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THE IMPACT OF THE U.S. ENERGY SITUATION ON HIGH SPEED GROUND TRANSPORTATION

WILLARD E. FRAIZE

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MITRE

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ABSTRACT

U. S. energy supply issues for the next few decades are summarized with a view toward their impact on high speed ground transportation (HSGT) modes. As background, the energy characteristics of intercity passenger modes, including 300 mph tracked levitated vehicle (TLV) systems, are presented and discussed. In the short and mid terms (through 1985 or 1990), energy shortages are seen to impact HSGT modes mainly through increased operating (fuel) costs; and the need for greater capacity flexibility. In the long term, HSGT modes may have to adapt to non-fossil fuels. Research topics for addressing energy impacts on HSGT are suggested.

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INTRODUCTION

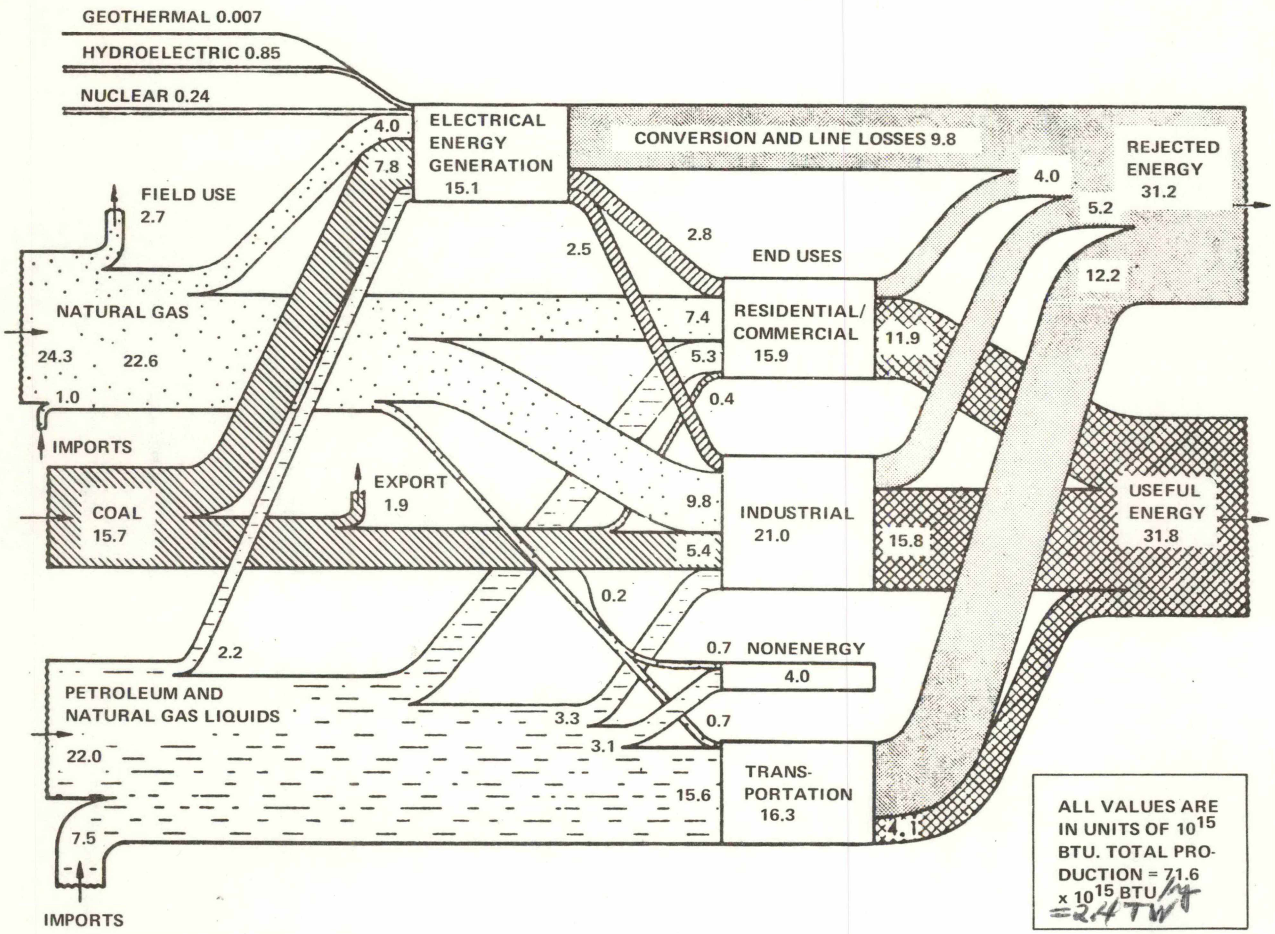
The purpose of this paper is to summarize the current U.S. energy supply situation and recent government projections for the future, to describe the energy characteristics of U.S. transportation modes, to discuss the potential impact of energy supply changes on high speed ground transportation (HSGT), and to delineate those R&D areas essential to accommodating HSGT to future energy situations. The intent is not to present a thorough analysis of U.S. transportation energy issues, but rather to provide a working paper that can stimulate discussion on the topic.

U.S. ENERGY SUPPLY

The overall energy flow pattern for the United States in 1970 is comprehensively illustrated in Figure 1, which shows energy sources, energy consuming sectors, and energy use efficiency (fraction of consumed energy which performs the intended function - moving a vehicle, heating a building, driving an electric generator, etc.). Nearly 25% of all U.S. energy is consumed by the transportation sector, more than 95% of it in the form of petroleum and natural gas liquids. An insignificant portion of transportation energy is supplied as electric power. Electric power is almost entirely dependent on fossil fuels as the energy source; less than 2% of the electric power generated in 1970 was dependent on nuclear energy, while 6% was hydropower.

Projections of energy supplies for the future involve many assumptions which make all projections necessarily tentative. Nevertheless, projections, such as that shown in Figure 2, are essential to the planning process. Figure 2 shows projected supply, by domestic source, and projected demand through the year 2000. The difference in the demand/domestic supply projections represents imported energy requirements and/or shortages. Shortages will be accommodated through conservation and other demand-reducing measures.

If conservation were not employed and the energy demand curve of Figure 2 continued to rise, the U.S. energy future might be as portrayed in Figure 3. Such a projection, from a recent report of the U.S



CONVERSION:*

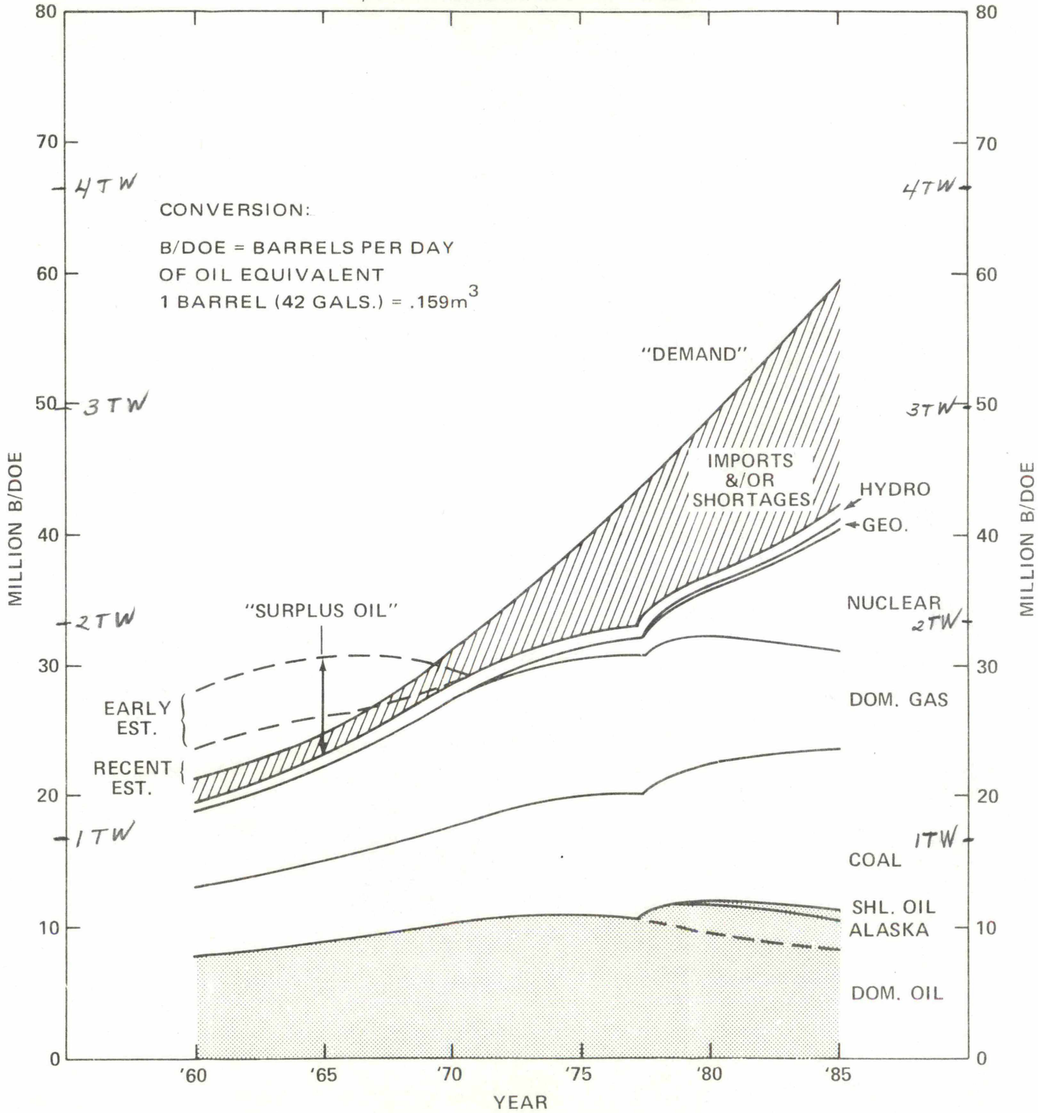
1 BTU = 1055 JOULE

*A MORE COMPLETE TABLE APPEARS AT THE END OF THIS PAPER.

