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COST AND PERFORMANCE OF AUTOMOTIVE EMISSION CONTROL TECHNOLOGIES

by

Glen R. Cass

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About the Author

Glen Cass is currently a graduate student in Environmental Engineering Science at the California Institute of Technology. He holds degrees in mechanical engineering from the University of Southern California and from Stanford University. Before returning to school, the author was employed as an engineer by the U.S. Public Health Service and the Environmental Protection Agency, where he worked as an advisor to state and local air pollution control agencies.

Introduction

The problem at hand is to investigate the near-term commercial feasibility of a wide range of automotive emission control technologies. The central issues can best be explained in terms of the emission control characteristics of each technology and their costs.

Governmentally established emission control standards may be viewed as constraints on the use of a given vehicle and engine design. Either the technology meets the standard in use or it will not be sold.

Emission control technologies that show promise of near-term manufacturability will be identified. Then, without presuming what future emission standards will be, the emission characteristics of example vehicle-engine combinations will be listed. Technologies that are acceptable, given a specified emission standard, can then be identified by a process of elimination.

The approach to identifying the relevant costs associated with a given technology is not as clear cut. One would like to think that the most basic question governing the adoption of a given feasible technology is, "Will it be purchased by the public?" The second part of this paper will discuss the impact of pollution control technology on the economic decisions facing the new car customer.

The cost considered by the rational new car consumer involves more than first cost. Other important factors include maintenance, operating expenses, resale value, and financing charges. Since resale value and financing charges are highly time dependent, it is possible that a new car purchaser's decision on which technology to buy may depend on how long he plans to keep the car. A cost annualization procedure will thus be developed which considers these factors.

Emission Control Technologies

Recent studies by the National Academy of Sciences Committee on Motor Vehicle Emissions[1] have identified low-emission engine designs that could be developed to the point of mass production within the next few years. These engines include:

1. The conventional spark-ignition piston engine with engine modifications and a variety of add-on control devices. Principal feasible control devices include exhaust-gas recirculation (EGR) and catalytic converters.
2. The diesel engine, potentially equipped with EGR.
3. The Wankel engine, potentially equipped with EGR and thermal reactors.
4. The three-valve stratified charge engine, possibly equipped with EGR.

A fuel-injected spark-ignition piston engine, with electronic sensors and a two-way catalyst, was also studied extensively by the NAS subcommittee, but will not be covered here because of a lack of emission control durability data for this type of vehicle.

Other low-emission engine concepts abound, such as the Rankine cycle (steam) engine and the Stirling cycle (hot air) engine. But extensive further development of these designs will be needed before mass production can be attempted, according to the NAS study. The following discussion will thus be limited to the technologies listed above which show potential for near-term manufacturability.

The effect of a series of emission control devices, when applied to an engine, is not usually additive or multiplicative. Actual emission test data obtained from test vehicles are required in order to compare the effectiveness of a given mix of control technologies. Furthermore, engine emissions cannot be considered independently of the vehicle to which the engine is fitted. Fair comparison thus requires that the discussion be limited as much as possible to real emission data from actual tests of different control technologies applied to vehicles of equivalent size.

Review of available emission test data for the technologies identified as approaching near-term manufacturability shows greatest data overlap between technologies for the case of the Pinto-sized 2,750-pound test weight vehicle. In other words, emission data for larger standard American-sized vehicles equipped with unusual engines are scarce. The following comparisons of emission control technologies will thus be illustrated by reference to small cars of equivalent size. Comparison of larger vehicles equipped with similar technologies can be attempted by the same procedure, given sufficient data.

Each example vehicle-engine combination shown in Tables I through IV is identified by the model year in which it was typically marketed (if appropriate), and by a brief listing of the principal control techniques involved in achieving its emission test results. Fuel economy and emissions data reported were obtained using the Environmental Protection Agency CVS test procedures,[2] and reflect vehicle certification-type test results, including compensation for control system deterioration over 50,000 miles of driving, unless otherwise indicated. Environmental Protection Agency fuel economy data are representative of urban driving conditions, and may tend to overestimate actual average fuel consumption. EPA fuel economy figures were chosen because they match the conditions under which the emission data were collected.

These example vehicles are each tagged with a mass production sticker price and annual engine-emission control system maintenance cost developed in accordance with the procedure outlined in a report by a subcommittee of the NAS's Committee on Motor Vehicle Emissions.[3] A word of caution concerning these price figures is in order.

Ideally, one would like to be able to compare vehicle prices using actual market data. Unfortunately, that is impossible for the case at hand. Several vehicle-engine combinations of interest have yet to reach mass production, and thus have no price history. Furthermore, most of the cars of this vehicle weight have traditionally been produced in foreign countries, and their true cost stated in U.S. dollars is obscured by a complex tangle of currency devaluations, excise tax changes, and relative rates of international inflation.

TABLE I

CONVENTIONAL CARBURETED PISTON ENGINE SUBCOMPACT CAR

MODEL YEAR	PRINCIPAL EXHAUST EMISSION CONTROLS	CONSTRUCTED STICKER PRICE (1972 DOLLARS)[l]	FUEL ECONOMY (MPG)	ROUTINE ANNUAL ENGINE & EMISSION SYSTEM MAINTENANCE COST ($)	EXAMPLE EXHAUST EMISSION (GRAMS/MILE)[j]		
					HC	CO	NO_x
1970	Internal Engine Modifications	1960[a]	19[b]	36[a]	2.7	22.5[k]	
1973[c]	Engine Modifications EGR Air Pump	2037[d]	18[b]	(49)[d]	2.14	23.6	2.10[g]
Future[i]	Engine Modifications EGR Air Pump Oxidation Catalyst	2086[d]	(17)[e]	(62)[d]	[0.42 to 0.50] ≈0.46	[2.6 to 3.8] ≈3.2	[2.0[f] to 1.0] ≈1.5
Future[i]	Engine Modifications EGR Oxidation Catalyst Air Pump Reduction Catalyst	2142[a]	(17)[e]	72[a]	Unless durability[h] of NO_x catalysts improves, emission performance at 25,000 miles will be about the same as without NO_x catalyst.		

NOTES:
- a Reference 3, Supplemental Report, Pages 22-23.
- b Reference 4, assuming 1970 vehicle does not suffer fuel penalty vs. pre-control car.
- c Reference 1, page 91.
- d Constructed by unbundling cost of unused control devices from "1976 Configuration" in Reference 3's data base.
- e Assume small economy drop vs. 1973 due to additional exhaust system constriction.
- f Reference 1, page 24, range of worst average results for GM & Nissan 1975 development fleets.
- g Reference 5, average of results of all 1973 emission certification tests of 2750# vehicle class.
- h Reference 1, pages 39-41.
- i Assume catalyst change obtained at 25,000 mile intervals; 2 catalyst changes in 5 years.
- j 2750# vehicle test weight.
- k Reference 8, page 7, average of 2750# vehicle emission tests.
- l Excludes costs of meeting Federal safety requirements imposed since 1970 baseline model year.

