Energy-Related, Environmental, and Economic Benefits of Florida's High-Speed Rail and Maglev Systems Proposals

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The environmental, energy, and economic benefits of specific, though different, proposed statewide high-speed rail (HSR) systems, to be combined with a proposal for a regional magnetically levitated (maglev) train under review in Florida, are examined. One of the HSR proposals and the maglev system are projected to be fully authorized within the next 18 months and operational by the 1994–1996 period. The specifics of each applicant's proposals are integrated into a complex computer model reflecting different (a) technologies and speeds, (b) energy demands and other resource needs, (c) system service-level characteristics, (d) ridership levels, and (e) modal splits, combined with (f) other system differences. This computer model then integrates the unique (a) fuel consumption and (b) emission levels of the actual electrical generation grid supplying the HSR and maglev systems in central and south Florida. Finally, the model quantitatively combines these data with equivalent emissions, energy, and other systems information on automobile and airplane transportation modes. These data and pertinent user characteristics enable the model to estimate precise environmental, energy, and economic benefits (expressed in 1990 dollars) for each unique HSR and maglev transportation system for the year 1999 alone.

The economic, environmental, and energy benefits of high-speed rail (HSR) and magnetically levitated (maglev) trains are directly related to the technology's energy supply, electricity, and the diversity and control of the sources of fuel that generate the power. Central station generation facilities use diverse sources of fuel in a more environmentally efficient form and can control their emissions far more effectively than competing automobile and aircraft sources.

A more detailed examination of potential HSR and maglev applications in Florida will fully clarify the potential range of energy, economic, and environmental benefits available and the nature of their interrelationships. All projections for this analysis are based on actual Florida-specific HSR applicant proposals submitted by the Florida High Speed Rail Corporation (FHSRC) (*1*, *2*) and TGV of Florida (*3*, *4*). (On October 27, 1989, TGV of Florida withdrew its application from further review in Florida. However, their proposal is included in this analysis because of the extensive amount of in-depth HSR analysis performed by the TGV Company, and because the results of their work are readily available.) The maglev system information is drawn specifically from the Florida maglev proposal submitted by Maglev Transit, Inc. (*5*). Where necessary, these reports are supplemented with information contained in a federally funded Florida HSR study completed in 1984 (*6*).

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These data are further augmented with Florida-specific data and research on power plant (*7*), energy production (*8*), sources of fuel, emission levels (*9*, *10*), and cost of fuel. Other needed information, such as aircraft and automobile emissions, are adapted from standard U.S. Environmental Protection Agency (EPA) (*11*), U.S. Department of Energy (DOE) (*12*), and Florida Department of Environmental Regulation (DER) sources (*9*).

FLORIDA HIGH-SPEED RAIL AND MAGLEV APPLICANT PROPOSALS

Florida High-Speed Rail Corporation Proposal

The FHSRC proposes to use a Swedish HSR train manufactured by ASEA Brown Boveri and called Fastrain. It would be capable of operating in excess of 150 mph and would travel between Miami and Tampa in 160 to 175 min. The FHSRC proposal would ultimately include 13 stations. Ridership is forecast to increase from 1.6 million in 1995 to 2.78 million in 2020 (see Table 1). These preliminary forecasts are being revised on the basis of new surveys conducted by FHSRC in mid-1989. These preliminary estimates do not include induced ridership or short trips.

For purposes of the analysis in this paper, the ridership in 1999 of 1.7 million will be used as a baseline for the FHSRC emission benefit estimation. In addition, the FHSRC proposal indicates that Fastrain sets would carry 480 passenger seats and consume 14,000 kwh for each one-way trip between Miami and Tampa. Fastrain therefore would produce a gross energy consumption of 972 Btu per seat mile. If a passenger per seat occupancy ratio of 70 percent is assumed, the FHSRC Fastrain provides a consumption of 1,388 Btu per passenger mile. This value is higher than that of the original generic Florida High Speed Rail Study (*6*). FHSRC estimates total train weight at 1.31 million lb (1.36 tons) per seat.

