	3.5
18.....	³ 2.0	98.0	2.5
19.....	³ 1.0	99.0	1.0
20.....	³ .5	99.5	.5

¹Incremental data from year 1 to year 15 used in deriving scrappage data in table 4.

²Assumed--datum used in study.

³Assumed--data not used in study.

Source: Derived from "Model year registration data (U.S.)" in Automobile Facts and Figures, 1960 and 1971 editions, published by Automobile Manufacturers Association, Inc.

The average percent incremental retirement data, that is, the percentage of automobiles retiring from the year of production each succeeding year, was applied to post-1975 light-duty-vehicle production (column 4, table 2). This procedure implies that post-1975 light-duty vehicles will have about the same retirement rate as pre-1967 passenger automobiles. Equivalent registration data for pre-1970 heavy-duty vehicles were not available, thus a similar procedure was not used for vehicles over 6,000 pounds GVW. However, based on historical precedent, this vehicle class will account for only 7 percent of all annual motor vehicle production after 1975 (table 2). The platinum demand for this vehicle class is an assumed percentage of the light-duty-vehicle demand, and will be discussed in a later section (New or Primary Platinum Demand).

Table 4 shows the platinum that could be salvaged from scrappage of light-duty vehicles retiring after 1975 at various percentage recoveries, and the consequent effect on new platinum requirement.

Platinum recovery will depend on the degree to which the salvage value of the converter exceeds the removal cost to the autowrecker. The average value of platinum in the converter of a scrapped post-1975 automobile is estimated at \$10 to \$15 (1971 dollars). It is reasonable to assume that since platinum is costly and virtually all new U.S. supply must be imported, there will be sufficient salvage incentive to autowreckers to insure platinum recovery of at least 50 percent and possibly 75 percent or higher. Currently, recycling of platinum accounts for 70 to 80 percent of platinum used in the United States. Glogau estimated that a minimum of 75 percent of platinum used in converters would be recovered and recycled from the scrappage of retired vehicle converters, just as the lead in car batteries is presently recycled.¹⁰

Replacement Converters

A converter lasting the life of an average automobile would be required to reduce exhaust pollution to acceptable levels for about 100,000 miles which would mean about 10 years usage of the original converter. Although such converter longevity would be most desirable, it is more realistic to assume that at least one replacement of the converter would be necessary at the present state of catalytic converter technology. Glogau considers a platinum-based oxidation catalyst longevity of 50,000 miles to be a reasonable expectation.¹¹ Current EPA regulations stipulate a maintenance free converter life of 50,000 miles, regardless of type of converter or catalyst. This longevity is assumed in tables B-1 to B-4 (appendix B). Replacement of the catalytic converter originally installed in an average post-1975 light-duty vehicle thus would be required after about 50,000 miles or 4 years' use. EPA future maintenance regulations may permit a converter replacement under 50,000 miles; for example, replacement may be made at 25,000 miles if a converter durability of 50,000 miles proves unattainable. The additional platinum demand for a 25,000-mile converter longevity contrasted with the 50,000-mile longevity assumed in this study is compared in table C-1 and figure C-1 (appendix C).

¹⁰Page 5 of work cited in footnote 9.

¹¹Page 3 of work cited in footnote 9.

TABLE 4. - Platinum recycled at indicated percentages by scrappage of light-duty vehicles retiring after 1975,¹ thousand troy ounces, unless otherwise specified

Year	Total number of light-duty vehicles, thousand units (1)	25 percent		50 percent		75 percent		90 percent	
		Platinum recovered by scrap-page of retired vehicles (3)	New platinum required (column 2 minus column 3) (4)	Platinum recovered by scrap-page of retired vehicles (5)	New platinum required (column 2 minus column 5) (6)	Platinum recovered by scrap-page of retired vehicles (7)	New platinum required (column 2 minus column 7) (8)	Platinum recovered by scrap-page of retired vehicles (9)	New platinum required (column 2 minus column 9) (10)
1975	12,300	0	1,230	0	1,230	0	1,230	0	1,230
1976	12,600	0	1,260	1	1,259	1	1,259	1	1,259
1977	12,900	2	1,288	3	1,287	5	1,285	6	1,284
1978	13,200	3	1,317	6	1,314	9	1,311	12	1,308
1979	13,500	5	1,345	10	1,340	15	1,335	18	1,332
1980	13,700	11	1,359	21	1,349	32	1,338	38	1,332
1981	13,900	21	1,369	43	1,347	64	1,326	77	1,313
1982	14,000	41	1,359	82	1,318	123	1,277	148	1,252
1983	14,200	72	1,348	145	1,275	217	1,203	260	1,160
1984	14,400	114	1,326	227	1,213	341	1,099	409	1,031
1985	14,600	158	1,302	315	1,145	472	988	567	893
1986	14,800	198	1,282	397	1,083	596	884	715	765
1987	15,100	229	1,281	457	1,053	686	824	823	687
1988	15,400	258	1,282	516	1,024	774	766	929	611
1989	15,500	280	1,270	561	989	842	708	1,010	540
1990	15,700	299	1,271	598	972	896	674	1,076	494

¹Assuming negligible platinum loss during life of converter and in reprocessing.

²From table 2, column 4.

Source: Derived from incremental retirement data in table 3, column 3.

Column 3 in table B-1 and column 7 in tables B-2, B-3, and B-4 show the total new platinum demand (50,000-mile converter longevity) under several assumed percentages of salvage or recycle from vehicle scrappage and converter trade-ins. Table 5 is a summary of new platinum demand from these four appended tables; the data are also shown graphically (fig. 3).

TABLE 5. - Summary of new platinum demand annually at several assumed percentages of platinum recycled from scrappage of retired light-duty-vehicle converters and converter trade-ins, assuming a converter life of 50,000 miles, thousand troy ounces

Year	No recycled platinum from vehicle scrappage or converter trade-ins ¹ (1)	Recycled platinum from 50 percent vehicle scrappage and 75 percent converter trade-ins ² (2)	Recycled platinum from 75 percent vehicle scrappage and 90 percent converter trade-ins ³ (3)	Recycled platinum from 90 percent vehicle scrappage and 90 percent converter trade-ins ⁴ (4)
1975.....	1,230	1,230	1,230	1,230
1976.....	1,260	1,259	1,259	1,259
1977.....	1,290	1,287	1,285	1,284
1978.....	1,320	1,314	1,311	1,308
1979.....	2,560	1,642	1,456	1,453
1980.....	2,610	1,659	1,462	1,456
1981.....	2,659	1,664	1,453	1,440
1982.....	2,699	1,643	1,407	1,382
1983.....	2,748	1,607	1,336	1,293
1984.....	2,788	1,550	1,234	1,166
1985.....	2,828	1,487	1,125	1,030
1986.....	2,858	1,427	1,022	903
1987.....	2,907	1,402	964	827
1988.....	2,957	1,378	908	753
1989.....	2,987	1,348	852	684
1990.....	3,026	1,336	820	640

¹Data from column 3, table B-1 (plotting data for curve a, fig. 3).

²Data from column 7, table B-2 (plotting data for curve b, fig. 3).

³Data from column 7, table B-3 (plotting data for curve c, fig. 3).

⁴Data from column 7, table B-4 (plotting data for curve d, fig. 3).