TABLE II

DIESEL ENGINE SUBCOMPACT VEHICLE

MODEL YEAR	PRINCIPAL EXHAUST EMISSION CONTROLS	CONSTRUCTED STICKER PRICE (1972 DOLLARS)[i]	DIESEL FUEL ECONOMY (MPG)	ROUTINE ANNUAL ENGINE & EMISSION SYSTEM MAINTENANCE COST ($)	EXAMPLE EXHAUST EMISSION (GRAMS/MILE)[h]		
					HC	CO	NO_x
1973	None (Bare Engine)	2225[a]	24[b]	21[a]	0.40	1.16	1.34[c]
Future	EGR	2264[d]	24[e]	26[f]	(0.4)	(1.16)	(0.8)[g]

NOTES:
- [a] Constructed by removing cost of EGR and supercharger from "1976 Configuration" in Reference 3's data base.
- [b] Reference 4, diesel-Opel (worst mileage).
- [c] Reference 6, page 68, diesel-Opel.
- [d] Constructed by removing cost of supercharger from "1976 Configuration" in Reference 3's data base.
- [e] Reference 6, page 68, EGR does not affect diesel fuel economy.
- [f] Reference 3, Supplemental Report, Table 5.
- [g] Estimated from comments in Reference 1, page 104.
- [h] Slightly above 2750# test weight. Still basically the same vehicle, but diesels are heavier for the same physical vehicle dimensions.
- [i] Excludes cost of meeting Federal safety standards imposed since 1970 baseline model year.

TABLE III

WANKEL ENGINE SUBCOMPACT VEHICLE

MODEL YEAR	PRINCIPAL EXHAUST EMISSIONS CONTROLS	CONSTRUCTED STICKER PRICE (1972 DOLLARS)[g]	FUEL ECONOMY (MPG)	ROUTINE ANNUAL ENGINE & EMISSION SYSTEM MAINTENANCE COST ($)	EXAMPLE EXHAUST EMISSION (GRAMS/MILE)[f]		
					HC	CO	NO_x
1973	Air Pump Thermal Reactor	2101[a]	12.35[b]	51.0[a]	1.95	17	1.05[b]
Future	Thermal Reactor Air Pump	2101[a]	11.55[c]	51.0[a]	0.36	2.6	0.87[d]
Future	Thermal Reactor Air Pump EGR	2139[a]	10.87[c]	56.2[a]	0.35	2.2	0.49[e]

NOTES:
[a] Constructed by unbundling cost of unused control devices from "1976 Configurations" in Reference 3's data base. Since test results are for a small 2-rotor engine, cost of small 2-rotor engine used here instead of 1-rotor engine assumed by Reference 3. Body remains same as Reference 3's subcompact. Actual list price of 1973 Mazda RX-2 is considerably higher than price given here. Possible reasons include current novelty of the technology.
[b] Reference 5, Mazda RX-2.
[c] Reference 1, page 53, fuel penalty for Toyo Kogo vehicles applied to Reference 5 Mazda RX-2 fuel consumption.
[d] Reference 1, page 53, high mileage.
[e] Reference 1, page 53, low mileage, but little deterioration expected.
[f] 2750# vehicle test weight.
[g] Excludes cost of meeting Federal safety standards imposed since 1970 baseline model year.

TABLE IV

CARBURETED STRATIFIED CHARGE SUBCOMPACT VEHICLE

MODEL YEAR	PRINCIPAL EXHAUST EMISSION CONTROLS	CONSTRUCTED STICKER PRICE (1972 DOLLARS)[c]	FUEL ECONOMY (MPG)	ROUTINE ANNUAL ENGINE & EMISSION SYSTEM MAINTENANCE COST ($)	EXAMPLE EXHAUST EMISSION (GRAMS/MILE)		
					HC	CO	NO_x
Future	None (Bare Engine)	2026[a]	19.4[b]	41[a]	0.28	3.08	1.56[b]

NOTES: [a] Constructed by removing cost of EGR and emission control system heat exchanger from "1976 Configuration" in Reference 3's data base.
[b] Reference 7, Table II, 3000# test weight. Emission data for 2750# test weight unavailable.
[c] Excludes cost of meeting Federal safety standards imposed since 1970 baseline model year.

Sticker prices presented in Tables I through IV were estimated by pricing individual engine and vehicle subassemblies, and then adding labor and subassembly costs to obtain a factory manufacturing cost in constant 1972 dollars for the whole car. Manufacturing cost estimates were then marked up using a standard formula. An attempt was made to allow for the capital cost of retooling factories to reproduce new engine and emission control system components, if required. Tooling costs were first estimated for a complete production line designed to manufacture a single component. Production tooling costs for all components required by a given emission control system were totaled, and then divided by anticipated production volume using that tooling to arrive at capital investment requirements per vehicle produced. Thus capital investment costs per car are very tentative, since they are highly dependent on production volume. This procedure is detailed in Reference 3 and briefly illustrated in Figures 1 and 2.

While the method for computing these sticker prices has a measure of internal consistency, the values arrived at will be below the current market price for a similar new subcompact car. The reasons are fairly straightforward. In order to compare various emission control system proposals, a baseline model had to be chosen. The 1970 conventional carbureted piston-engine subcompact car was chosen as this reference model. The resulting baseline vehicle's constructed sticker price of $1,960 compares closely with the $1,970 POE list price of a 1970 model Toyota Corona. At that time, even a larger Ford Maverick sedan listed for under $2,000.

FIGURE 1

SUBCOMPACT CAR WITH CONVENTIONAL ENGINE EQUIPPED WITH DUAL-CATALYST EMISSION CONTROL SYSTEM

Component:	Cost (1972 Dollars)	
Body Shell		
Raw Materials	$ 240	
Stamping Labor	125	
Body Subcomponents (seats, wheels, etc.)		
Parts and Labor	417	
Total Body Cost		$ 782
Engine Components other than Emission Controls (Parts and Labor)	$ 110	
Dual-Catalyst System Emission Control Components (Parts and Labor)	86	
Total Engine and Emission Control Costs		196
Total Assembly Labor Cost, Body and Engine		343
Total Manufacturing Cost of Car		$1,321
Basic Sticker Price using Markup of about 1.6 Times Manufacturing Cost	$2,120	
Capital Investment needed to Tool up for Manufacture of Emission Controls	22	
Constructed Sticker Price		$2,142

(from p. 36 of Reference 3.)