Finally, FHSRC indicates that 61 percent of HSR trips systemwide would be diverted from the automobile, 29 percent from the airplane, and the remaining 10 percent from other modes—specifically bus and train (*2*). These will be the technical components of the FHSRC modal split, ridership, and energy needs used for analysis of net emission and energy trade-off reported in this paper for their system.

TGV of Florida Proposal

The Florida TGV proposes to use the French HSR train manufactured in France by Alsthom and Bombardier, Inc. The

TABLE 1 PRELIMINARY RIDERSHIP PROFILE: THE FHSRC HSR SYSTEM

Mode	FHSRC High Speed Rail Mode	Diversions From Automobile Mode	Diversions From Airline Mode	Diversions From Other Masses	Induced Trips
Passenger Miles	391,529,000	238,832,690	113,543,410	39,152,900	N/A
# of Passengers	1,702,300	1,038,403	493,667	120,230	N/A
Passengers/Day	5,674	3,461	1,646	507	N/A
Average Trip Length (Miles)	230	230	230	230	N/A
Days Operation/Year	300	300	300	300	N/A
Mode Occupancy %*	70%	50%	60%	--	N/A

* Mode occupancy percentages based on FHSRTC calculations.

French system is referred to as *train à grande vitesse* (TGV). The train is capable of operating at 185 mph and would travel between Miami and Tampa in 160 min. The TGV proposal includes seven stations. Ridership is forecast to increase from 2.77 million in 1995 to almost 11 million in 2020. These estimates include (a) all intermediate and short trips and (b) an estimated 10.5 percent induced ridership.

For the analysis in this paper, the ridership in 1999 of 5.88 million, with the 617,000 induced riders removed, or 5.26 million trips, will be used as a baseline for the TGV emission benefit estimation. TGV states (*13*):

> The diversion of . . . four million passengers from auto (80% of diverted) and one million from . . . airplane (20% of diverted) in 1999 will result in consumption of 110 million kilowatt hours . . . to transport approximately 5 million passengers. . . . This is equivalent to roughly 11 million gallons of fuel . . . to transport TGV passengers a total of 705 million miles.

Finally, the TGV proposal indicates that each train set would carry 366 passenger seats and consume 9,000 kwh for each one-way trip between Miami and Tampa. The TGV train, therefore, would produce a gross energy consumption of 803 Btu per seat mile. If a passenger per seat occupancy ratio of 70 percent is assumed, the TGV would provide a consumption of 1,147 Btu per passenger-mile (see Table 2).

This energy consumption rate is also higher than the original generic Florida High Speed Rail Study levels (*6*). This system, however, proposes train speeds up to 185 mph, which is considerably above that of the generic Florida HSR systems examined in the study completed in 1984. This energy consumption level is also below that of the FHSRC Fastrain, even though at maximum speed the TGV proposes to operate 35 mph faster than the Fastrain. Most travel times between stations are, however, very close between these two competing systems. The TGV estimates total train weight at 0.975 million lb (1.33 tons) per seat. This is virtually identical to the FHSRC value of 1.36 tons/seat.

These technical components of the TGV modal split, ridership, and energy needs will be used for analysis of the net emission and energy tradeoff reported in this paper for their system.

MAGLEV TRANSIT, INC., PROPOSAL

The Maglev Transit, Inc., proposal was submitted to the FHSRTC by a consortium of Japanese and German manu-

TABLE 2 TGV HSR SYSTEM PROPOSED RIDERSHIP PROFILE

Mode	TGV HSR Mode	Automobile Mode	Airline Mode	Induced Trips
Passenger Miles	735,000,000	526,260,000	131,565,000	77,175,000
# of Passengers	5,262,000	4,210,000	1,052,520	617,400
Passengers/Day	19,600	14,034	3,508	2,058
Average Trip Length (Miles)	140	140	140	140
Days Operation/Year	300	300	300	300
Mode Occupancy %*	70%	50%	60%	0

* Mode occupancy percentages based on FHSRTC calculations.

facturing, banking, and business interests. The German Transrapid maglev system is proposed to operate between the Orlando Airport and the Walt Disney World Epcot Center, a distance of approximately 18 mi, and achieve speeds of 310 mph (see Table 3). The proposal indicates average travel time of 7½ min for the approximately 18 mi between Epcot and the Orlando Airport.