NEW (PRIMARY) PLATINUM DEMAND

Light-Duty Vehicles

Curve a in figure 3 presents an unlikely premise and is shown only for comparison. Most of the platinum demand in the United States is met by recycling used platinum (secondary recovery of platinum scrap, residues, spent catalysts, other platinum-bearing materials, and toll refining). Curve b is a pessimistic estimate of platinum recycle potential and assumes little financial incentive to the autowrecker and relatively lax requirements for exchange of old for replacement converters. Curve c is the author's selection

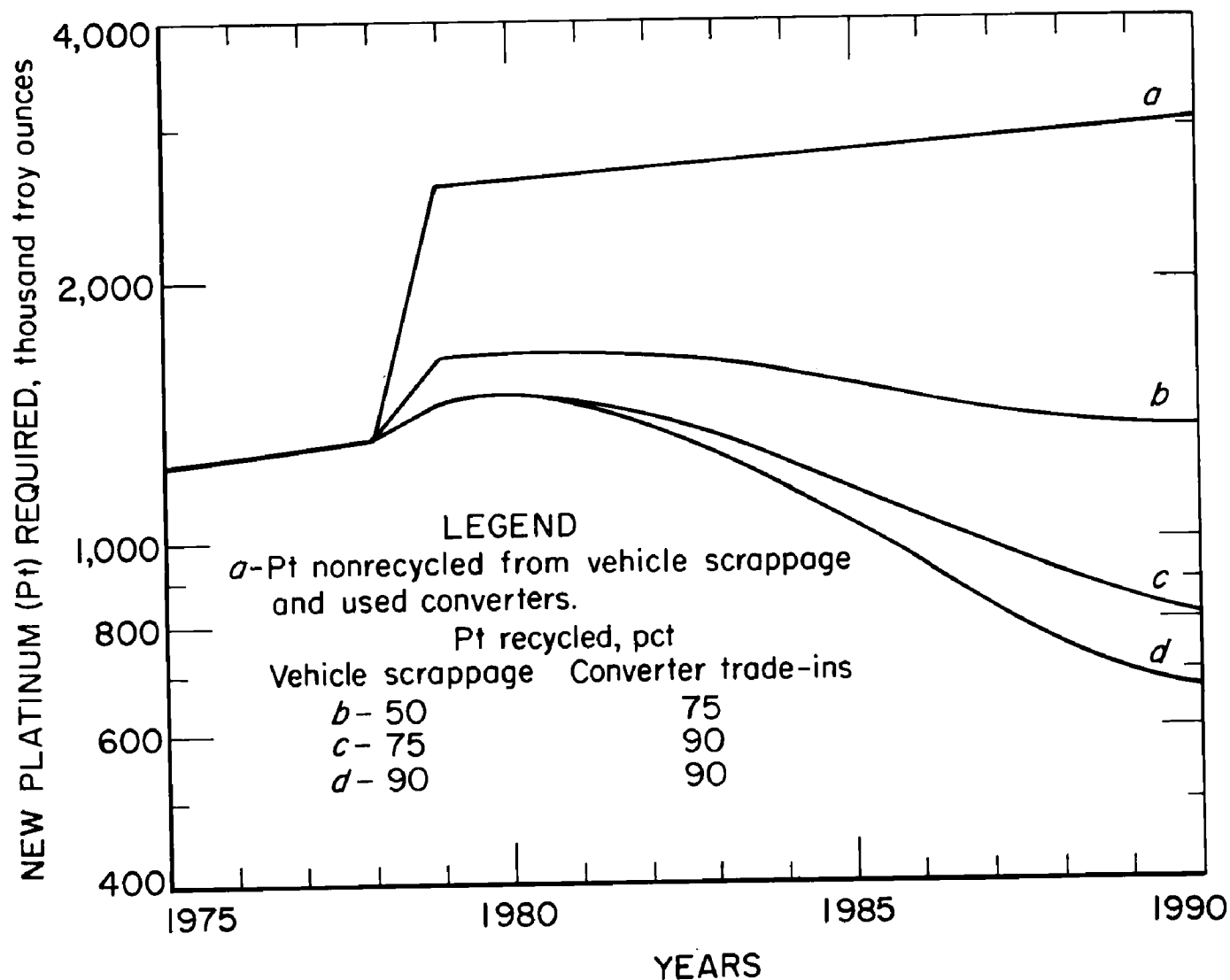


FIGURE 3. - Estimated New Platinum Demand Annually at Several Assumed Percentages of Platinum Recycled From Scrapped Light-Duty-Vehicle Converters and Converter Trade-Ins, Assuming a Converter Life of 50,000 Miles.

for a realistic platinum recycle situation. The conditions require assuring an adequate salvage value to the autowrecker to insure a high percentage recovery from vehicle scrappage, and firmly enforced old-for-new converter exchange controls. Curve *d*, on the other hand, represents a probably unattainable degree of salvage from vehicle scrappage.

Heavy-Duty Vehicles

Heavy-duty vehicles are defined by EPA as those motor vehicles over 6,000 pounds GVW. These vehicles comprise 7 percent of the total annual vehicle production projected from 1975 to 1990 (table 2). Unavailability of longevity data precluded the same analysis provided for the light-duty vehicles (motor vehicles under 6,000 pounds GVW) that comprise 93 percent of the total annual vehicle production projected for the same period. However, platinum demand for the heavy-duty vehicle class was assumed to be 15 percent of the

annual new platinum demand shown in column 3, table 5, for light-duty vehicles. This assumption is based on the premise that although heavy-duty vehicles probably will be only 7 percent of all vehicle production in 1975 and beyond, their larger engines and consequently greater exhaust volumes suggest at least double the catalyst demand of light-duty vehicles.

All Vehicles Produced From 1975-90

The forecast for new platinum demand by new and replacement catalytic converters of all vehicles (light- and heavy-duty vehicles produced from 1975 to 1990 and distributed in the United States) is given in tabular form (table 6) and shown graphically (fig. 4). As is evident in figure 4, the demand for new or primary platinum in 1975 for use in automotive exhaust converters is almost three times greater than requirements for all uses, as shown by the 20-year (1951-70) trend line for 1975 (524 thousand troy ounces).

TABLE 6. - Estimated new platinum demand for new and replacement catalytic exhaust converters of light- and heavy-duty vehicles, 1975-90

Year	Vehicle production, million units ¹			Platinum demand, thousand troy ounces		
	Light-duty vehicles (1)	Heavy-duty vehicles (2)	All vehicles (3)	Light-duty vehicles ² (4)	Heavy-duty vehicles ³ (5)	All vehicles (6)
1975.....	12.3	1.0	13.3	1,230	184	1,414
1976.....	12.6	1.0	13.6	1,259	189	1,448
1977.....	12.9	1.0	13.9	1,285	193	1,478
1978.....	13.2	1.0	14.2	1,311	197	1,508
1979.....	13.5	1.0	14.5	1,456	218	1,674
1980.....	13.7	1.0	14.7	1,462	219	1,681
1981.....	13.9	1.0	14.9	1,453	218	1,671
1982.....	14.0	1.1	15.1	1,407	211	1,618
1983.....	14.2	1.1	15.3	1,336	200	1,536
1984.....	14.4	1.1	15.5	1,234	185	1,419
1985.....	14.6	1.1	15.7	1,125	169	1,294
1986.....	14.8	1.1	15.9	1,022	153	1,175
1987.....	15.1	1.1	16.2	964	145	1,109
1988.....	15.4	1.1	16.5	908	136	1,044
1989.....	15.5	1.2	16.7	852	128	980
1990.....	15.7	1.2	16.9	820	123	943

¹Data from table 2.

²Data from table 5, column 3.

³An assumed 15 percent of column 4.

The increase in demand for new or primary platinum (table 6 and curve shown in figure 4) from 1975 to 1978 is due to the annual increase in new car production and the relatively insignificant allayment to demand by platinum recycled from automobiles scrapped during this period. The sharper rise from 1978 to 1979 is a reflection of the foregoing factors plus the 50,000-mile replacement of converters of existing 1975 model cars. After 1980, the peak