FIGURE 2

DUAL-CATALYST SYSTEM EMISSION
CONTROLS FOR SUBCOMPACT CAR

COMPONENT COSTS TO MANUFACTURER*

Component:	Cost (1972 Dollars)
PCV Valve	$ 1
Evaporative Emission Control System	5
Special Air Cleaner	2
Exhaust-Gas Recirculation	17
Air Pump	14
Catalytic Converter, Pellet	26
Catalytic Converter, Monolith	21
Total Component Cost to Manufacturer	$86

NOTE: Cost of internal engine modifications, such as a redesigned carburetor are included within the basic engine cost structure and not among the emission control system components listed above.

*Cost data supplied by Mr. LeRoy Lindgren, consultant to NAS's Committee on Motor Vehicle Emissions.

So far so good. But in more recent model years, rapid inflation and expensive Federally mandated safety equipment have added to emission control costs in pushing subcompact car prices well above the levels of four years ago. However, in order to compare emission control systems on a fair basis, changes in vehicle prices between model years due to factors other than emission control system costs had to be ruled out. Sticker prices were computed in constant 1972 dollars, and safety equipment added since the 1970 baseline model year was excluded from the price computation. Capital costs incurred by automobile companies in shifting from large-car to small-car production to meet changing market demands would also be excluded. The result is a series of constructed base prices that represents the cost differential due to various engine and emission system packages, but which fall substantially below current market prices. A cost annualization procedure based on cost differences between vehicles will take this difficulty into account.

Annualized Cost Comparison

First, assume that the vehicles described in Tables I through IV are perceived by the consumer as alike in every respect except for the costs associated with the choice of emission control technologies. This means that the consumer derives no special satisfaction out of owning a Wankel engine *per se*, and further that the individual consumer attaches no extra value to a car that is cleaner than legal emission standards would otherwise allow.

Under this assumption, the rational consumer would be expected to purchase the engine-vehicle combination which presented him with the lowest annualized cost of ownership.

Consider a likely stream of payments faced by the vehicle owner:

Initial vehicle purchase costs:

Case 1: A. Sticker price, less discount (if any).

B. Sales tax.

C. License and vehicle registration.

Or, Case 2: Down payment on loan that finances vehicle price, plus tax and license.

Periodic operating expenses:

1. Car payments, if any.
2. Fuel expenses.
3. Lubrication and oil costs.
4. Routine maintenance of engine and emission control system.
5. Maintenance of vehicle other than engine and emission control system.
6. Insurance.
7. Registration renewal.

Revenue from vehicle resale:

1. Resale value at that time.
2. Less loan balance, if any.

Possible permutations and combinations of the expenses shown above using varying fuel prices, finance charges, resale dates, etc., are nearly endless.

For that reason, a few simplified examples will be developed to show how these expenses for each of the vehicle types under study may be converted into an approximate annualized cost of emission control above that of the baseline 1970 subcompact car. The purpose of these examples is to illustrate the impact of assumptions required by a cost annualization procedure, not to arrive at cost of ownership figures that can be indiscriminately applied to the "average" car owner. A baseline example will be worked out in detail, and then the results of that analysis will be perturbed by doubling the assumed fuel price, and by advancing the date of vehicle resale.

Example 1: Assume the following circumstances:

The consumer purchases his car on credit. Late 1973 Bank of America loan terms will be used:

Loan period: 36 months

Initial amount of loan: 70 percent of total purchase cost

Interest rate: 11 percent -- simple annual interest

Discounts from list price will not be considered. Neglecting dealer discounts below list price is a fair assumption for the small, relatively inexpensive vehicles under study, especially during periods of high demand for small cars.

Fuel price will be assumed at 45 cents per gallon.

Mileage will be accumulated at 12,000 miles per year.

For simplicity, and with only minor distortion, yearly fuel cost will be represented as a year-end, lump-sum payment.

Periodic engine and emission control system maintenance will be represented as a series of year-end, lump-sum payments at the rates shown in Tables I through IV.

Annual cost of oil changes, maintenance of vehicle other than engine, insurance, and registration renewal will be assumed the same for each engine-vehicle combination under study, and thus will not contribute to additional cost due to emission control over baseline model levels.

Some assumption must be made about intended vehicle resale. After all, the vehicle population on the highways is determined by the collective actions of new car consumers. Amortizing a car purchase over the vehicle's entire useful life would not be expected to reflect the circumstances faced by the typical new car purchaser. If it did, the current large market in late-model used cars wouldn't exist. An attempt to predict future used car prices would surely be subject to errors which are large compared to the marginal cost of some of the emission control systems under study. But future used car prices aren't the real issue. The relevant consideration affecting which vehicle will actually be bought is the new car buyer's expectation at the time of purchase of what future vehicle resale value will be.

For the sake of this example, assume the consumer plans to resell his car at the end of the three-year loan period. Further, assume that the consumer at the time of purchase views expected resale price three years hence in terms of the then current nominal dollar resale price of a three-year-old car of the same model. December 1973 wholesale blue book value of a three-year-old Toyota Corona is $1,225. Assume that the new car purchaser bases his expected resale value at end of three years on this $1,225 figure, irrespective of the emission control technology selected for his new car.

Finally, some assumption must be made about the vehicle purchaser's opportunity cost for capital; i.e., the rate of return that he could get on his money if it were invested rather than tied up in an automobile purchase. For this example, we will assume the consumer could otherwise invest his funds at 7 percent true annual interest.

Figure 3 illustrates the way in which data from Table I and the above assumptions are used to estimate an annualized cost differential between ownership of the baseline 1970 conventional subcompact car and its dual-catalyst equipped* counterpart. Table V presents the result of this sort of calculation applied to each of the alternative car-engine combinations listed in Tables I through IV for the same set of assumptions just outlined.

Results of two important variations in the previous set of assumptions about vehicle costs are also shown in Table V. The "high fuel cost" example shows the effect of doubling the cost of fuel to 90 cents per gallon, while leaving all other assumptions in Example 1 the same. The

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*Identical 2,750-pound test-weight car equipped with engine modifications, EGR, air pump, oxidation catalyst, and reduction catalyst.