Maglev Transit's application indicates that the system could attract between 6½ and 8½ million (one-way) passenger trips a year during the first years of operation.

In the Maglev Transit system, each maglev coach would carry 100 passenger seats and each train would carry 400 passengers and on average consume 0.11 kwh per seat-mile. Again assuming a 70 percent ridership occupancy factor, the gross energy consumption rate would be 1,573 Btu per passenger mile on this maglev system (Table 4). The Transrapid 07 has an average weight of 0.75 ton per passenger seat for first class and 0.45 ton per passenger seat for second class (see Table 4) (*14*). These weights are considerably lighter than either the TGV- or FHSRC-proposed HSR system, being 34 and 56 percent, respectively, of these systems' average seat weight (see Figure 3).

The proposed operating speed of the Maglev Transit system is five to six times faster than that of the automobile, and as much as twice that of the HSR applicants. Surprisingly, this system consumes only 11 percent more energy than the FHSRC high-speed rail system, although operating at approximately 110 percent higher speeds. This capability is especially interesting given that energy consumption increases as the square of speed. The differences are obviously in weight and technology design. Similarly, although consuming 25 percent more energy than the TGV HSR train, the Maglev Transit system operates at almost 70 percent higher average speed. These are the technical components of the Maglev Transit proposal used in this analysis.

MODEL DEVELOPMENT

Tables 5 and 6 present an overview of the key transportation mode energy efficiencies and the fundamental assumptions and relationships that underlie the development of this model and the research conclusions in this paper. Each of the key HSR and maglev proposals discussed earlier is appropriately factored into the model's specification and summarized in these tables.

Cost of fuel and other pertinent electrical generation information were derived from the Florida Public Service Commission and Florida Power Coordinating Group sources (*7*). Other pertinent transportation modeling information, such as that developed for aircraft emissions and operating conditions, was developed from widely accepted industry standards using relatively conservative assumptions (*11*, *12*).

CENTRAL AND SOUTH FLORIDA-SPECIFIC ELECTRICAL ENERGY PRODUCTION SOURCES AND ESTIMATED EMISSION LEVELS

Perhaps one of the greatest secondary benefits of developing the HSR and maglev transportation networks is the substantial promise that these systems hold for improvements in the environment. These improvements may be second in importance only to slowing down the future increases in environ-

TABLE 3 MAGLEV TRANSIT, INC., PROPOSED SYSTEM

Mode	Maglev Mode	Automobile Mode	Induced Trips
Passenger Miles	144,000,000	144,000,000	0
# of Passengers	8,000,000	8,000,000	0
Passengers/Day	19,600	19,600	0
Average Trip Length (Miles)	18	18	0
Days Operation/Year	300	300	0
Mode Occupancy %*	70%	50%	0

*Mode occupancy percentages based on FHSRTC calculations.

TABLE 4 ENERGY EFFICIENCIES OF THE TRANSPORTATION MODES CONSIDERED

	MAGLEV ENERGY CONSUMPTION		.GV ENERGY CONSUMPTION	FHSRC ENERGY CONSUMPTION	AUTOMOBILE ENERGY CONSUMPTION	
kWh per/seat mile	0.11	MIAMI-TAMPA kWh	9,000	14,000	PASSENGERS/AUTO	1.9
NET Btus/Seat Mile	366	#SEATS/PER TRAIN	366	480	MILES/GALLON	20
GROSS Btus/seat mile	1,099	MILES/TRIP	306	300	Btus/gallon	125,000
Assumed capacity factor	0.70	TOTAL SEAT MILES/TRI	111,996	144,000	PASSENGER MILE/GALLON	38
Reciprocal of cap factor	1.43	NET Btu/trip	30,000,000	46,666,666	Btus/PASSENGER MILE	3,289
GROSS Btus/pass mile	1,570	Gross But/trip	90,000,000	140,000,000		
		gross Btu/seat mile	804	972		
		gross Btu/pass mile	1,148	1,389		