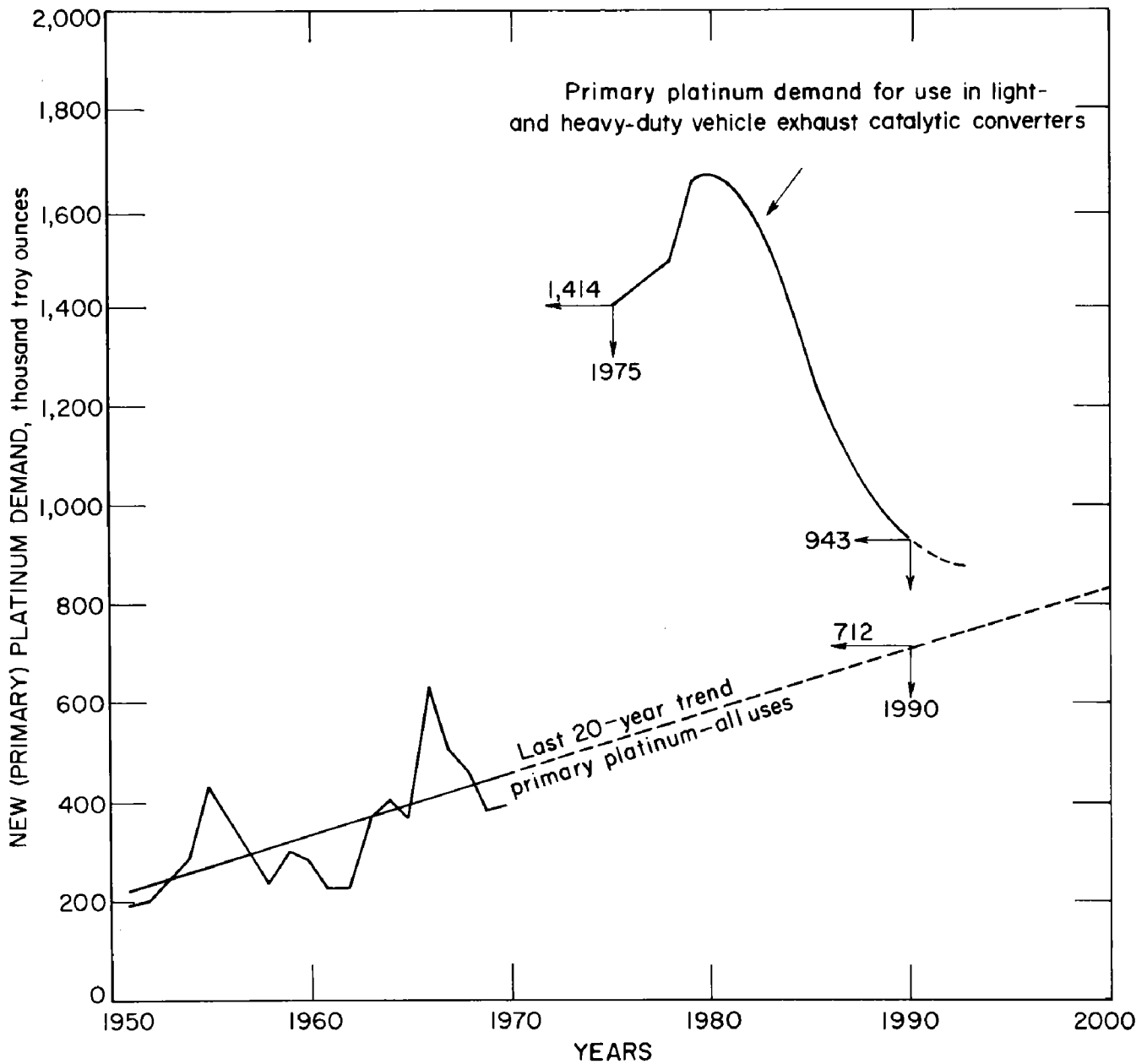


FIGURE 4. - Estimated New Platinum Demand for New and Replacement Catalytic Exhaust Converters of Light- and Heavy-Duty Vehicles, 1975-90. The last 20-year (1951-70) trend projection for primary platinum is shown for comparison.

demand year for new platinum, the demand decreases as the supply rate of recycled platinum from vehicle scrappage and converter trade-ins accelerates. From 1980 to 1990, inclusive, the new platinum demand decreases by almost 44 percent from the peak demand of 1,681 thousand troy ounces in 1980 to the low demand of 943 thousand troy ounces in 1990. The segment of the curve in figure 4 shown as dashed lines indicates only the probable direction of the curve if the annual rate of new automobile output remains essentially constant after 1990--it is not intended to suggest a valid continuation of the curve.

Auxiliary or "Add-on" Converters

If platinum is selected for use in automotive pollution control systems, it is presumed in this study that it will be limited to new and replacement converters for vehicles produced in and after 1975. Any retrofitting of pre-1975 vehicles will probably be restricted to those cars in large metropolitan centers where smog and air pollution is a major problem. The additional platinum for such possible demand is not considered in this study. Unless pollution control systems are developed that are not dependent on a costly and domestically scarce material many pre-1975 vehicles will continue to pollute in diminishing number until their virtual extinction near the end of this century.

PLATINUM DEMAND IN PETROLEUM REFINING

General Discussion

The use of catalytic emission control systems will require virtually lead-free gasoline especially if platinum is used either as an oxidation catalyst to control HC and CO emissions or as a reducing catalyst to control NO_x emissions. EPA has published an advance notice of proposed rulemaking indicating its intention to control or prohibit the use of alkyl lead in motor vehicle gasoline.¹² It is anticipated by EPA that regulations will be proposed which provide for general availability by July 1, 1974, of lead-free gasoline of an octane quality suitable for 1975 and subsequent model light-duty vehicles and for reduction of the lead content of the current regular and premium grades of gasoline. It has been suggested that within 10 years most of the gasoline marketed will be nonleaded.¹³

If the octane levels of gasoline are restored to near comparability with current leaded fuels, changes will be required in the petroleum refining industry. Such changes may include greater output of high-octane components such as aromatic hydrocarbons to provide satisfactory performance characteristics to gasoline without the use of lead or other additives. Aromatics are produced by the refinery process of reforming and isomerization. Both processes require platinum, either alone or in combination with another nonplatinum-metal-group catalyst (bimetallic catalyst); reforming accounts for the major share of aromatic output. Expansion of refinery reforming and isomerization capacity to enable greater output of aromatics (benzene, toluene, and xylenes) will be required. This expansion will in turn require additional platinum over the existing refining inventory used in the isomerization and reforming processes.

Estimated Platinum Demand by the Petroleum Industry

The octane requirements for future lead-free gasolines as well as the technical approach to making these gasolines are yet to be completely defined.

¹²U.S. Code of Federal Regulations. Title 42; Chapter IV; Part 479--Regulation of Fuel Additives. Federal Register, v. 36, No. 21, Jan. 30, 1971, p. 1486.

¹³Cohn, Victor. EPA Offers 10-Year Plan To Make Gas Lead-Free. Washington Post, Feb. 5, 1972, sec. A, p. 1.

The date by which virtually all gasoline must be essentially lead-free has not been firmly established; present indications are that it will be within 10 years. Considering these basic unknowns, any estimates or projections of platinum demand for the manufacture of lead-free gasoline must be considered as conjectural. However, an order-of-magnitude estimate is that 1 million troy ounces of platinum will be required to satisfy the potential reforming capacity growth rate of 9 percent per year from 1972 to 1981. This quantity would be in addition to an estimated normal operating demand of 2 million troy ounces (based on historical precedent from 1961 to 1970) that will be required from 1972 to 1981.

A development that could minimize platinum demand by the petroleum industry is the interest by automakers in the Wankel engine, an internal combustion rotary engine.¹⁴ Apart from the virtues of interest to automakers, the Wankel engine, though at least as pollutive with respect to exhaust emissions as a conventional piston engine, can run on octanes in the low eighties and reportedly runs very well on lead-free gasoline. Although it would require an antipollution device to control exhaust emissions, the engine's relatively low-octane requirements would minimize the need for aromatic hydrocarbons in gasoline. Thus the need for additional reforming and isomerization capacity (with an attendant platinum demand) by the petroleum industry would be minimized or eliminated. In addition to the Wankel engine, other propulsion alternatives, generally less pollutive, are being considered.¹⁵

The development of filters that would remove lead from automobile exhaust gases, if successful, could make unnecessary the petroleum industry's conversion to lead-free gasoline. A device reportedly capable of removing virtually all particulates from the exhaust effluents, and presumably, most of the lead compounds has been described.¹⁶ Control of HC, CO, and NO_x emissions would require either catalytic conversion (if the filtered exhaust gases were sufficiently low in lead), or a thermal conversion device with suitable NO_x control.

PRIMARY PLATINUM SUPPLY

U.S. Production

The national output of platinum is produced as a byproduct of copper smelting and from placer deposits in Alaska. Domestic annual production of platinum-group metals (platinum, palladium, iridium, osmium, rhodium, and ruthenium) provides less than 1 percent of the world's annual production of these metals.¹⁷ Of this domestic quantity, about 50 percent is estimated to be platinum. The United States is almost completely dependent on imports to meet its demand for primary platinum, as well as for the other members of the platinum-group metals.

¹⁴Cole, David E. The Wankel Engine. Sci. Am., v. 227, No. 2, August 1972, pp. 14-23.

¹⁵U.S. News and World Report. Radical New Engines for Cars--One Here, Others on the Way. V. 72, No. 18, May 1, 1972, pp. 44-46.

¹⁶Markowitz, Jack. Getting Lead Out: PPG's Answer. Pittsburgh Post-Gazette, Mar. 1, 1972, Sec. 2, p. 23.