FIGURE 3

EXAMPLE: ADDITIONAL COST OF OWNERSHIP OF SUBCOMPACT CAR WITH DUAL-CATALYST EMISSION CONTROL SYSTEM VERSUS 1970 BASELINE VEHICLE UNDER ONE POSSIBLE SET OF ASSUMPTIONS

1970 Conventional 2750# Test-Weight Vehicle		Dual-Catalyst Equipped 2750# Test-Weight Vehicle	

A. Purchase Price:

Sticker Price:	$1,960	Sticker Price:	$2,142
5% Sales Tax	97	5% Sales Tax	107
License & Registration	47	License & Registration	47
Total Purchase Price	$2,104	Total Purchase Price	$2,296

B. Finance Terms: 36-month period, 11% true annual interest, loan value = 70% of total purchase price (Bank of America):

Loan Value	$1,473	Loan Value	$1,607
Down Payment	631	Down Payment	689
Equivalent Annual Car Payment	598	Equivalent Annual Car Payment	653

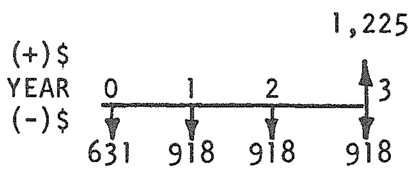
C. Yearly Operating Cost: 12,000 miles, 45¢/gal. fuel price:

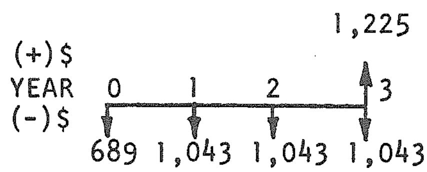
Gasoline (@ 19 MPG)	$ 284	Gasoline (@ 17 MPG)	$ 318
Engine & Emission System Maint.	36	Engine & Emission System Maint.	72
Operation Subtotal	$ 320	Operation Subtotal	$ 390

NOTE: Yearly insurance, oil, license, and maintenance other than engine & emission system assumed identical and thus do not contribute to comparison of cost difference between vehicles.

D. Resale value at end of 3 years: To be assumed the same for all vehicles in this study, at $1,225.

E. Cash flow (excluding: insurance, oil, maintenance other than engine & emission system, license renewal)





F. Annualized Cost: Above expenses discounted to year zero at 7% interest (consumer's opportunity cost for capital), then annualized at 7% into 3 equivalent, year-end payments.

1970 Baseline Vehicle } $777 Dual Catalyst Equipped Vehicle } $924

G. Additional Annual Cost of Ownership of Dual-Catalyst Configuration over annual cost of baseline 1970 Model Year Vehicle:

$147 per year

TABLE V

SUBCOMPACT AUTO ADDITIONAL ANNUALIZED USER COST OF VARIOUS EXHAUST EMISSION CONTROL TECHNOLOGIES ABOVE 1970 CONVENTIONAL VEHICLE

ENGINE TYPE	PRINCIPAL EXHAUST EMISSION CONTROLS	ADDITIONAL ANNUALIZED COST (1972$) EXAMPLE 1*	YEAR-END MODEL CHANGE EXAMPLE**	HIGHER FUEL COST EXAMPLE***
Conventional	1970 Minor Engine Modifications	Baseline Example 1	Baseline with 1-year resale	Baseline with 90¢/gal. fuel
Conventional	1973 Engine Modifications, EGR, Air Pump	62	119	78
Conventional	Engine Modifications, EGR, Air Pump Oxidation Catalyst	113	206	147
Conventional	Engine Modifications, EGR, Air Pump, Oxidation Catalyst, Reduction Catalyst	147	281	181
Diesel	Bare Engine	38	234	-21
Diesel	EGR	59	283	0
Wankel	1973 Version w/Air Pump & Thermal Reactor	228	331	381
Wankel	Further Emission Reduction w/Thermal Reactor & Air Pump	258	361	441
Wankel	Thermal Reactor Air Pump, EGR	308	440	520
Carbureted Stratified Charge	Bare Engine	27	136	21

*Example 1 assumes: a) 36-month loan covering 70% of total purchase price, 11% true annual interest.
b) Sticker prices & maintenance costs from Tables I through IV.
c) 45¢/gal. fuel cost.
d) 12,000 miles per year driven.
e) Consumer's investment opportunity interest rate at 7%.
f) Resale of vehicle at end of 3 years for $1,225.

**Same as Example 1 except vehicle resold at end of one year for $1,600.

***Same as Example 1 except assume 90¢/gal. fuel cost.

FIGURE 4

SUBCOMPACT VEHICLE
HYDROCARBON EMISSION VS. ADDITIONAL
ANNUALIZED COST OF OWNERSHIP
(FROM EXAMPLE 1, TABLE V)