SOURCE: AUSTIN ET AL.
LAWRENCE LIVERMORE LABORATORIES, 1972

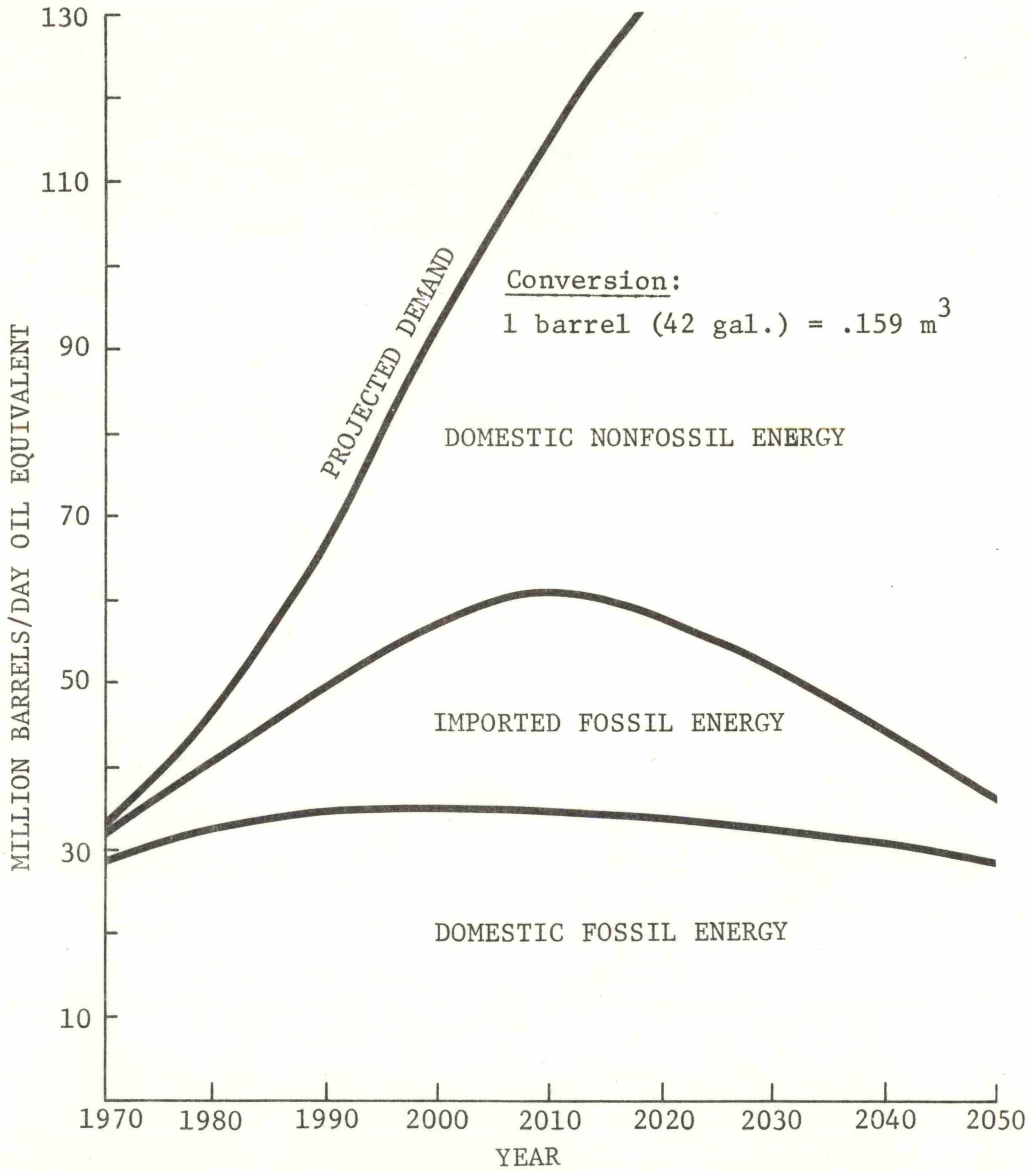
FIGURE 1
ENERGY FLOW PATTERNS IN THE U.S.A.—1970

"SUPPLY/DEMAND"
(1960-1985)
B/D OIL EQUIVALENT vs YEARS



SOURCE: "UNDERSTANDING THE NATIONAL ENERGY DILEMMA", A REPORT OF THE JOINT COMMITTEE ON ATOMIC ENERGY, 15 AUGUST 1973.

FIGURE 2
"SUPPLY/DEMAND"
(1960-1985)
B/D OIL EQUIVALENT VS YEARS

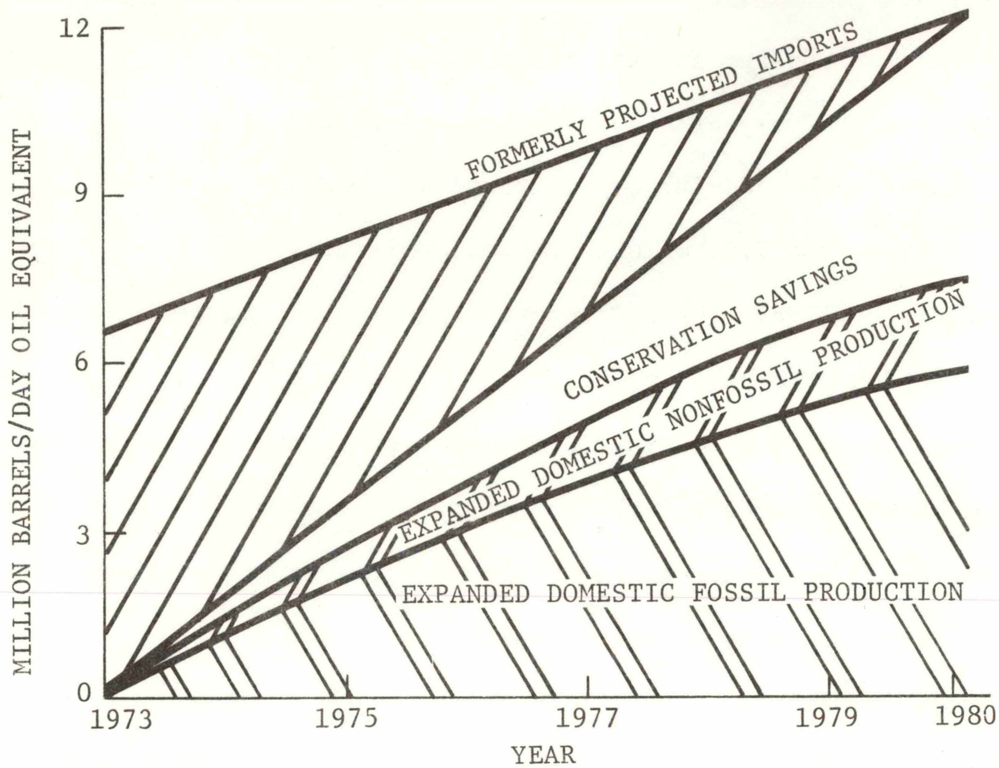


SOURCE: AEC, THE NATION's ENERGY FUTURE, December 1973

FIGURE 3
U.S. ENERGY FUTURE WITHOUT SELF-SUFFICIENCY

Atomic Energy Commission (AEC), acknowledges growing reliance on imported fossil energy and assumes a nearly steady supply of domestic fossil energy (relying heavily on increased use of coal and, possibly, oil shale) combined with rapid growth in domestic non-fossil energy. If, however, the U.S. were to become self-sufficient from an energy standpoint by 1980, the AEC report suggests, in Figure 4, how this might be done through a combination of energy conservation and expanded domestic fossil and non-fossil energy production. Conservation efforts would have to reduce formerly projected imports by 1/3 by 1980, while increased domestic energy production would account for the remaining 2/3. Since formerly projected energy imports for 1980 amounted to 25% of projected energy demand, then conservation strategies, if self-sufficiency is to be realized by 1980, would entail an 8% (1/3 of 25%) reduction in projected demand by that year. Because transportation accounts for 25% of all U.S. energy consumption, conservation measures of this magnitude will have a major impact on the evolution of transportation systems over the next decade or two.

The need to introduce non-petroleum fuels into our energy supply to meet expected demand over the next few decades raises the prospect of alternative fuels to which transportation systems must adapt. The availability of new domestic fossil fuel sources, in the short and mid terms (1974-1980 and 1980-1990, respectively) will be a function of world oil prices. Figure 5, suggested by the Hudson Institute at a recent symposium at the MITRE Corporation, indicates an approximate



Conversion:

1 barrel (42 gal.) = $.159m^3$

IMPORT REPLACEMENT

(Million Barrels/Day Oil Equivalent)	YEAR 1973	1980
Formerly Projected Imports	6.5	12.0
Conservation Savings*		4.7
Expanded Domestic Nonfossil Production		1.5
Expanded Domestic Fossil Production		5.8

*Includes both conservation techniques and energy real price increases.