¹⁷U.S. Bureau of Mines Minerals Yearbook. Platinum-Group Metals. V. 1, 1961-1971.

World Production

World production of platinum-group metals, their properties, and character of deposits worldwide, are described in depth by Mertie.¹⁸ The bulk of world supply of platinum-group metals (more than 98 percent in 1970), in order of output, currently comes from three countries--the U.S.S.R., the Republic of South Africa, and Canada; in order of estimated platinum metal output, they are the Republic of South Africa (1,068 thousand ounces in 1970), the U.S.S.R. (660 thousand ounces in 1970), and Canada (200 thousand ounces in 1970); these three nations supplied an estimated 92 percent of the world's platinum output in 1970. Supply-demand relationships for platinum are shown in appendix D. Figure D-1 shows the supply-demand relationships for platinum in 1970, and table D-1 shows the supply-demand relationships for platinum from 1961 to 1970.

Apparent Reserves of Platinum-Group Metals and Platinum

U.S. platinum-group-metal reserves are almost entirely in copper ores and thus are a byproduct of the copper industry. A very small and diminishing reserve is in placers at Goodnews Bay, Alaska. Total domestic reserves are estimated at 3 million troy ounces,¹⁹ of which about 50 percent is assumed to be platinum.

In 1970, Africa's recoverable reserves of platinum-group metals were estimated at 200 million troy ounces averaging, on the basis of past production, about 70 percent platinum, 25 percent palladium, and 5 percent minor platinum-group metals. The occurrence of platinum-group metals in significant quantities of the Merensky Reef horizon of the Bushveld igneous complex in the Republic of South Africa indicates that the quantity of platinum-bearing ore may be considerably larger. Prospecting and exploration of the Great Dyke ultrabasic formation in Southern Rhodesia has disclosed several significant occurrences of platinum-group metals which may indicate potential resources approaching 100 million troy ounces.²⁰ A revised (1972) estimate by the Bureau of Mines now considers Africa's recoverable reserves of platinum-group metals to be 350 million troy ounces.

Although reliable information on production and reserves of the U.S.S.R. is unavailable, the country has been producing platinum-group metals since the 1830's and has produced at least one-half of the world supply to date. Reserves of platinum-group metals are estimated to be at least 200 million troy ounces, of which 30 percent estimated as platinum and 60 percent as palladium.²¹

The platinum-group-metal content of proven nickel-copper ore reserve of the Sudbury Basin and Thompson, Manitoba, areas in Canada is estimated at 16 million troy ounces, of which 43 percent is estimated to be platinum.²²

¹⁸Mertie, John B., Jr. Economic Geology of the Platinum Metals. U.S. Geol. Survey Prof. Paper 630, 1969, 120 pp.

¹⁹Ageton, Robert W., and J. Patrick Ryan. Platinum-Group Metals. Ch. in Mineral Facts and Problems. BuMines Bull. 650, 1970, p. 656.

²⁰Page 657 of work cited in footnote 19.

²¹Page 657 of work cited in footnote 19.

²²Page 657 of work cited in footnote 19.

Total world platinum reserves could be in excess of 375 million troy ounces, according to a recent (1972) Bureau of Mines estimate.

Potential Production

The reserves of platinum and therefore the potential production of the Republic of South Africa appear to be much greater than those of any other country. One marked difference between the South African lodes and those of Canada and the U.S.S.R. is that platinum metals are the principal output of the former, with a byproduct of nickel, copper, and other metals, whereas in the two latter countries the reverse is true.²³ Thus, a restrictive byproduct relationship is relatively inconsequential in the case of the expansion of South Africa's platinum production.

Two of South Africa's largest platinum producers--Rustenburg Platinum Mines, Ltd., and Impala Platinum Ltd.--have published assurances that an adequate supply of platinum will be available for antipollution use in automobiles and, presumably, for the metal's correlative refinery demand in making nonleaded gasoline nationally available by 1975, given assurance of continuing demand and a lead time of several years.²⁴

Rustenburg Platinum Ltd. is the free world's leading producer of platinum, and claims to hold an estimated 200 million ounces of undeveloped platinum reserves on South Africa's Bushveld igneous complex. Impala is the second largest producer in the free world; it has a present producing capability of 250,000 ounces of platinum per year. The company claims that its mining area of an ore body in the Merensky Reef is sufficiently large to sustain a rate of production of 1 million ounces of platinum per year for over 30 years.

Economic Factors

Marketing prices for platinum-group metals have been varied and unpredictable. Historically this has resulted in widely fluctuating prices and the multiprice markets for platinum metals. The major refiners (Engelhard Industries and Johnson-Matthey) have a producer's price; dealers market at a different price; the U.S.S.R. markets at still another price; and metal traded on the futures market may be higher or lower than the other three prices.²⁵

²³Page 4 of work cited in footnote 18.

²⁴Wall Street Journal. Platinum Is Available for Antipollution Use in Cars, Agency Told. July 22, 1971, p. 10.

Impala Platinum Limited. Communication to EPA, Apr. 30, 1971, Relative to Impala's supply capabilities, reserves, and expansion capabilities. Available upon request from the Environmental Protection Agency, National Air Pollution Control Office, Rockville, Md. 20852.

²⁵U.S. Bureau of Mines, Division of Nonferrous Metals. Platinum-Group Metals Commodity Statement (internal working paper). Mar. 30, 1971. Available from Assistant Director of Planning, Washington, D.C.

The time-price relationship for platinum is shown in figure 5 and the world platinum resources recoverable at various prices are shown in table 7. All prices shown are producer prices. The concern that a rapid rise in platinum demand would result in sharp price increases does not appear justified, according to both Rustenburg Platinum Mines, Ltd., and Impala Platinum Ltd. These free world leading producers refer to the relatively stable producers' prices prevailing for the 5 years prior to 1971 and further indicate that continuing demand for platinum is directly contingent upon a reasonably stable price.

TABLE 7. - Assessment of world platinum resources recoverable at various prices, million troy ounces

	Price, constant 1970 dollars per ounce platinum metal		
	\$133 ¹	\$145	\$175
North America:			
Canada.....	7.1	7.1	7.1
United States.....	1.3	1.5	1.7
Total.....	8.4	8.6	8.8
South America: Colombia.....	3.5	4.9	5.6
Europe: U.S.S.R.....	60.0	61.5	63.0
Africa: Republic of South Africa....	245.0	265.0	300.0
World total.....	316.9	340.0	377.4

¹Average producer's price for platinum in 1970.

Source: Bureau of Mines, Division of Nonferrous Metals (internal working paper--Platinum Metals, 1971).

SUMMARY AND CONCLUSIONS

The total annual demand for new or primary platinum for all uses in the future will be a summation of (1) platinum's possible use as the sole catalyst in automobile exhaust converters beginning in 1975; (2) its additional requirement by the petroleum industry in expanding reforming and isomerization capacity for the production of lead-free gasolines, now already in progress; and (3) its growing demand for other uses. Other uses for platinum, in order of 1970 demand, include industrial chemicals, petroleum refining, electrical equipment, ceramics and glass, jewelry and arts, miscellaneous uses, and dental supplies.

The estimated demand considered in this study was limited quantitatively to platinum use as an oxidation catalyst for the reduction of pollution from automobile exhausts in the United States. For a catalytic converter longevity of 50,000 miles the data shown in table 6 and figure 4 indicate a drastic rise in demand for new platinum, beginning in 1975, reaching a peak of 1.68 million troy ounces in 1980, and then decreasing curvilinearly to the lowest annual demand of 0.94 million troy ounces in 1990. The estimated additional platinum