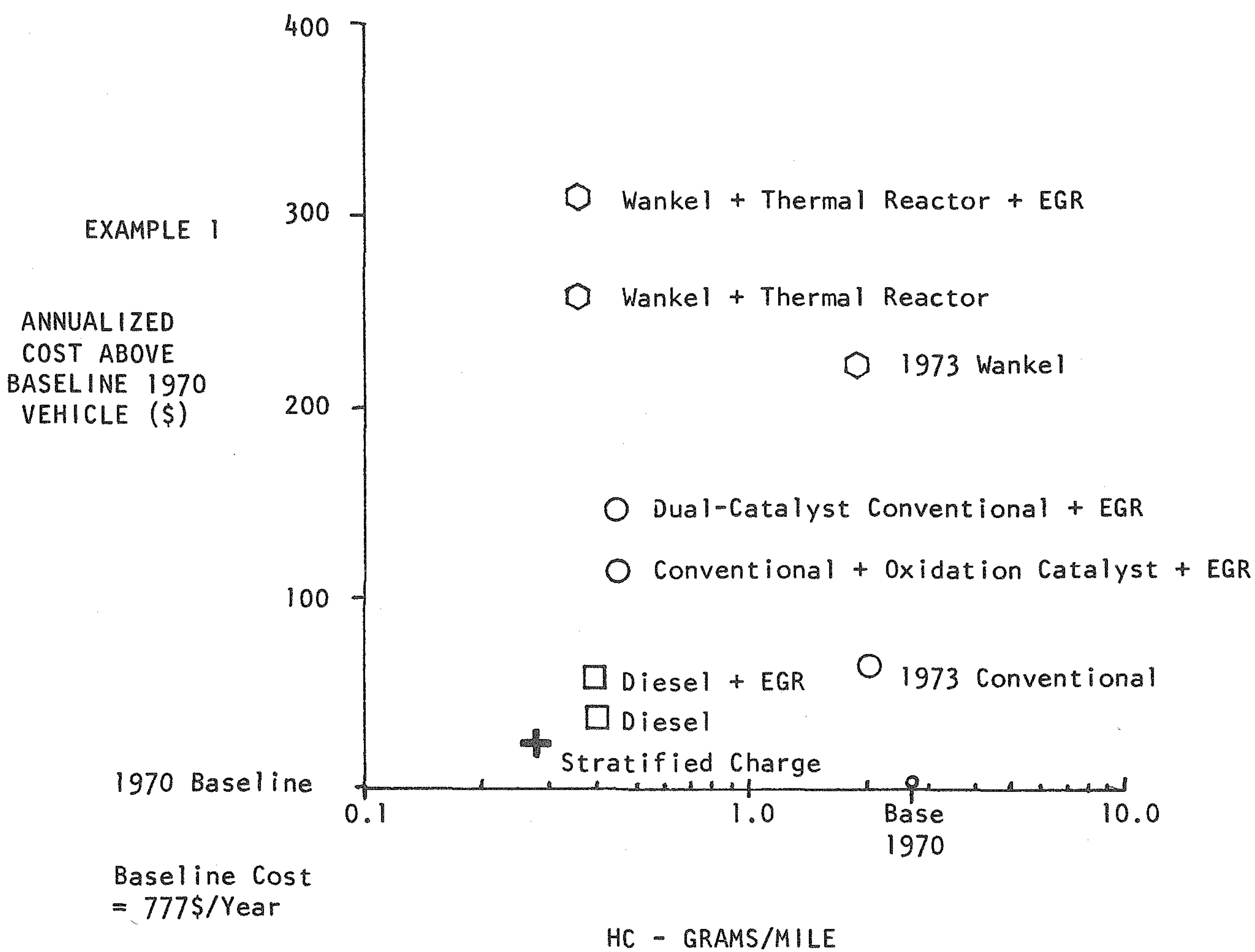


FIGURE 5

SUBCOMPACT VEHICLE
CARBON MONOXIDE EMISSIONS VS.
ADDITIONAL ANNUALIZED COST OF OWNERSHIP
(FROM EXAMPLE 1, TABLE V)

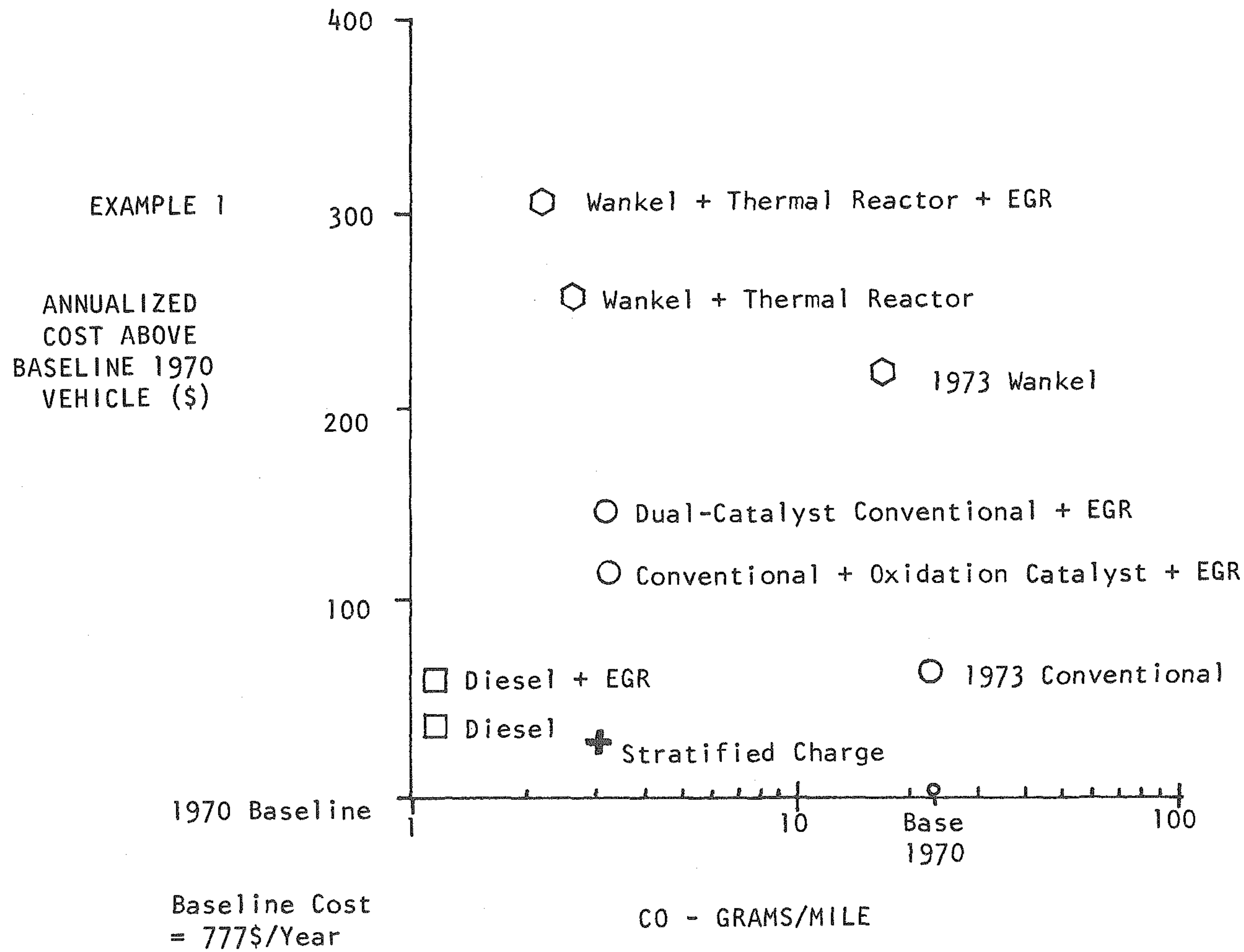


FIGURE 6

SUBCOMPACT VEHICLE
NITROGEN OXIDES EMISSIONS VS.
ADDITIONAL ANNUALIZED COST OF OWNERSHIP
(FROM EXAMPLE 1, TABLE V)