SOURCE: AEC, THE NATION's ENERGY FUTURE, December 1973

FIGURE 4
SELF-SUFFICIENCY BY 1980 THROUGH CONSERVATION AND EXPANDED PRODUCTION

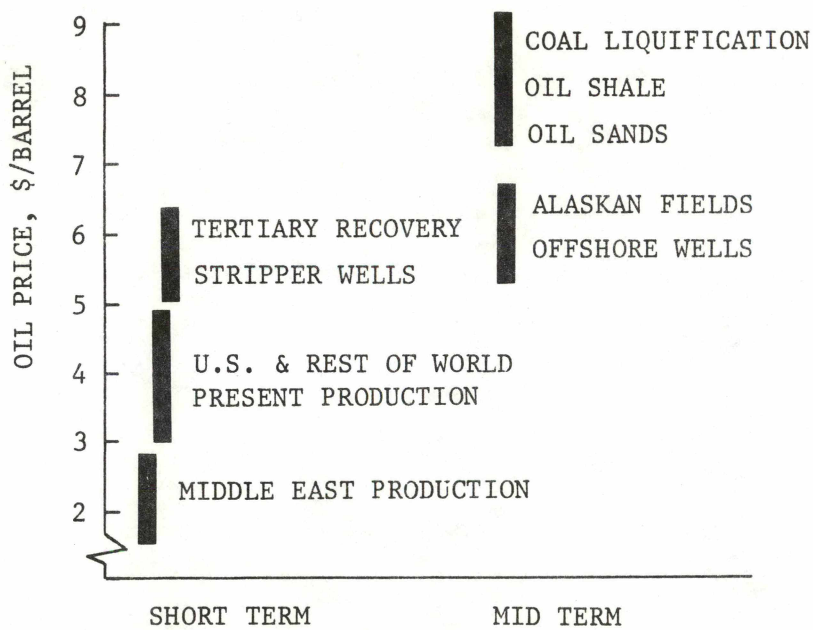


FIGURE 5
APPROXIMATE SUPPLY/PRICE SCALE FOR PETROLEUM AND OTHER FOSSIL FUELS (SUGGESTED BY THE HUDSON INSTITUTE)

supply/price scale for new petroleum and other fossil fuels. The Middle East oil is a large supply and the cheapest to produce; it is the only fossil fuel that can be produced at a profit for a price as low as $2 to $3 per barrel*. Production from the U.S. and most of the rest of the world is more expensive than Middle East oil. At a price of $5 to $6 per barrel, it becomes profitable to work small producer "stripper" wells and to stimulate existing wells to greater production. In the same higher price range, new Alaskan and offshore supplies could be brought in. Finally, at a price of $7 to $9 a barrel, working of oil sands, oil shale and coal-based liquid fuels begins to look profitable.

None of the alternative fossil fuels indicated in Figure 5 will affect transportation systems except, of course, by way of increased unit costs for fuel. The various required grades of fossil fuels now in use (gasoline, kerosene, diesel fuel, etc.) can all be produced from oil sands, oil shale, and coal. With the potential growing use of non-fossil energy sources (nuclear, solar, geothermal, etc.) there is the prospect that non-fossil energy may have to be used by the transportation sector, particularly if unforeseen extraction or environmental problems make the use of coal and oil shale impractical. With abundant electric and/or solar power available, the possibility of using alcohol (methanol) and hydrogen as alternative transportation fuels needs to be considered. The potential for using stored electric,

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* The current price of $11 to $12 per barrel for Middle East oil is artificially high, and does not reflect production cost.

mechanical, and high temperature thermal energy* in transportation systems also needs study. Alcohol, while more expensive and lower in specific energy content than hydrogen, offers the advantage of convenient storage and transport as a liquid. Hydrogen suffers from inconvenient and costly storage and handling problems, but is otherwise a potentially viable alternate to fossil fuels. The unique safety aspects of hydrogen as a fuel must be addressed. Hydrogen, the cleanest burning of all chemical fuels, could well permit the use of on-board power generation for intercity ground transportation systems in dense urban corridors where air quality standards would otherwise force the use of wayside electric power. Of all transportation modes, large aircraft appear to be the best suited for use of hydrogen as a fuel. Electric, mechanical, and thermal stored energy systems are clean and compatible with total energy systems, but require major improvements in energy density before application to intercity systems can be considered.

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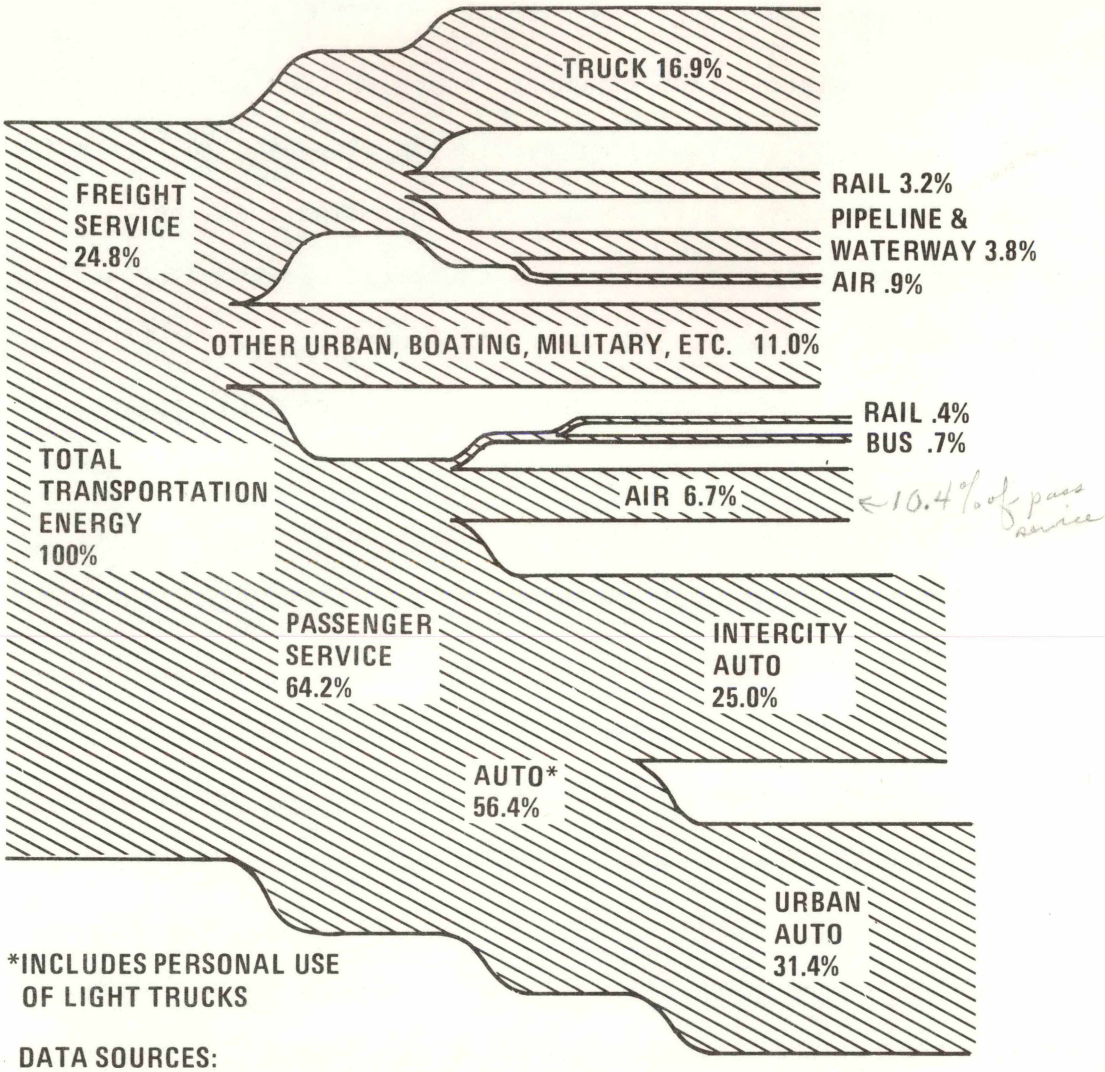
*N.V. Philips Aachen Laboratory, Federal Republic of Germany, has pioneered recent advances in storage of thermal energy as the heat of fusion in fluoride eutectic salts. Up to 30 times the energy density of the lead-acid battery have been achieved.

U.S. TRANSPORTATION ENERGY CONSUMPTION

The 1970 distribution of energy among the various transportation modes for freight and passenger service is displayed in Figure 6. The energy considered here is only the operating fuel energy. As Dr. Hirst has demonstrated (Ref. 7) the total energy associated with a mode should account for its manufacturing energy input, the energy associated with distributing, maintaining, licensing, housing, and insuring the vehicles, as well as the fuel energy required to operate the system. For the automobile, Dr. Hirst calculated that the total energy consumed by the automobile on the above basis is nearly twice the operating fuel energy requirement.