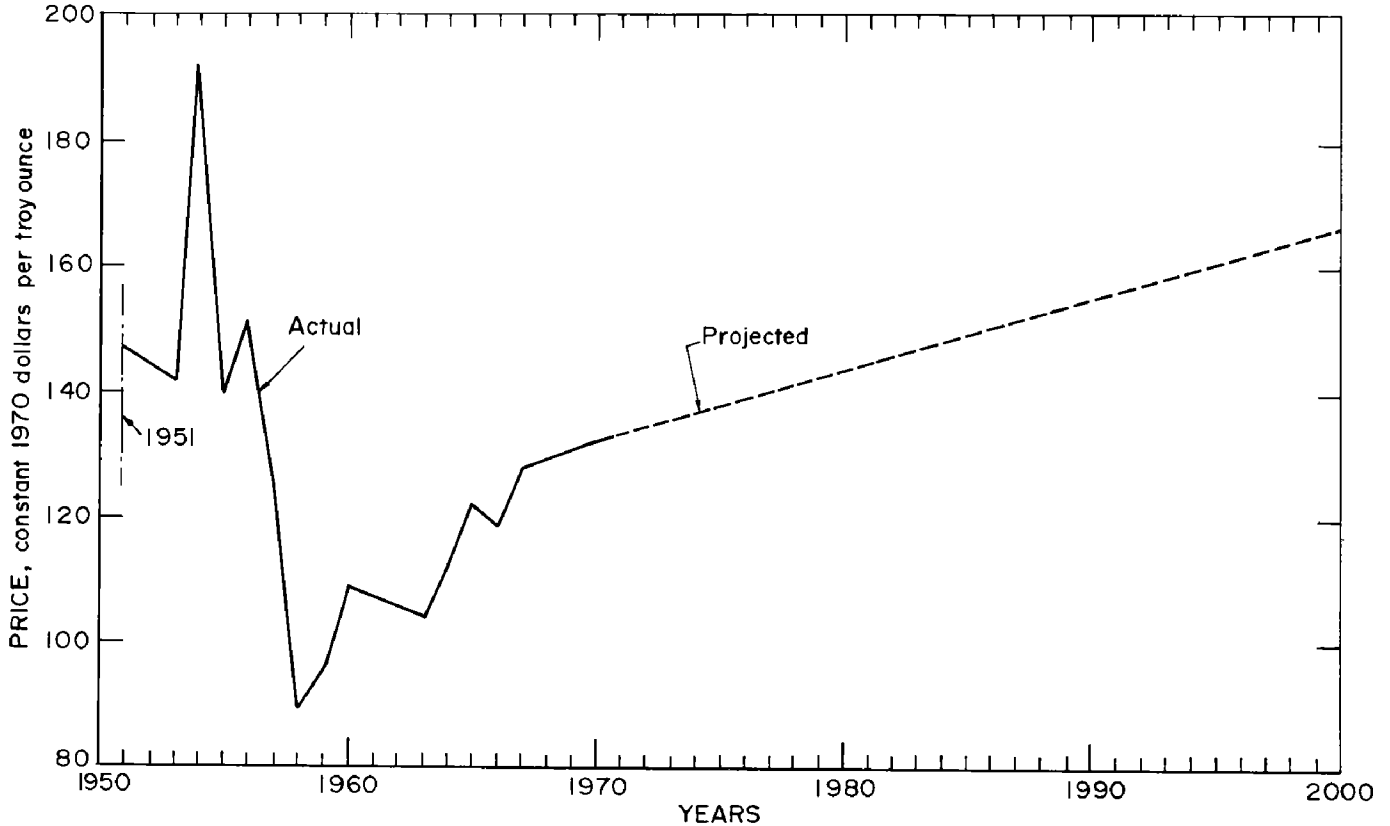


FIGURE 5. - Platinum Time-Price Relationship.

demand, should the converter longevity prove to be only 25,000 miles, is shown in table C-1 and figure C-1. The peak platinum demand of 1,920 thousand troy ounces is reached in 1982 and declines to 1,260 thousand troy ounces in 1990.

The petroleum industry in its almost certain conversion to the production of lead-free gasolines will require new platinum. This demand could total as high as 1 million troy ounces between 1972 and 1981 and is in addition to a normal operating demand of domestic refineries, estimated to total 2.0 million troy ounces during this period. After 1981, when conversion potential to unleaded gasoline is assumed virtually complete, the demand is expected to moderate. Refinery demands for new platinum will then depend primarily on the growth rate of the petroleum industry.

Automobile pollution abatement may represent by far the largest single national use for platinum for both the short and long haul. However, this is true only if platinum is irreplaceable in automotive pollution abatement measures. World reserves, particularly South African reserves, appear adequate to meet U.S. platinum requirements for the abatement of automotive pollution until well into the next century.

Other factors that could lower or even eliminate platinum demand in automotive uses should be considered. An obvious one, and one well within the realm of possibility, is the replacement of platinum as a catalyst by another material. Automakers are investigating many nonplatinum-metal-group catalysts as possible substitutes for platinum.

For oxidation catalysis (HC and CO to H₂O and CO₂), a partial list includes V, Cr, Mn, Fe, Co, Ni, Cu, Nb, Mo, Tc, Ag, Ta, W, Re, Au, and the rare earth elements. Reduction catalysis (NO_x to N₂ and O₂) may be accomplished with noble metals or nonnoble metal catalysts, although as of January 1971, a commercial NO_x catalyst was not available. In a recent report to EPA, General Motors had almost ruled out noble metal catalysts on the grounds of their high cost, availability considerations, and poor performance characteristics in a number of cases.²⁶ The company's share of the domestic automobile market, estimated to range between 40 and 50 percent, would indicate a drastic curtailment in platinum demand if they select a nonplatinum catalyst. Possibly General Motors' attitude regarding noble metal catalysts has changed. A recent journal article reports that the company includes platinum among the relatively few materials now being considered as catalysts; the other two major domestic automakers (Ford and Chrysler) reportedly currently favor platinum.²⁷

The ultimate choice of a catalyst, if catalytic conversion will be included in a system to control automobile exhaust emissions, is thus still to be made or announced by automakers. Nevertheless, it is obvious that should a low-cost and relatively abundant nonnoble metal catalyst be developed that can equal or surpass platinum in fast warmup and conversion efficiency, and of satisfactory durability, the market for platinum as an automobile exhaust oxidation catalyst would be eliminated.

The factors that could alleviate the demand for platinum to reduce pollution from automobile exhausts are, at this point in time, conjectural. In view of the technological effort being exerted to produce effective control devices that will not require platinum--nonnoble metal catalysts or systems not requiring catalysts--it would be equally conjectural to assume that platinum demand will soar. However, if platinum is the catalyst selected and its position as a catalyst remains unchallenged, and if the internal combustion engine remains the principal automotive propulsion source from 1975 to 1990, then the demands discussed in this study are reasonable.

²⁶ General Motors Corp. Progress and Programs in Automotive Emissions Control. A Progress Report to the U.S. Environmental Protection Agency. Mar. 12, 1971, p. 21.

²⁷ Chemical Week. Who Will Clear the Air of Automobile Emissions? V. 110, No. 18, May 3, 1972, p. 42.

APPENDIX A.--SOURCES OF CO, HC, AND NO_x EMISSIONS NATIONALLY
AND EPA STANDARDS AND GOALS FOR THE REDUCTION
OF EXHAUST POLLUTION FROM MOTOR VEHICLES

TABLE A-1. - Percentage of national emissions in 1969

Source	CO	HC ¹	NO _x ¹
Motor vehicles.....	64.7	45.7	36.6
Other forms of transportation.....	9.0	7.2	10.5
Fuel combustion in stationary sources.....	1.2	2.4	42.0
Industrial processes.....	7.9	14.7	.8
Solid waste disposal.....	5.2	5.3	1.7
Miscellaneous.....	12.0	24.7	8.4
Total.....	100.0	100.0	100.0

¹In addition, emissions of HC and NO_x from motor vehicles and other sources undergo complex chemical reactions in the atmosphere and contribute to the formation of photochemical oxidants associated with urban smog.

Source: EPA estimates.

TABLE A-2. - National exhaust emission standards, light-duty vehicle

Pollutant	Baseline emissions, GVM ¹	1970	1971	1975 (proposed)	
	1972-75 test cycle	GVM	GVM	GVM	Reduction, percent
Exhaust HC.....	17.0	4.1	-	0.41	90
Exhaust CO.....	121.9	34.0	-	3.4	90
Exhaust NO _x	² 5.4	-	4.0	³ 3.4	90

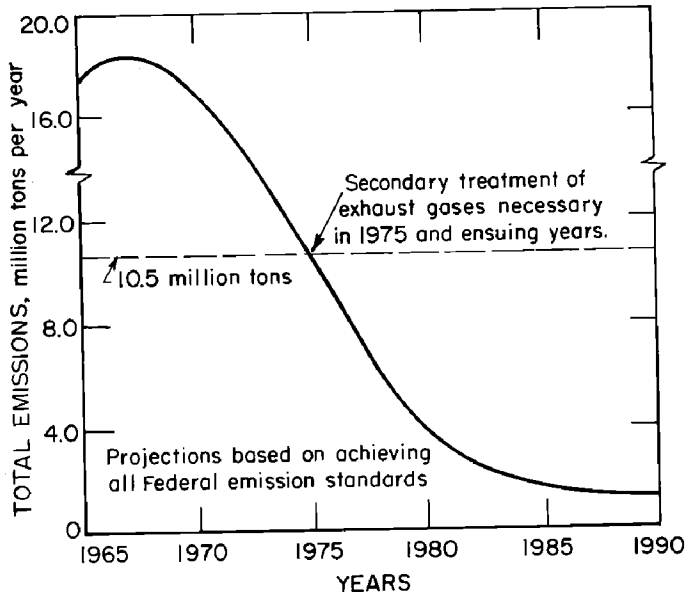
¹Baseline emissions apply to pre-1968 models.