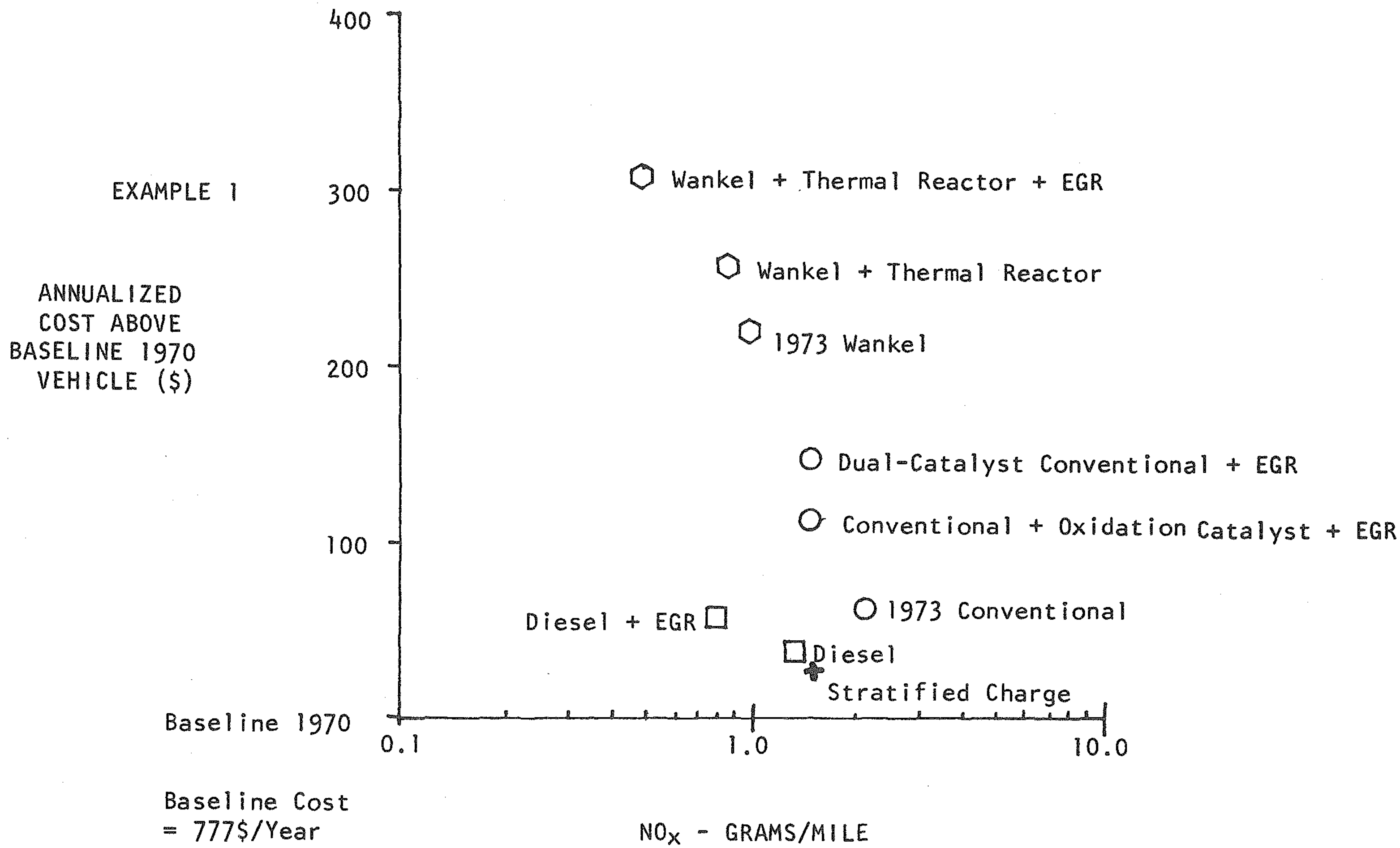


FIGURE 7

SUBCOMPACT VEHICLE
HYDROCARBON EMISSIONS VS. ADDITIONAL
ANNUALIZED COST OF OWNERSHIP
(90¢/GALLON FUEL COST, FROM TABLE V)