Looking only at fuel energy, Figure 6 shows that better than half (56%) of transportation fuel energy is consumed by the automobile, with urban auto usage consuming the larger share. Note that light trucks when used for personal transportation are included in the statistics for the automobile. Freight consumes nearly 25% of all transportation fuel, with two-thirds of this amount going to trucking. Thus, the fuel consumed by all highway vehicles is three-quarters of the total for transportation. Eleven percent of the total goes to recreational vehicles, general aviation, and the military, with the military consuming by far the largest share. The air passenger mode consumes about 7%, several times what bus and passenger rail together consumed. Auto and air are the dominating energy consumers, in the aggregate, for intercity travel.



DATA SOURCES:

- MOTOR VEHICLE MANUFACTURERS ASSOC., 1972 (14)
- HIRST, MARCH 1972 (24)
- STROMBOTNE, JANUARY 1973 (25)
- AMERICAN TRANSIT ASSOC., 1971-1972 (26)
- CIVIL AERONAUTICS BOARD, 1971 (27)
- CAMPBELL, APRIL 1973 (28)
- MALLIARIS & STROMBOTNE, FEBRUARY 1973 (29)

SOURCE: FRAIZE ET AL, THE MITRE CORP., FEB. '74

FIGURE 6
U.S. TRANSPORTATION ENERGY DISTRIBUTION BY MODE (1970)

A more detailed analysis of transportation energy consumption, again for 1970, is given by Table 1 which presents not only the energy consumption for each mode, but the useful transport work (passenger-miles or ton-miles), the load factor, and the energy intensiveness (Btu/pass. mi., or Btu/ton mi.). Energy intensiveness is the energy consumed per unit of useful transport work (passenger-miles or ton-miles), and is, therefore, inversely related to a transport mode's efficiency.

The historical trends in U.S. transportation energy consumption are displayed in Figures 7 and 8. Figure 7, showing the energy distribution according to mode, displays the growth in highway and air modes at the expense of a declining rail mode. A portion of the decline in railroad energy consumption is due to the improved efficiency of the diesel engine locomotives which were replacing the relatively inefficient steam locomotives in the early part of the period. Figure 8 displays the growing fraction of transportation energy consumed in passenger service (60% in 1970).

The efficiency of energy use is expressed either in terms of energy intensiveness (energy consumption per unit of useful transport work, such as passenger miles, seat miles, ton miles, etc.) or in terms of fuel economy (e.g., seat miles/gal., pass. miles/gal., ton miles/gal., etc.); one is the inverse of the other. The historical trends in energy intensiveness (Btu/pass. mile) for U.S. passenger modes between 1950 and 1970 is presented in Figure 9. In this period, the only significant changes in energy intensiveness occurred for the

TABLE I
U.S. TRANSPORTATION ENERGY–1970

MODE	TRANSPORT WORK (Pass.Mi. or Ton mi.)	LOAD FACTOR	ENERGY INTENSIVENESS (Btu/pass.mi. or Btu/ton mi.) (At current load factor)	ENERGY CONSUMPTION (10^{15} Btu) Subtotals	Additive Totals
PASSENGER SERVICE					
Auto: Urban	.69 x 10^{12}	1.4 pass/veh.	7550 (12.1 mpg)	5.2	
Intercity	1.04	2.5	3250 (16.0 mpg)	3.4	
(Small cars) ALTERNATE BREAKDOWN	(.27)	1.9	3220 (21.2 mpg)	(.87)	
(Stnd. & compact cars)	(1.46)	1.9	5300 (12.9 mpg)	(7.73)	
AUTO MODE	1.73	1.9	4980 (13.6 mpg)	8.6	8.6
Light Truck	.08	1.4	9000 (10.1 mpg)		.72
Air: Short haul (<500 mi.)	.018		12200	.22	
Long haul (>500 mi.)	.101		8720	.88	
AIR MODE	.119	49%	9300	1.10	1.10
Bus: Urban	.017	10 pass/veh.	2940 (4.4 mpg)	.05	
Intercity	.028	22	1070 (5.5 mpg)	.03	
School	.052	25	770 (6.75 mpg)	.04	
BUS MODE	.097	19.2	1240 (5.5 mpg)	.12	.12
Rail: Urban	.007	25%	4300	.03	
Intercity	.011	37%	2730	.03	
RAIL MODE	.018		3330	.06	.06
ALL PASSENGER SERVICE	2.044x10^{12}pass.mi.		5250 Btu/pass.mi.		10.6
FREIGHT SERVICE					
Truck: Single Units	.15	1.09 ton mi./veh.mi.	10650 Btu/ton mi.	1.6	
Combinations	.35	9.21	3440	1.2	
(Motor Carrier) ALTERNATE BREAKDOWN	(.39)				
(Private Truck)	(.11)				
TRUCK MODE	.50	2.63	5600	2.8	2.8
Rail	.77		675		.52
Air	.004		37500		.15
Pipeline	.43		420		.18
Waterway	.60		750		.45
ALL FREIGHT SERVICE	2.304x10^{12}ton mi.		1780 Btu/ton mi.		4.1
OTHER					
General Aviation					.10
Recreational Vehicles					.20
Military					1.5
TOTAL TRANSPORTATION					16.5

Data Sources:
- Motor Vehicle Manufacturers Assoc., '72 (14)
- Hirst, March '72 (24)
- Strombotne, Jan. '73 (25)
- Malliaris & Strombotne, Feb. '73 (29)
- American Transit Assoc., '71-'72 (26)
- Campbell, April '73 (28)
- Civil Aeronautics Board, 1971 (27)

CONVERSION:
1 BTU = 1055 HOULE
1 TON = 907.2 KGM
1 MILE = 1.62 KM
1 TON MILE = 1470 KGM KM
1 BTU/PASS MI = 650 JOULE/PASS KM
1 BTU/TON MI = .717 JOULE/KGM KM

SOURCE: FRAIZE, W. E. ET AL, THE MITRE CORP., FEB. 1974

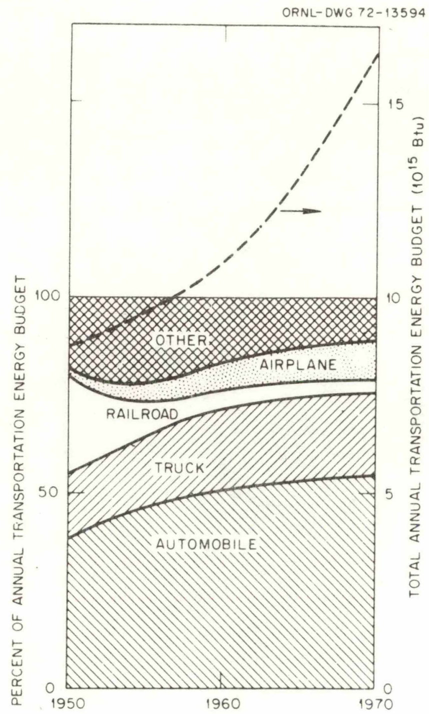


FIGURE 7
DISTRIBUTION OF TRANSPORTATION ENERGY BY MODE

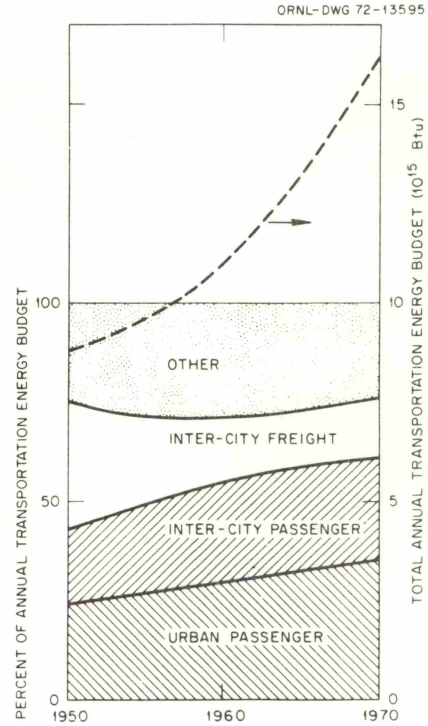


FIGURE 8
DISTRIBUTION OF TRANSPORTATION ENERGY BY PURPOSE

CONVERSION:

1 BTU = 1055 JOULE

SOURCE: HIRST, E., ENERGY INTENSIVENESS OF PASSENGER AND FREIGHT TRANSPORT MODES, 1950-1970, OAK RIDGE NATIONAL LABORATORY, REPORT ORNL-NSF-EP-44, APRIL 1973.