²1968-71 test cycle.

³NO_x standard initially applicable to 1976 models.

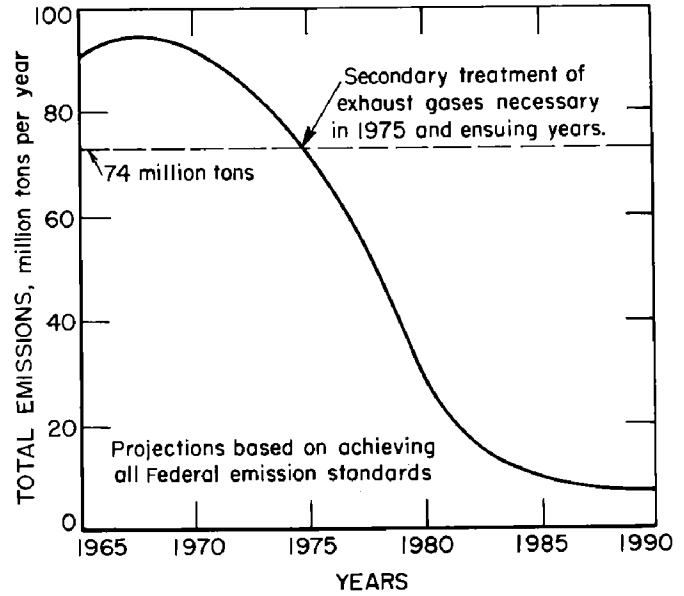
Note.--GVM = grams per vehicle mile.

Source: EPA summary as of June 30, 1971.



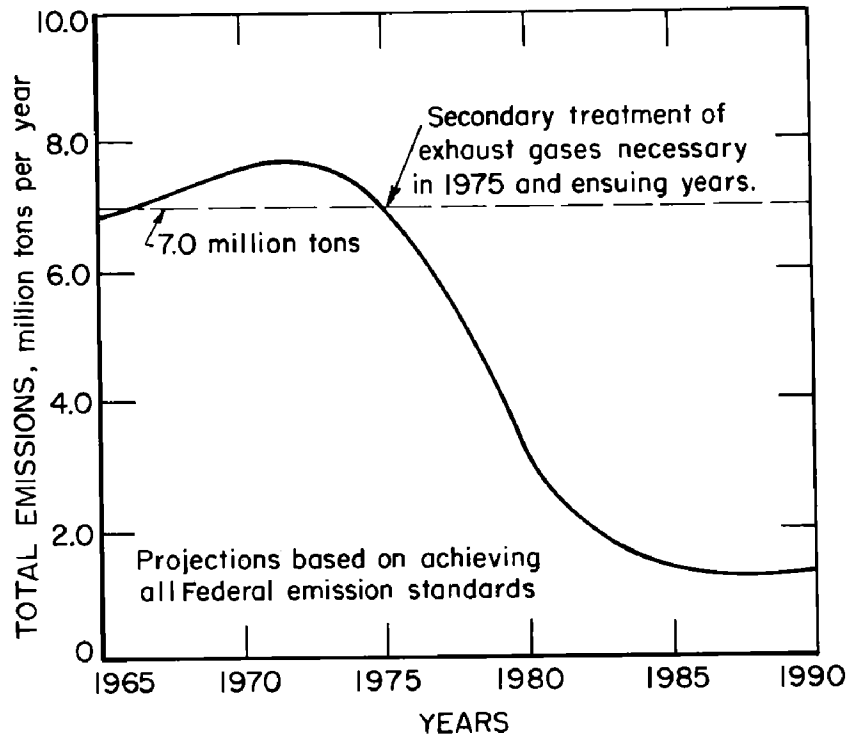
Source: Annual report of the Environmental Protection Agency to the Congress of the United States, July 1, 1971. Adapted from figure 4.

FIGURE A-1. - Reduction in HC Emissions From Motor Vehicles in the United States, 1965-90.



Source: Annual report of the Environmental Protection Agency to the Congress of the United States, July 1, 1971. Adapted from figure 5.

FIGURE A-2. - Reduction in CO Emissions From Motor Vehicles in the United States, 1965-90.



Source: Annual report of the Environmental Protection Agency to the Congress of the United States, July 1, 1971. Adapted from figure 3.

FIGURE A-3. - Reduction in NO_x Emissions From Motor Vehicles in the United States, 1965-90.

APPENDIX B.--ESTIMATED PLATINUM DEMAND FOR LIGHT-DUTY VEHICLES ANNUALLY,
ASSUMING (1) NONRECYCLING OF PLATINUM AND (2) SEVERAL
CONDITIONS OF RECYCLE FROM VEHICLE SCRAPPAGE
AND CONVERTER TRADE-INS

TABLE B-1. - Estimated new platinum demand annually for light-duty-
vehicle converters, assuming nonrecycling of platinum
from vehicle scrappage or used converters,
thousand troy ounces

Model year	New platinum demand for new car converters ¹ (1)	New platinum demand for replacement converters ² (2)	Total new platinum demand (column 1 plus column 2) (3)
1975.....	1,230	-	1,230
1976.....	1,260	-	1,260
1977.....	1,290	-	1,290
1978.....	1,320	-	1,320
1979.....	1,350	1,210	2,560
1980.....	1,370	1,240	2,610
1981.....	1,390	1,269	2,659
1982.....	1,400	1,299	2,699
1983.....	1,420	1,328	2,748
1984.....	1,440	1,348	2,788
1985.....	1,460	1,368	2,828
1986.....	1,480	1,378	2,858
1987.....	1,510	1,397	2,907
1988.....	1,540	1,417	2,957
1989.....	1,550	1,437	2,987
1990.....	1,570	1,456	3,026

¹Data from table 4, column 2.

²Replacement assumed to be required after vehicle accumulates 50,000 miles, which would occur about 4 years after the model year; for example, 1975 model year vehicles would require replacements in 1979. Platinum demand for replacement converters installed in any particular year (for example, 1979) will be less than initially required for the applicable model year (1975) due to vehicles retired during the 4-year interim. The number of vehicles surviving after 4 years is an estimated 98.4 per cent (table 3, column 1).

TABLE B-2. - Estimated new platinum demand annually for light-duty vehicle converters, assuming 50 percent platinum recycled by vehicle scrappage and 75 percent recycled from converter trade-ins, thousand troy ounces

Model year	Platinum demand-- new car converters ¹	Platinum demand-- replacement converters ²	Total platinum demand-- new car and replacement converters (column 1 plus column 2)	Platinum recycled by vehicle scrappage	Platinum recycled from converter trade-ins (75 pct of column 2)	Total platinum recycled (column 4 plus column 5)	Total new platinum demand (column 3 minus column 6)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1975.....	1,230	-	1,230	0	-	0	1,230
1976.....	1,260	-	1,260	1	-	1	1,259
1977.....	1,290	-	1,290	3	-	3	1,287
1978.....	1,320	-	1,320	6	-	6	1,314
1979.....	1,350	1,210	2,560	10	908	918	1,642
1980.....	1,370	1,240	2,610	21	930	951	1,659
1981.....	1,390	1,269	2,659	43	952	995	1,664
1982.....	1,400	1,299	2,699	82	974	1,056	1,643
1983.....	1,420	1,328	2,748	145	996	1,141	1,607
1984.....	1,440	1,348	2,788	227	1,011	1,238	1,550
1985.....	1,460	1,368	2,828	315	1,026	1,341	1,487
1986.....	1,480	1,378	2,858	397	1,034	1,431	1,427
1987.....	1,510	1,397	2,907	457	1,048	1,505	1,402
1988.....	1,540	1,417	2,957	516	1,063	1,579	1,378
1989.....	1,550	1,437	2,987	561	1,078	1,639	1,348
1990.....	1,570	1,456	3,026	598	1,092	1,690	1,336

¹Data from table 4, column 2.