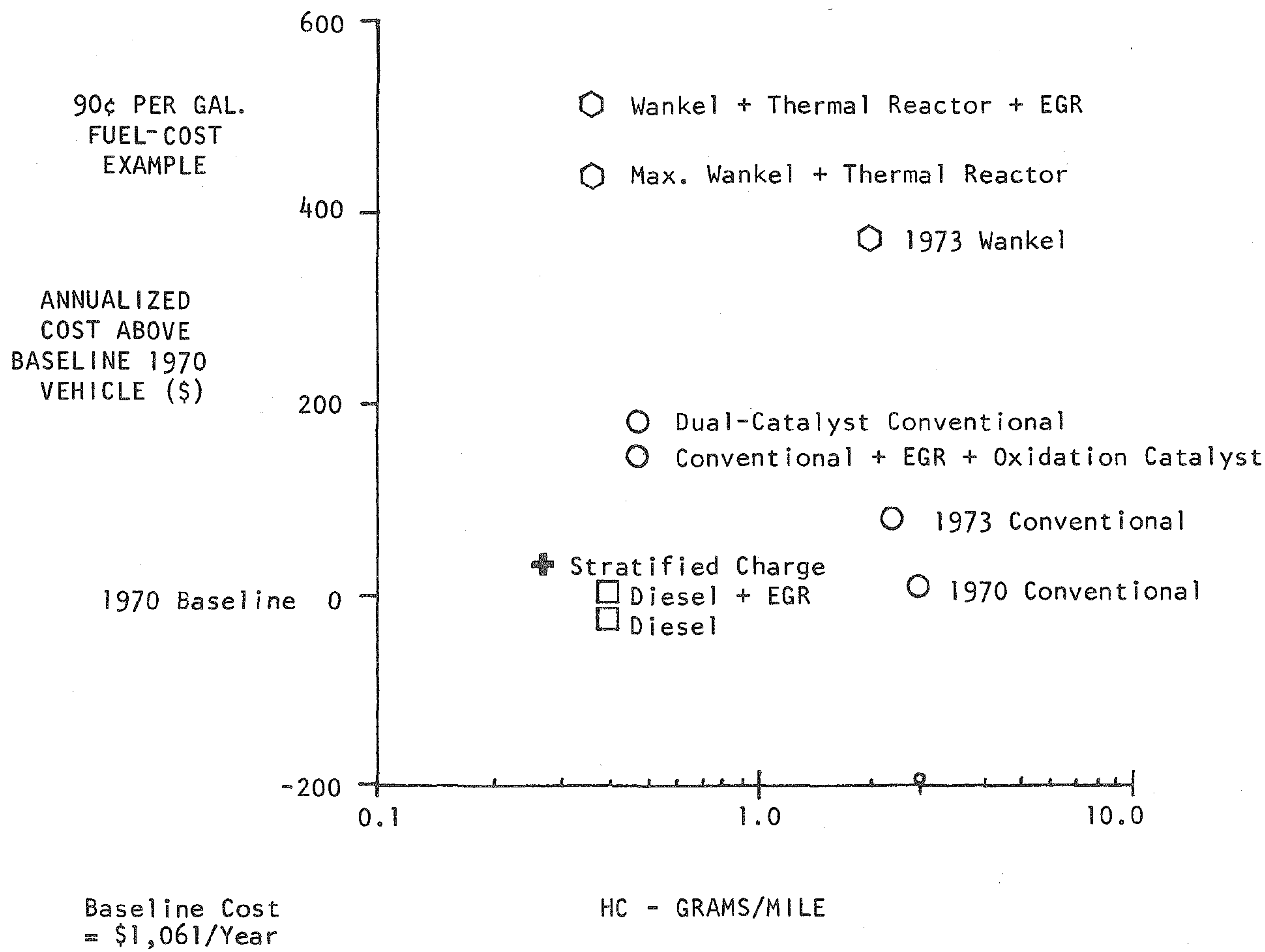


FIGURE 8

SUBCOMPACT VEHICLE
CARBON MONOXIDE EMISSIONS VS.
ADDITIONAL ANNUALIZED COST OF OWNERSHIP
(90¢/GALLON FUEL COST, FROM TABLE V)

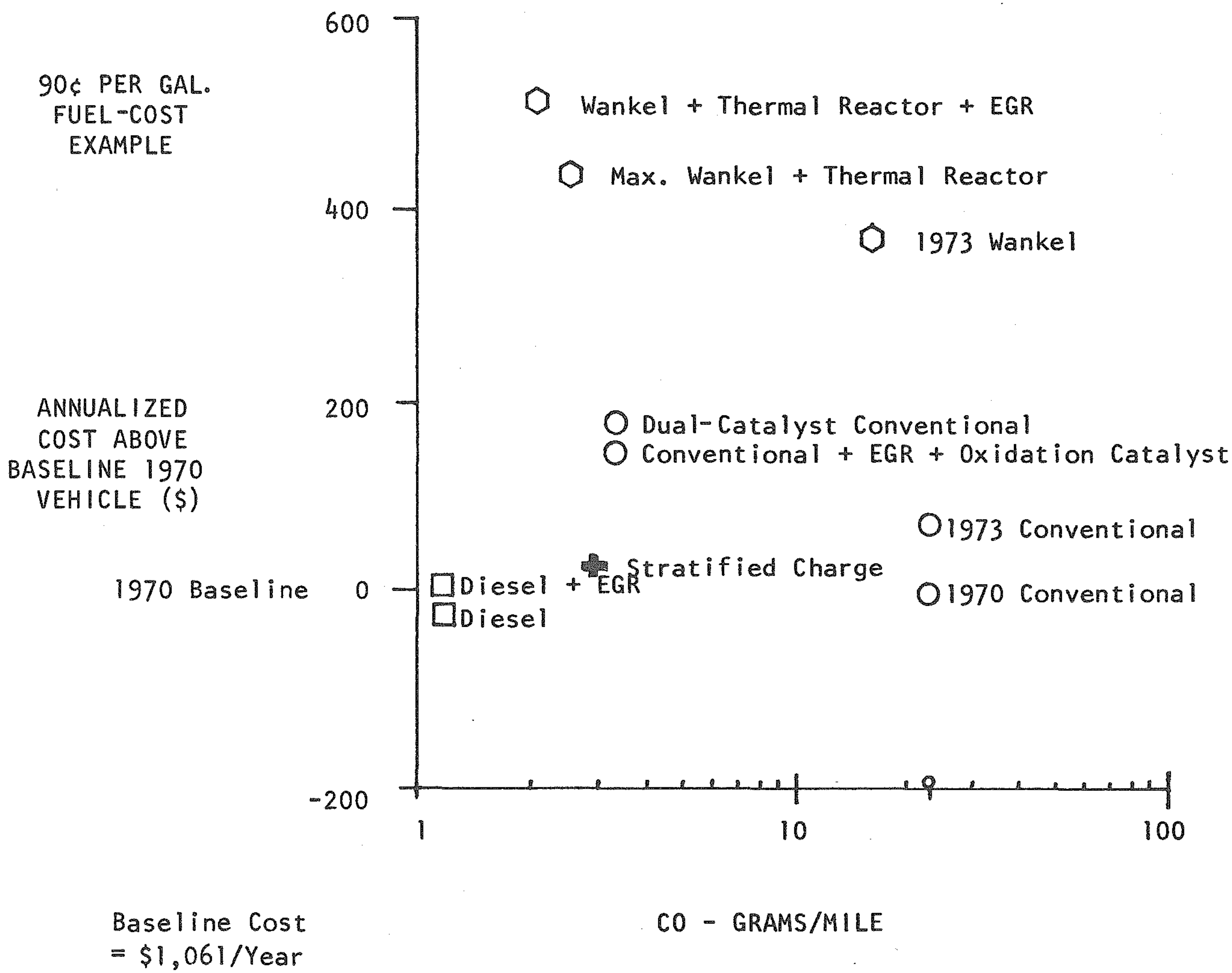
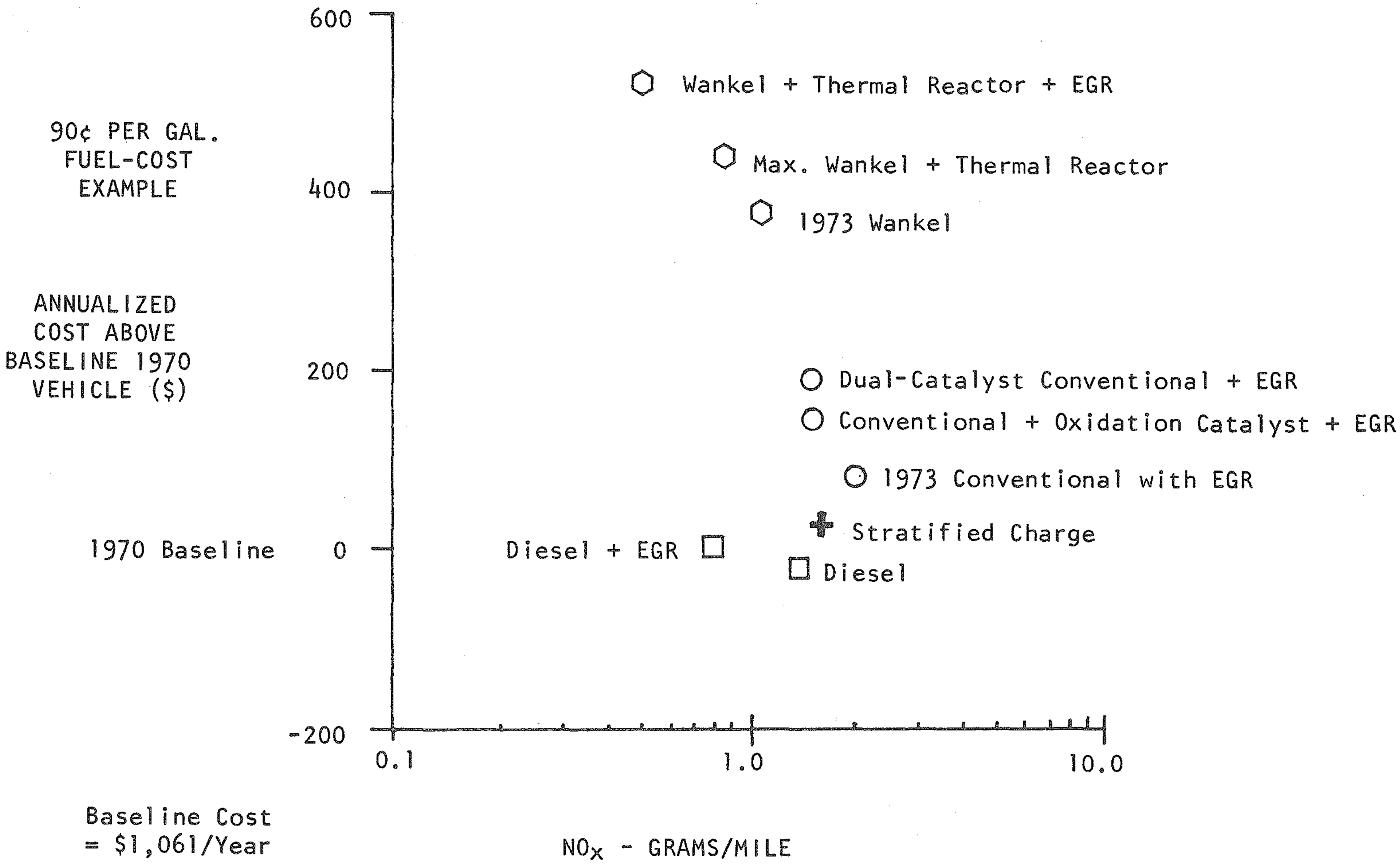