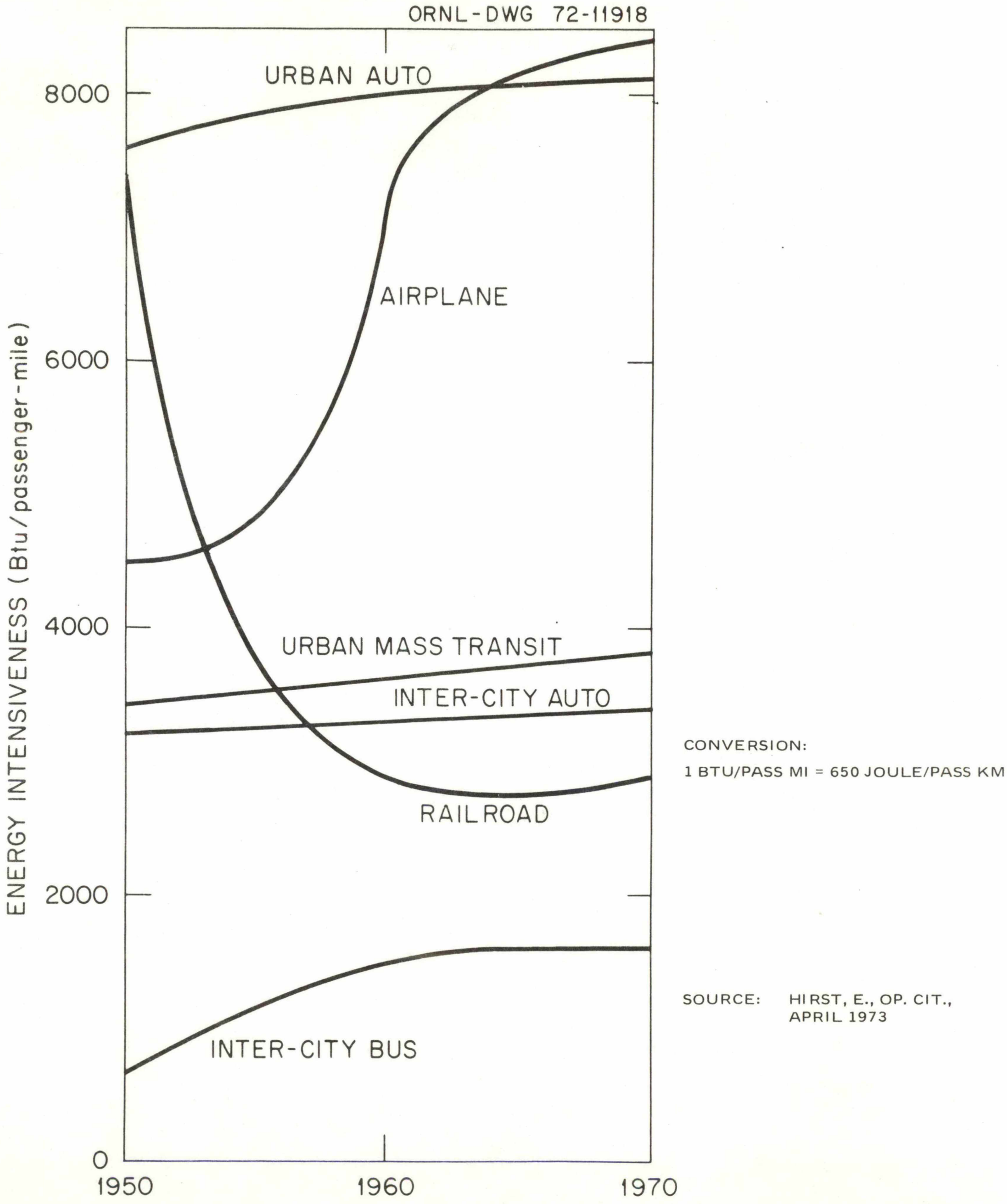


FIGURE 9
HISTORICAL VARIATION IN ENERGY INTENSIVENESS FOR PASSENGER MODES

intercity mass modes:

- energy intensiveness for air increased rapidly (by a factor of 2) with the advent of higher speeds made possible by the commercial jet engine around 1960;
- energy intensiveness for rail declined rapidly in the first half of the period (1950-1960) as steam locomotives were phased out;
- intercity bus became less efficient as highway speeds increased.

The energy intensiveness (or fuel economy) on a passenger mile basis incorporates the effect of load factor; energy usage on a seat mile basis allows comparison of system potential performance without regard to load factor and is, therefore, a more objective measure for comparing transportation vehicle systems on an energy basis. The fuel economy for a number of passenger modes, as reported by several investigators, is summarized in Table II. Both seat-mile/gallon and passenger-mile/gallon bases are used. Table II illustrates the difficulty in obtaining consistent values of fuel economy for a given mode. Not only is there the obvious difference between passenger miles, seat miles, and vehicle miles (the effects of load factor and vehicle seating configuration, both of which affect the quality of service in a direction opposite to fuel economy), but also the differences in vehicle speed, cruise performance versus overall duty-cycle performance, measured versus calculated performance, and reliability of data sources that must be taken into account.

TABLE II

REPORTED MODAL FUEL ECONOMY

INVESTIGATOR (Reference)	DOT/TSC (1)	DOT/OTEP (2)	RICE (3)	HIRST (4)	HIRST (5)	NCMP (6)	DOT/OST (7)	FRAIZE (8)	LIEB (9)	AUSTEN (10)	MOOZ (11)	FLIGHT (12)
UNITS	PSGR mpg	PSGR mpg	SEAT mpg	PSGR mpg	PSGR mpg	PSGR mpg	SEAT mpg	SEAT mpg	SEAT mpg	SEAT mpg	PSGR mpg	SEAT mpg
AUTOMOBILE												
SUBCOMPACT							100	100	85	91		
AVERAGE	30	30	64	32	38	32				78	25	120
INTERCITY BUS	110	104	215	125	82	125	300	250	270		78	450
TRAIN												
CROSS COUNTRY	50	150+	144	80	46	80					50	393
METROLINER			75				210	210				
COMMUTER			200			100						
SUBURBAN			400			200						
AIRPLANE												
WIDE BODIED JET			40			22		63				57-68
AVERAGE	16	14	34	14	16	21	52	36	22		18	41

SOURCE: For Table II - Nutter, R. D., "A Perspective on Transportation Fuel Economy," The MITRE Corporation, March 1974.

Conversion:

1 seat mile/gal = 427 seat km/m^3

REFERENCES FOR TABLE II

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2. U.S. Department of Transportation Energy Policy, U.S. DOT (informal planning papers), November 1973.
3. Rice, R. A., "System Energy as a Factor in Considering Future Transportation," ASME paper 70-WA/Ener 8, December 1970.
4. Hirst, Eric, "Energy Consumption for Transportation in the U.S.," Oak Ridge National Laboratory, ORNL-NSF-EP-15, March 1973.
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7. U.S. DOT, Office of the Secretary, "High Speed Ground Transportation Alternatives Study," January 1973.
8. Fraize, W. E., P. Dyson, S. W. Gouse, Jr., "Energy and Environmental Aspects of U.S. Transportation, MITRE paper MTP-391, February 1974.
9. Lieb, J., MITRE internal memorandum D23-M2388, July 1973.
10. Austen and Hellman, "Passenger Car Fuel Economy--Trends and Influencing Factors," SAE paper 730790, September 1973.
11. Mooz, W. E., "Energy Trends and Their Future Effects Upon Transportation," RAND Corporation Paper P-5046, July 1973.
12. FLIGHT International, "Where has all the Fuel Gone," November 1973 - NOTE: values for European vehicles.

RAIL AND BUS SYSTEMS

The impact of speed for intercity bus and new rail systems is demonstrated in Figure 10, which shows cruise energy intensiveness (But/seat mile) as a function of cruise speed. Figure 10 illustrates several factors that bear on the energy consumption of bus and rail systems:

- At high speeds (above 50 mph) aerodynamic drag predominates for rail systems (the same is true for bus, but is not illustrated by calculation in Figure 10).
- On the basis of cruise performance, a rail system can, for the same energy expended per seat mile, operate at twice the cruise speed of highway vehicles (i.e., bus). The major reasons for the cruise energy advantage of rail over bus are:
    - Reduced rolling friction (steel wheels on rail yield 1/10 the rolling resistance of rubber tires on concrete).
    - Better fineness ratio (volume to frontal area) and, hence, lower aerodynamic drag for rail compared to bus.
- Because of the relatively small effect of vehicle weight on cruise performance of rail systems, rail vehicles can be considerably heavier in terms of weight/seat than bus, thereby providing greater flexibility in vehicle design, including the option for more spacious seating and other on-board passenger services. However, vehicle weight exacts an energy cost in actual duty cycles which include acceleration and