²Replacement assumed to be required after vehicle accumulates 50,000 miles, which would occur about 4 years after the model year; for example, 1975 model year vehicles would require replacements in 1979.

Platinum demand for replacement converters installed in any particular year (for example, 1979) will be less than initially required for the applicable model year (1975) due to vehicles retired during the 4-year interim. The number of vehicles surviving after 4 years is an estimated 98.4 percent (table 3, column 1).

TABLE B-3. - Estimated new platinum demand annually for light-duty-vehicle converters, assuming 75 percent platinum recycled by vehicle scrappage and 90 percent recycled from converter trade-ins, thousand troy ounces

Model year	Platinum demand-- new car converters ¹ (1)	Platinum demand-- replacement converters ² (2)	Total platinum demand--new car and replacement converters (column 1 plus column 2) (3)	Platinum recycled by vehicle scrappage (4)	Platinum recycled from converter trade-ins (90 pct of column 2) (5)	Total platinum recycled (column 4 plus column 5) (6)	Total new platinum demand (column 3 minus column 6) (7)
1975.....	1,230	-	1,230	0	-	0	1,230
1976.....	1,260	-	1,260	1	-	1	1,259
1977.....	1,290	-	1,290	5	-	5	1,285
1978.....	1,320	-	1,320	9	-	9	1,311
1979.....	1,350	1,210	2,560	15	1,089	1,104	1,456
1980.....	1,370	1,240	2,610	32	1,116	1,148	1,462
1981.....	1,390	1,269	2,659	64	1,142	1,206	1,453
1982.....	1,400	1,299	2,699	123	1,169	1,292	1,407
1983.....	1,420	1,328	2,748	217	1,195	1,412	1,336
1984.....	1,440	1,348	2,788	341	1,213	1,554	1,234
1985.....	1,460	1,368	2,828	472	1,231	1,703	1,125
1986.....	1,480	1,378	2,858	596	1,240	1,836	1,022
1987.....	1,510	1,397	2,907	686	1,257	1,943	964
1988.....	1,540	1,417	2,957	774	1,275	2,049	908
1989.....	1,550	1,437	2,987	842	1,293	2,135	852
1990.....	1,570	1,456	3,026	896	1,310	2,206	820

¹Data from table 4, column 2.

²Replacement assumed to be required after vehicle accumulates 50,000 miles, which would occur about 4 years after the model year; for example, 1975 model year vehicles would require replacements in 1979. Platinum demand for replacement converters installed in any particular year (for example, 1979) will be less than initially required for the applicable model year (1975) due to vehicles retired during the 4-year interim. The number of vehicles surviving after 4 years is an estimated 98.4 percent (table 3, column 1).

TABLE B-4. - Estimated new platinum demand annually for light-duty-vehicle converters, assuming 90 percent platinum recycled by vehicle scrappage and 90 percent recycled from converter trade-ins, thousand troy ounces

Model year	Platinum demand--new car converters ¹	Platinum demand--replacement converters ²	Total platinum demand--new car and replacement converters (column 1 plus column 2)	Platinum recycled by vehicle scrappage	Platinum recycled from converter trade-ins (90 pct of column 2)	Total platinum recycled (column 4 plus column 5)	Total new platinum demand (column 3 minus column 6)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1975.....	1,230	-	1,230	0	-	0	1,230
1976.....	1,260	-	1,260	1	-	1	1,259
1977.....	1,290	-	1,290	6	-	6	1,284
1978.....	1,320	-	1,320	12	-	12	1,308
1979.....	1,350	1,210	2,560	18	1,089	1,107	1,453
1980.....	1,370	1,240	2,610	38	1,116	1,154	1,456
1981.....	1,390	1,269	2,659	77	1,142	1,219	1,440
1982.....	1,400	1,299	2,699	148	1,169	1,317	1,382
1983.....	1,420	1,328	2,748	260	1,195	1,455	1,293
1984.....	1,440	1,348	2,788	409	1,213	1,622	1,166
1985.....	1,460	1,368	2,828	567	1,231	1,798	1,030
1986.....	1,480	1,378	2,858	715	1,240	1,955	903
1987.....	1,510	1,397	2,907	823	1,257	2,080	827
1988.....	1,540	1,417	2,957	929	1,275	2,204	753
1989.....	1,550	1,437	2,987	1,010	1,293	2,303	684
1990.....	1,570	1,456	3,026	1,076	1,310	2,386	640

¹Data from table 4, column 2.

²Replacement assumed to be required after vehicle accumulates 50,000 miles, which would occur about 4 years after the model year; for example, 1975 model year vehicles would require replacements in 1979. Platinum demand for replacement converters installed in any particular year (for example, 1979) will be less than initially required for the applicable model year (1975) due to vehicles retired during the 4-year interim. The number of vehicles surviving after 4 years is an estimated 98.4 percent (table 3, column 1).

APPENDIX C.--ADDITIONAL NEW PLATINUM REQUIRED FOR A
CONVERTER LONGEVITY OF 25,000 MILES

TABLE C-1. - Comparison of new platinum demand for a catalytic converter
service life of 50,000 miles versus 25,000 miles
(light- and heavy-duty vehicles),
thousand troy ounces unless
otherwise indicated

Model year	Service life 50,000 miles ¹	Service life 25,000 miles ²	Increase in platinum demand (column 2 minus column 1)	Percent increase in platinum demand
	(1)	(2)	(3)	(4)
1975.....	1,414	1,414	0	0
1976.....	1,448	1,448	0	0
1977.....	1,478	1,618	140	9.5
1978.....	1,508	1,651	143	9.5
1979.....	1,674	1,822	148	8.8
1980.....	1,681	1,832	151	9.0
1981.....	1,671	1,825	154	9.2
1982.....	1,618	1,920	302	18.7
1983.....	1,536	1,822	286	18.6
1984.....	1,419	1,708	289	20.4
1985.....	1,294	1,577	283	21.9
1986.....	1,175	1,415	300	20.4
1987.....	1,109	1,412	303	27.3
1988.....	1,044	1,352	308	29.5
1989.....	980	1,293	313	31.9
1990.....	943	1,260	317	33.6

¹Data from table 6, column 6.

²Calculated on a basis of 3 converter replacements--25,000 miles (2 years), 50,000 miles (4 years), and 75,000 miles (7 years) during the average life (100,000 miles) of a light-duty vehicle. The percentages of platinum recycled are 75 percent from scrapped vehicle converters and 90 percent from converter trade-ins, the same proportions as for a converter longevity of 50,000 miles. Heavy-duty-vehicle platinum demand is an assumed 15 percent of light-duty-vehicle demand.