FIGURE 9

SUBCOMPACT VEHICLE
NITROGEN OXIDES EMISSIONS VS.
ADDITIONAL ANNUALIZED COST OF OWNERSHIP
(90¢/GALLON FUEL COST, TABLE V)



"annual model change" example shows the effect of vehicle resale at the end of one year rather than three years of ownership, while leaving all other assumptions in Example 1 the same. Resale value at the end of the first year is assumed to be $1,600 for each vehicle under study. This figure is based on a 24 percent first-year depreciation rate typical of subcompact cars shown in the current wholesale Kelly Blue Book, applied to a $2,100 sticker price in the middle of the new car cost range under consideration. Current used car resale value data cannot be used to arrive at this estimate directly, because, as previously explained, new subcompact car prices have inflated well above the $2,100 level since our baseline model year.

Discussion

A glance at Tables I through IV indicates that the best proven emission control performance of the catalyst-equipped conventional engine can be equalled or bettered by at least one version of each of the alternative engine designs. Thus, any exhaust emission standard written so as not to exclude the conventional engine with dual-catalyst emission controls will also be attainable by suitable diesel, Wankel, or stratified-charge engines. A variety of technologies will thus probably be legally feasible in future years.

While Table V and the subsequent graphs may appear to pinpoint the lowest cost alternative engine technology, given a specific emission standard, the results are actually inconclusive. The plain fact of the matter is that given current prices, the collected margin of error involved in the assumptions made to determine annualized cost of ownership is probably larger than the differences in cost due to emission control technology between the closest competitive solutions. In most cases, the Wankel engine at its current state of commercial development seems substantially unattractive due to its very poor fuel economy. The remaining technologies probably could be marketed without the average consumer being able to distinguish his optimal choice clearly on the basis of cost alone, unless fuel prices climb sharply enough to place a higher premium on vehicle fuel economy.

Even if the uncertainties in analysis could be eliminated, there are very basic differences among consumer preferences that could lead some to prefer lower first cost over long-run operating economy. As Table V illustrates, the purchaser who plans vehicle resale at the end of one year is likely to see a different ordering of relative costs between emission control technologies than will the consumer who holds his car for a longer period of time. Individuals, of course, differ in the rate at which they accumulate mileage on their cars, which further differentiates consumers according to optimal level of first cost versus operating economy. These are but two of the market forces that argue for the commercial feasibility of more than one type of emission control technology when the basic cost differences between competing technologies are relatively small.

With new car consumers as a group uncertain to express a strong unified preference for one emission control technology over another on the basis of cost alone, the decision as to the mix of vehicles to be built may well pass from the control of the consumer. Most people would argue that it already has. Auto companies may find it easier to differentiate their products from their competitors' on the basis of advertising and body styles than to explain relative advantages and disadvantages of small differences in operating economy at the expense of higher first cost.

But while the economic consequences of one emission control technology over another are likely to escape the grasp of the new car consumer, the consequences to society as a whole are large and very real. The vehicle-engine combinations outlined in Tables I through IV differ dramatically in pollution potential and fuel consumption, even though the cost-conscious new car consumer may be indifferent between them on the basis of emissions alone. For example, emission standards set at about

HC gm/mi	CO gm/mi	NO_x gm/mi
0.41	3.4	1.5

could probably just barely be met by a conventional engine with oxidation catalyst and EGR. The Wankel engine with thermal reactor and bare stratified charge and diesel engines could also just meet these standards. But, in addition, each of these alternative engine designs appears to be substantially cleaner than the best proven performance of modified conventional engines with respect to at least one major pollutant. Emission standards set so as not to eliminate the conventional auto engine will provide no incentive to manufactures of other engine types to extract the best available pollution control performance from their vehicle power plants. Under these circumstances, superposition of an emission tax or credit system upon a set of exhaust emission standards might well be the best way to encourage the further exploration of a diversity of engine types by the auto manufacturers, while at the same time assuring an acceptable level of emission control and an incentive to do better than the standards demand, if possible. Minimum performance standards, or a taxation system, directed at improving fuel economy within the framework set by exhaust emission standards would similarly provide an incentive to vehicle manufacturers to develop a variety of alternative engine types. Deliberate promotion of sustained technological competition aimed at the joint reduction of auto exhaust emissions and consumer costs is likely to be the best means of assuring that superior automotive designs will be forthcoming in future years.

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