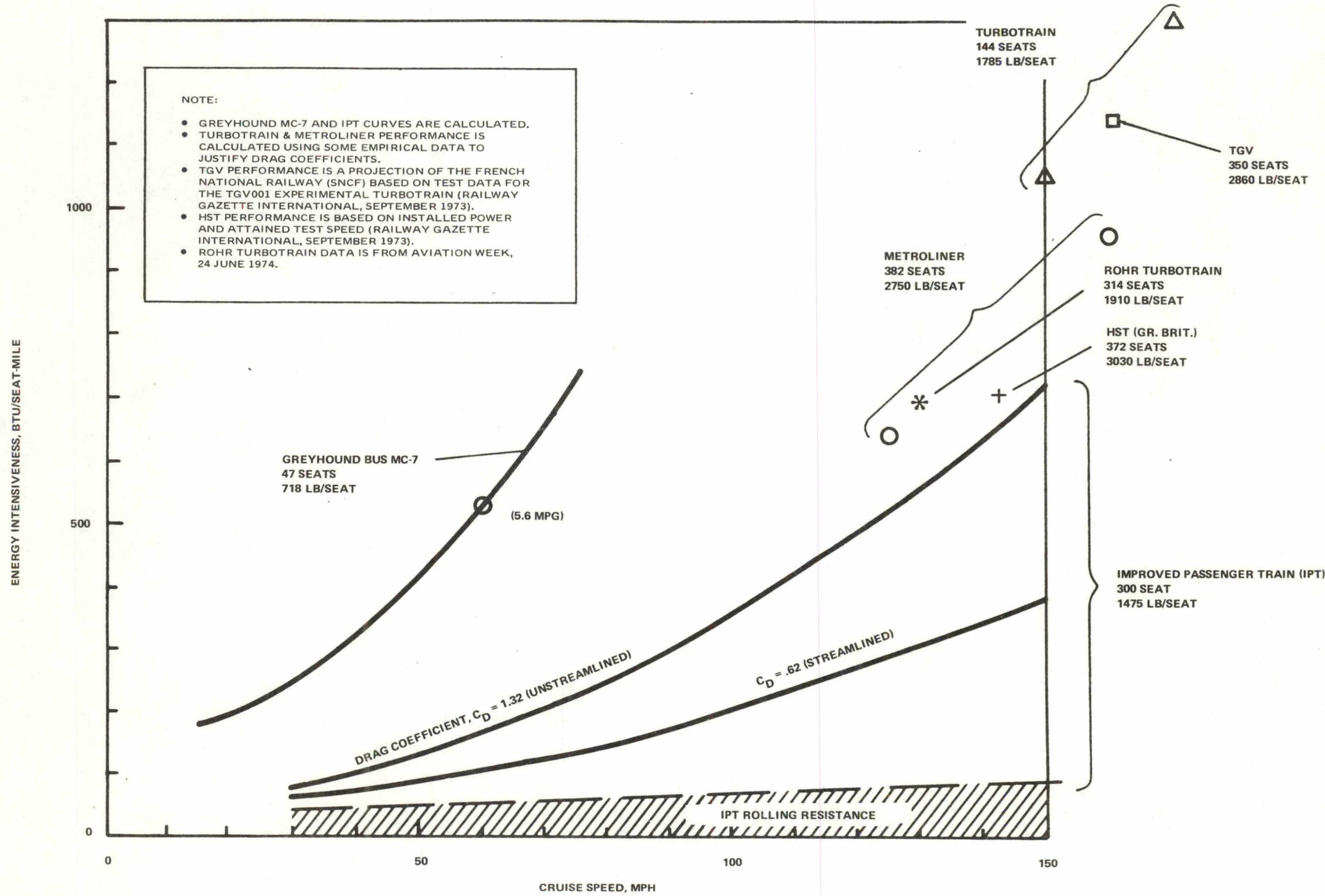


FIGURE 10
CRUISE ENERGY INTENSIVENESS, BUS AND NEW RAIL

grade requirements. Therefore, weight is not an insignificant factor by any means, and attempts to reduce weight are a major goal of all new high speed rail development efforts.

- The propulsion system efficiency has a direct effect on energy consumption (not motive power); the IPT model assumes an efficient regenerative gas turbine having an overall efficiency (engine plus transmission) of 28%; for the Turbotrain, using an aircraft gas turbine, the overall efficiency is approximately 16%; for the electrified Metroliner, the overall conversion efficiency is approximately 25%.

In addition to rolling resistance and fineness ratio, which affect cruise performance, rail systems have two other inherent energy-related advantages over bus:

- Rail rights-of-way are generally more level than highway.
- Rail travel involves less stop and start in getting out of a terminal and onto the main right-of-way than does bus.

As opposed to the inherent advantages of rail systems, as listed above, there are several practical operating characteristics of rail systems which tend to increase their energy intensiveness:

- Most passenger trains use electric drive, either diesel-electric or wholly electrified. The efficiency of the mechanical-to-electrical-to-mechanical conversions is lower than direct mechanical transmission used in the bus. On the other hand, the larger train diesels work under more nearly constant load and can therefore achieve a higher efficiency for the prime mover. The effects will tend to compensate.

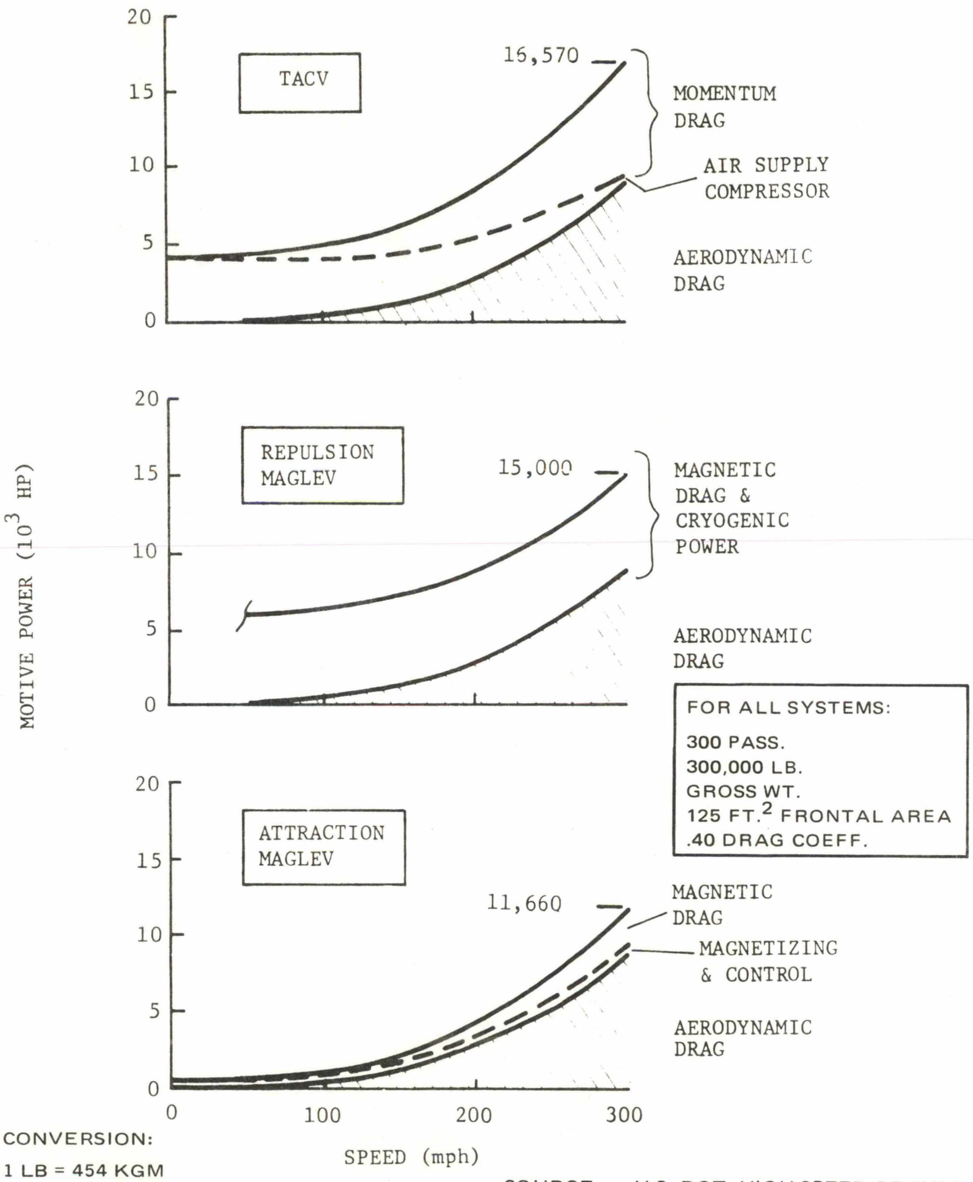
- Rail coach seating is far less dense than bus. In general, rail seating approximates first class air while bus approximates economy class air in seats per unit of floor space.
- Intercity trains frequently carry baggage cars, dining cars, and lounge cars which are normally not included in seat-mile estimation. Parlor cars and sleepers are very low density seating vehicles.
- Rail costs have been dominated by fixed costs and labor costs so that strong incentives for fuel economy have not existed as has been the case for bus.

TRACKED LEVITATED VEHICLE SYSTEMS

In the High Speed Ground Alternatives Study (Ref. 15), prepared by the MITRE Corporation for the U.S. DOT, the cruise performance and energy cost of improved rail systems and tracked levitated vehicles (TLVs) were estimated. Both magnetically levitated (MAGLEV) and air-cushion levitated vehicle concepts were considered. For all TLV systems, the motive power requirements, based on the state-of-knowledge as of late 1972, were calculated. The results are shown, as a function of cruise speed, in Figure 11 for three hypothetical 300 passenger, 300,000 lb. (1340 kN) gross weight vehicles:

- Tracked air cushion cehicle (TACV) using static air cushions.
- Tracked repulsion MAGLEV vehicle using on-board superconducting magnet coils.
- Tracked attraction MAGLEV vehicle.

On the basis of power alone, this comparison shows a decided advantage for the attraction MAGLEV system, because the magnetic drag is estimated to be considerably less than the comparable suspension-related drag for either of the other two systems. For all systems, aerodynamic drag is the same. For TLV systems, support and guidance power is relatively large, compared to the rolling resistance of rail systems (see Figure 10). At 300 mph cruise, aerodynamic drag accounts for only 54% of the motive power requirements for the TACV. The corresponding percentages for repulsion and attraction MAGLEV are 59% and 76% respectively.