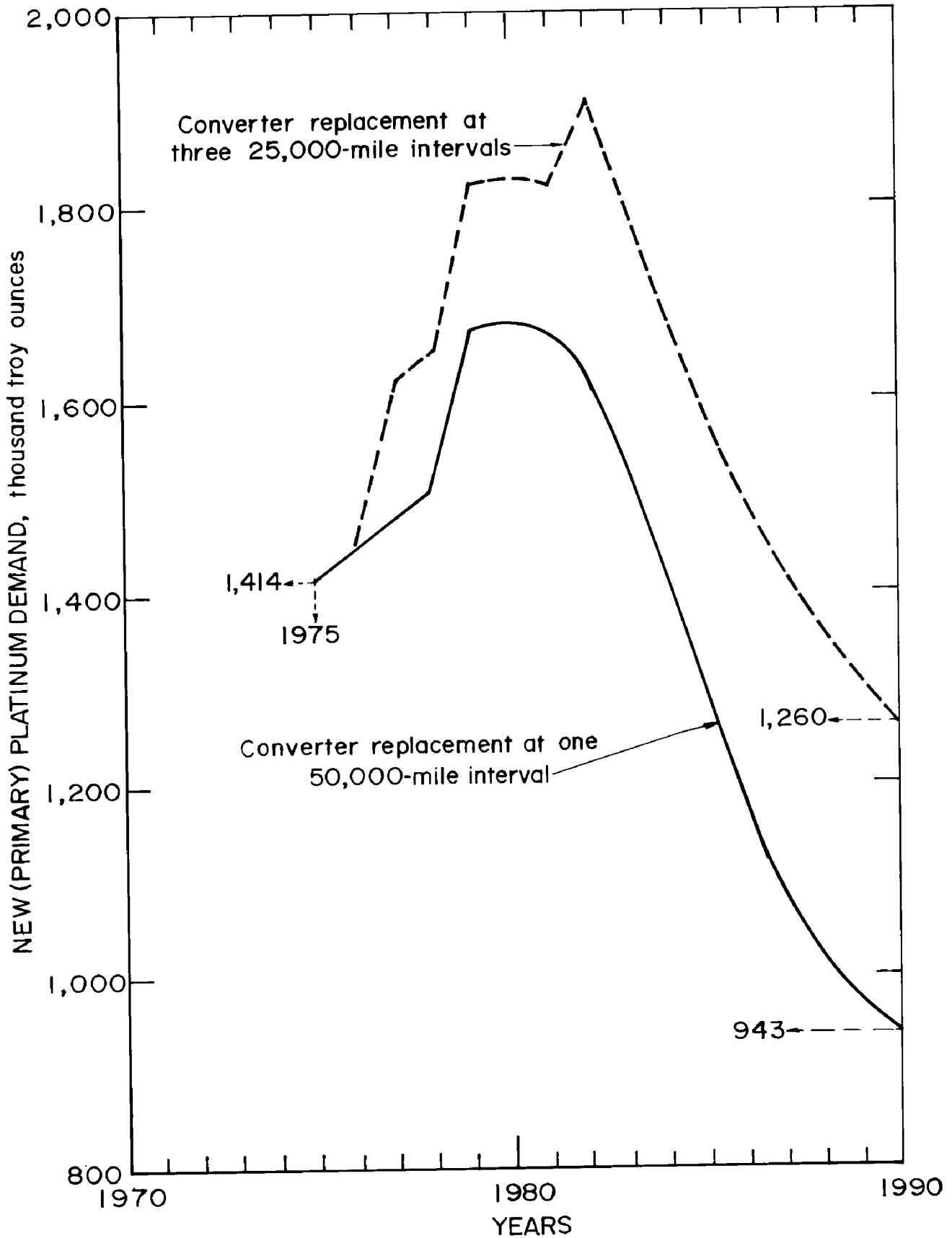


FIGURE C-1. - Comparison of New Platinum Demand for a Catalytic Converter Longevity of 50,000 Miles Versus 25,000 Miles (Light- and Heavy-Duty Vehicles).

APPENDIX D. -- SUPPLY-DEMAND RELATIONSHIPS FOR PLATINUM

TABLE D-1. - Platinum supply-demand relationships, 1961-70,¹ thousand troy ounces

	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
World production:										
United States.....	17	14	20	14	10	18	7	7	11	7
Rest of world.....	614	683	789	1,062	1,257	1,285	1,346	1,442	1,472	1,956
Total.....	631	697	809	1,076	1,267	1,303	1,353	1,449	1,483	1,963
Components of U.S. supply:										
Refinery production.....	17	14	21	16	11	18	7	5	9	8
Imports of metal.....	279	240	442	323	375	360	466	492	526	564
Secondary refined.....	49	68	51	63	51	47	121	111	122	118
Reported industry stock, Jan. 1.....	227	223	223	279	330	368	400	279	284	326
Government releases.....	0	0	0	0	0	316	0	0	0	0
Total U.S. supply.....	572	545	737	681	767	1,109	994	887	941	1,016
Distribution of U.S. supply:										
Reported industry stock, Dec. 31.....	223	223	279	330	368	400	279	284	326	270
Government acquisitions.....	50	0	0	0	0	0	0	0	0	0
Exports.....	41	50	51	125	73	102	162	223	224	271
Industrial demand.....	265	298	405	399	373	596	518	496	531	475
Apparent surplus (+), deficit (-).....	-7	-26	2	-173	-47	11	35	-116	-140	-
U.S. demand pattern:										
Industrial chemicals.....	72	88	156	137	132	191	159	158	175	148
Petroleum refining.....	20	7	22	57	43	107	130	77	74	110
Ceramics and glass.....	35	45	58	50	20	91	45	48	63	47
Electrical equipment.....	87	101	110	103	107	117	100	117	113	103
Dental equipment and supplies.....	17	23	19	19	26	24	25	25	22	18
Jewelry and arts.....	30	28	33	30	35	41	33	40	36	29
Other.....	4	6	7	3	10	25	26	31	48	20
U.S. primary demand (total demand minus secondary refined).....	216	230	354	336	322	549	397	385	409	357

¹Revised.

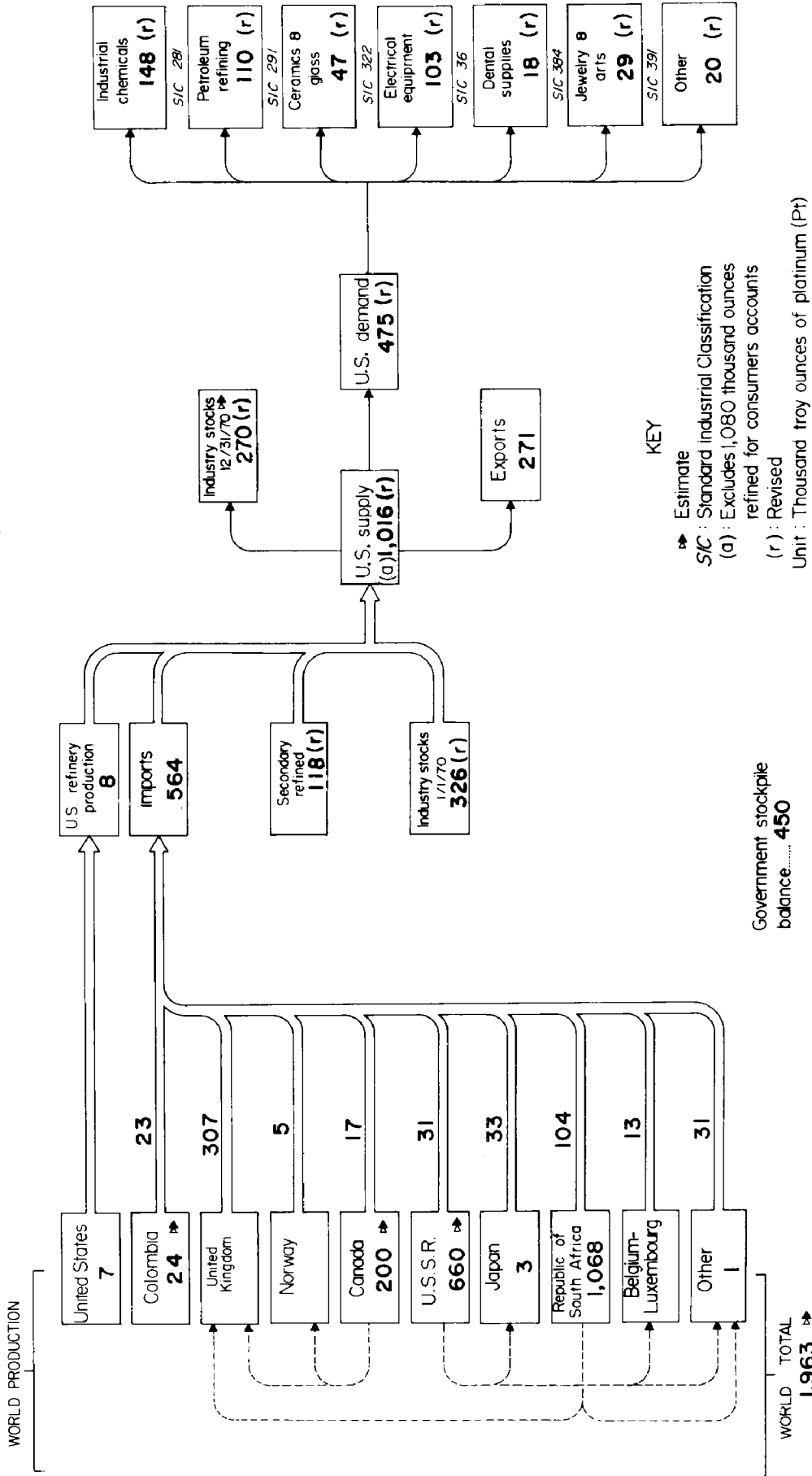


FIGURE D-1. - Supply-Demand Relationships for Platinum, 1970.