CONVERSION:

1 LB = 454 KGM

1 FT^2 = .093 M^2

1 HP = .746 KW

1 MPH = 1.62 KM/HR

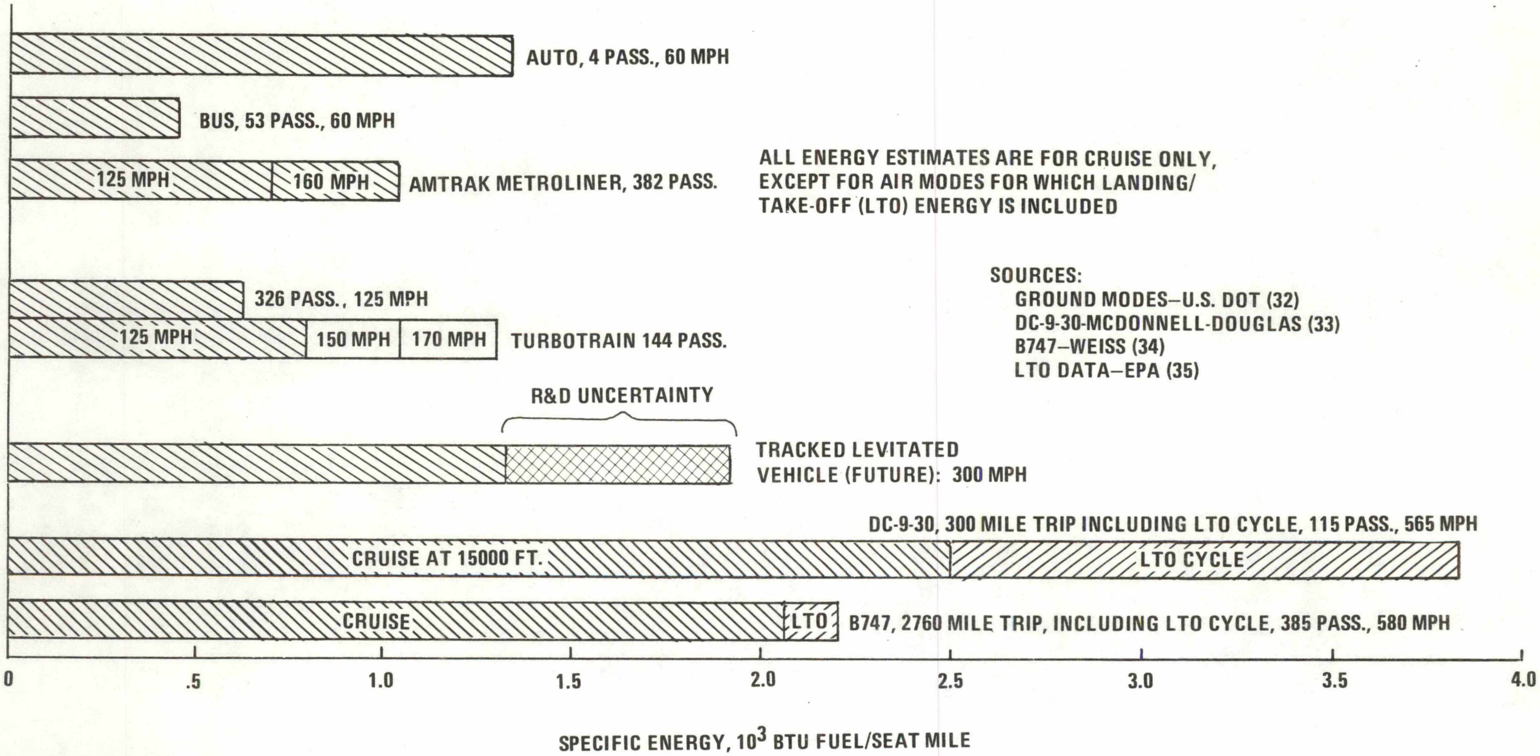
SOURCE: U.S. DOT; HIGH SPEED GROUND ALTERNATIVES STUDY, JANUARY 1973.

FIGURE 11
MOTIVE POWER REQUIREMENTS FOR TLV SYSTEMS

The 300 mph cruise performance for the TLV systems is shown in comparison with other modes in Figure 12. Each system is shown at its rated cruise speed, and for each,the energy intensiveness (Btu/ seat mile) has been estimated. The aircraft data include the estimated energy for the landing/take-off (LTO) cycle, because the LTO energy, at least for short-haul trips of 300 miles (483 km) or so is not negligible. Figure 12 indicates that future TLV systems can effectively compete, on an energy per seat-mile basis, with short-haul aircraft while offering a cruise speed of 300 mph (483 km/hr) (as opposed to 565 mph (915 km/hr) for short-haul aircraft). In intercity service, TLV sytems can provide city-center to city-center service so that the door-to-door time for TLV and short-haul may be comparable in spite of the significant difference in cruise speed.

The role for TLV systems as an alternate to short-haul air service in congested corridors will not involve significant savings in the total transportation energy budget for the United States. Figure 13 shows the cumulative distribution of fuel consumed and passenger miles for scheduled U.S. domestic air travel for 1968. If, for example, all air traffic for trips below 500 miles (810 km) in length were picked up by TLV systems, the maximum fuel savings involved would be less than 20% of the air mode fuel budget, or less than 1.5% of the nation's transportation energy budget.

Thus, while total energy savings will not likely, by itself, be a strong justification for TLV systems, there will be many situations

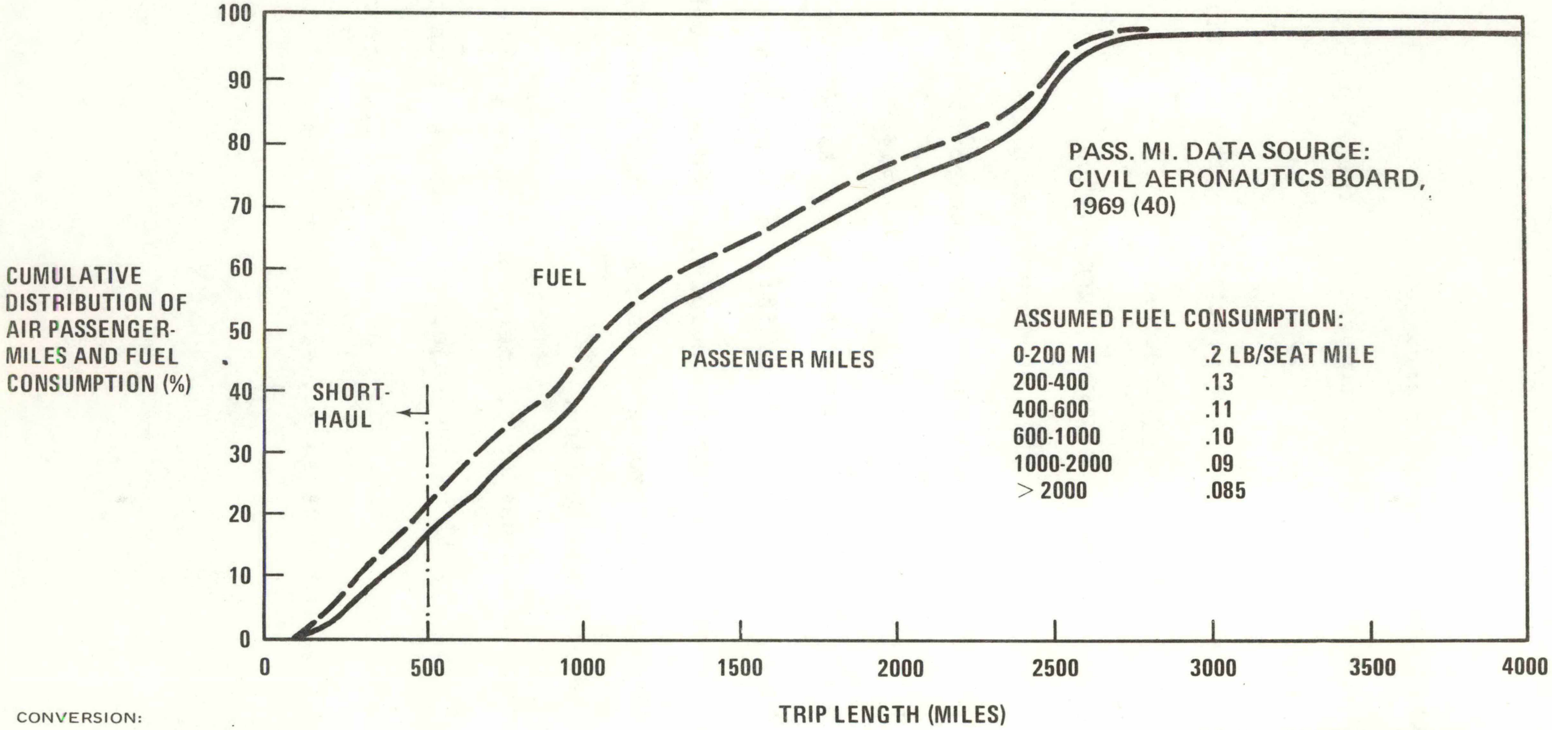


CONVERSION:

1 BTU/SEAT MILE = 650 JOULE/SEAT KM
1 MPH - 1.62 KM/HR
1 FT = .305M

SOURCE: FRAIZE, W. E. ET AL, THE MITRE CORP., REPORT MTP-391 FEBRUARY 1974

FIGURE 12
SPECIFIC ENERGY REQUIREMENTS FOR VARIOUS TRANSPORTATION MODES



CONVERSION:

1 MILE = 1.62 KM
1 LB/SEAT MILE = .28 KGM/SEAT KM

SOURCE: FRAIZE, W. E., ET AL, THE MITRE CORP., REPORT MTP-391, FEB. 1974

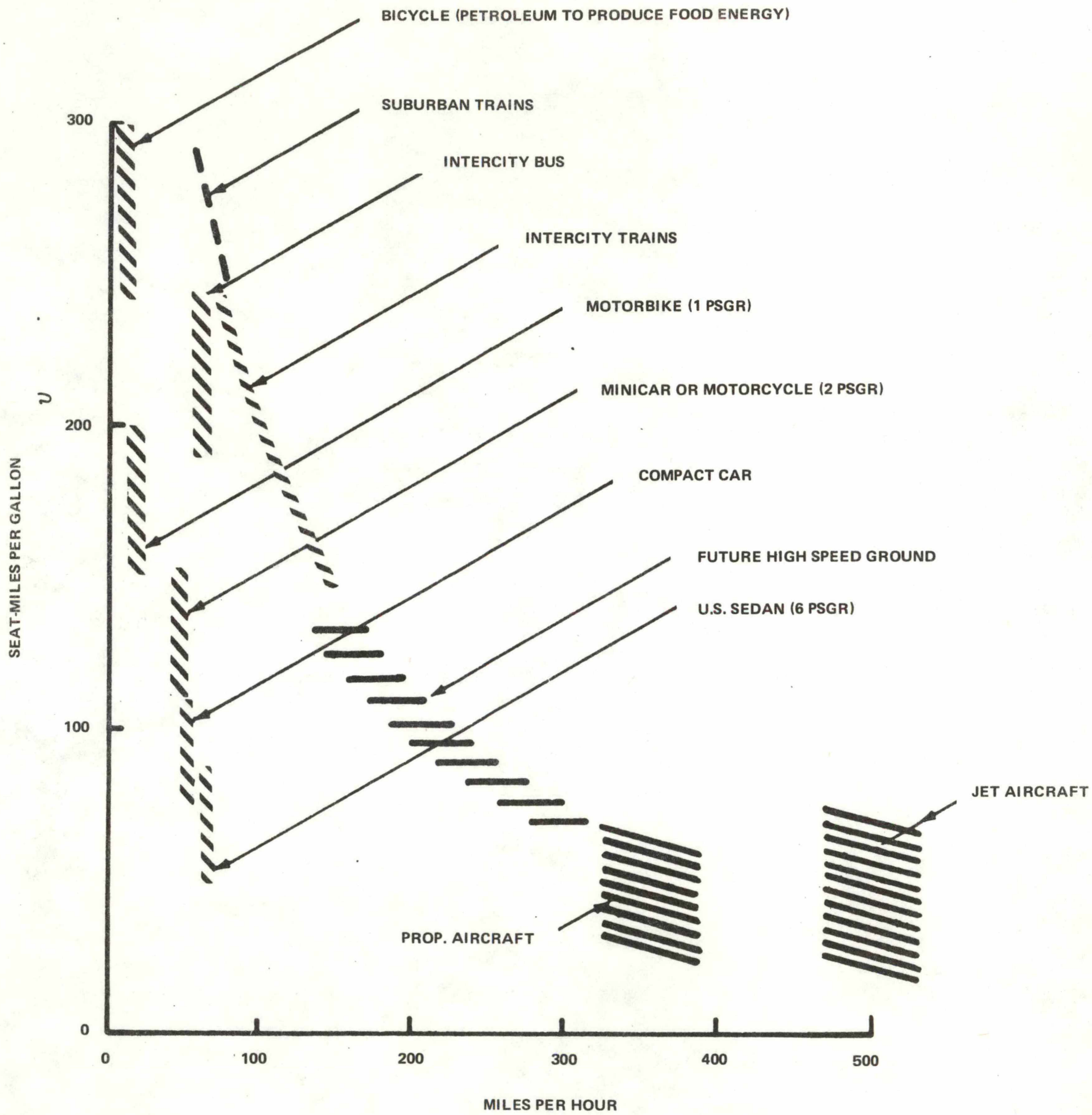
FIGURE 13
DISTRIBUTION OF U.S. DOMESTIC AIR TRAVEL, 1968

in congested intercity corridors where TLV's will be an attractive alternate, offering:

- City-center to city-center service.
- Reduced energy consumption compared to the short-haul air alternative.
- Flexibility, through wayside electric power, to utilize a wide range of basic energy sources.
- Reduced air corridor and highway congestion.

In summary, the potential fuel economy (seat miles/gallon) is displayed, for the most important passenger transportation systems, as a function of cruise speed in Figure 14. TLV systems are seen again to fill in the speed regime gap between 150 and 300 mph (483 km/hr). All ground systems are seen to fall below an envelope of shape given by $1/(\text{speed})^2$; this defines the aerodynamic drag of vehicles at sea level. Aircraft performance rises above this envelope because of operation in reduced air density.

None of the above discussion of energy should be construed to imply that energy is or will be the major determining force in HSGT system development. Other important travel-related factors not discussed here are: convenience, speed, safety, and comfort.



CONVERSION:
1 MILE/HR = 1.62 KM/HR
1 SEAT MILE/GAL = 427 SEAT KM/M^3

SOURCE: NUTTER, R.D., THE MITRE CORP, MAR. 1974

FIGURE 14
MODAL COMPARISON OF FUEL ECONOMY

IMPACT OF ENERGY SHORTAGES ON HSGT

Short term energy shortages of the sort experienced during the winter of '74, will likely be addressed through higher fuel costs, conservation measures wherever possible, and, for the private automobile driver, rationing either by regulation or through inconvenience in the purchase of fuel. Intercity service would not likely be severly curtailed because the bulk of any energy "short-fall" will be taken-up by the automobile user. On the other hand intercity mass transportation modes are apt to be strained to over-capacity as fuel supplies for automobile travel become less dependable.

In the mid-term, a steady state supply-demand equilibrium at the higher price established by new domestic energy sources would likely be realized. Prices might continue to rise slowly as domestic fuel sources begin to run short and become more expensive to extract.

In both the short and mid-terms (through 1985 or 1990), the major energy impact on HSGT will be through increased cost. Table III illustrates the effect of energy cost increases of 50% and 200% on the total cost of travel for several major modes. The automobile mode will suffer by far the biggest impact of rising fuel costs, because virtually the only cost perceived by the privare automobile operator is fuel cost. This suggests that fuel cost increases will produce strong pressure to shift traffic from auto to the mass modes; but, since the mass modes are relativelt insensitive to fuel costs (a three-fold increases in fuel cost yields less than a 20% increase in travel cost), there will be little economic pressure to shift among the

TABLE III

ENERGY CRISES COST FACTORS

Mode	Cost of Travel: Non-Energy Related Portion (C_n)	Cost of Travel: Energy Related Portion (C_e)	Total Cost Factor (C_t)*, Energy Crisis Equals: (F_e)** 1.5	Total Cost Factor (C_t)*, Energy Crisis Equals: (F_e)** 3.0
Auto	0%	100%	1.5	3.0
Air	90	10	1.05	1.20
Bus	95	5	1.025	1.10
IPT	97.5	2.5	1.0125	1.05
TLV	95	5	1.025	1.10

* $C_t = C_n + Fe\,(Ce)$

SOURCE: U.S. DOT, High Speed Ground Transportation Alternatives Study, Jan. 1973

** Fe = 1.5: 50% fuel cost increase

= 3.0: 200% fuel cost increase

mass modes. The mass modes can best accommodate future fuel cost increases by building in the ability to rapidly increase system capacity.

Finally, in the long term (2000 and beyond), transportation will adapt to long term stable energy sources with a range of fuels:

POTENTIAL LONG-TERM ENERGY SOURCES	COMPATIBLE FUELS
Solar/Geothermal/Wind	Hydrogen Methanol Electricity Stored Thermal Energy
Nuclear	Electricity Hydrogen
Coal	Distillates Methane Hydrogen
Oil Shale	Distillates

HSGT systems developed over the next 10 to 20 years should be designed for compatibility with the most likely long-term fuels to be available during the systems's lifetime.

RESEARCH TOPICS

Among the topics for research effort that will address the energy aspects of future HSGT are the following:

Systems Studies and Analysis

- Motivation for use of mass transportation systems.
- The impact of regulation and operating procedures on modal fuel efficiency.
- Measures to improve load factor.
- Land use/transportation relationships.
- Revised transportation demand projections, accounting for fuel supply shortages and changes.
- Passenger/freight service compatibility.

Technology R&D

- Rail electrification costs, benefits, and environmental impact.
- Hydrogen and methanol utilization as transportation fuels.
- Use of stored electric, mechanical, and high temperature thermal energy.
- Environmental impact of fossil fuel usage.
- Efficient engines (internal and external combustion prime movers) having a wide range of fuel flexibility.
- Improved power transmissions for ground vehicles.
- Means for reduced rolling resistance and aerodynamic drag for ground vehicles.
- Rail/right-of-way/suspension design to accommodate optimally both passenger and freight service.

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APPENDIX A

CONVERSION FACTORS

(English to SI Units)

1 ft	=	.305 metre
1 mile	=	1.62 kilometre
1 lbm	=	.454 kgm
1 ton	=	907.2 kgm
1 gallon	=	.00379 m^3
1 barrel (petroleum)	=	.159m^3
1 BTU	=	1055 joule
1 horsepower (HP)	=	.746 kilowatt
1 mile/gallon	=	427 kilometre/m^3
1 ton-mile	=	1470 kgm km
1 BTU/pass mile	=	650 joule/pass km
1 BTU/ton mile	=	.717 joule/kgm km

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