TABLE 5 THE FLORIDA HIGH SPEED RAIL CORPORATION (FASTRAIN) AND MAGLEV ENERGY ESTIMATES

Mode	Max. Speed	Avg. Speed	Energy Consumption Btu's/Mile/ Passenger	Auto	Air Plane	Maglev	FHSRC
FHSRC (FAS-TRAIN)	150+	130	1,388	2.25	4.48	1.13	1.00
Maglev	311	144	1,570	1.99	3.96	1.00	0.88
Auto-mobile	65	45	3,125	1.00	1.99	0.50	0.44
Airplane	500	450	6,220	0.50	1.00	0.25	0.22

Maglev and HSR mode passenger mile energy consumption is estimated for gross energy consumed at electrical generation station.

TABLE 6 TGV AND MAGLEV ENERGY ESTIMATES

Mode	Max. Speed	Avg. Speed	Energy Consumption Btu's/Mile/ Passenger	Auto	Air Plane	Maglev	The TGV
The TGV	185	130	1,148	2.72	5.42	1.13	1.00
Maglev	311	144	1,570	1.99	3.96	1.00	0.73
Auto-mobile	65	55	3,125	1.00	1.99	0.50	0.37
Airplane	500	450	6,220	0.50	1.00	0.25	0.18

Maglev and HSR mode passenger mile energy consumption is estimated for gross energy consumed at electrical generation station.

mental degradation that are inevitable with expansion of conventional transportation systems. In other words, one benefit is displacement of existing higher-polluting automobile and air traffic and the second benefit is to reduce or displace future demand for these higher-polluting modes.

These potential environmental improvements, like the increases in economic efficiency, owe their existence to HSR and maglev use of relatively clean stationary sources of energy production. As described earlier, electric power plants use diverse fuel source mixes to produce efficient energy and can use and manage large and efficient emission control technologies. These abilities result in substantial improvements in air pollution emissions over conventional transportation technologies in all but one regulated pollutant. Figure 1 shows that 15.4 percent of electrical generation is from nuclear sources, whereas 32 percent is from coal. Fuel for over 47 percent of this region's electrical generation is from sources that are not foreign controlled. Given that much oil and natural gas is domestic, the actual total domestic supply of fuel is much higher.

All power plant emission estimates in this model are derived from averaging historic 2-year (1986–1987) actual emissions from all major power plants in operation in central and south Florida. Table 7 presents a summary of all electric generation facilities serving central and south Florida and the results of 2 years of emission monitoring for principal pollutants. These data were derived from the Florida Department of Environmental Regulation (*9*) and were systematically analyzed to derive weighted averages of annual emissions for the region.

Southeast and central Florida were divided into three geographic electrical service areas. The first is the Tampa Bay

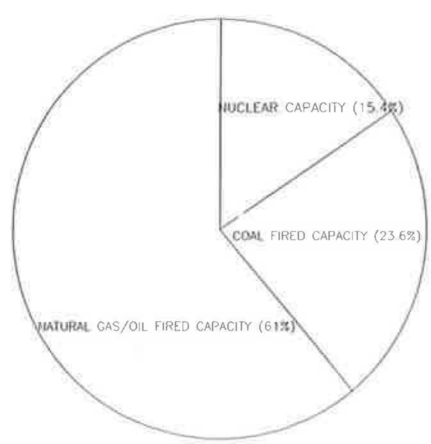

FIGURE 1 Central and south Florida available electric generation by fuel type.

TABLE 7 ELECTRIC POWER PLANT AND ANNUAL POLLUTION EMISSIONS INVENTORY 1986–1987

REGION #3 & OPERATOR	FACILITY NAME	TOTAL SITE MW	YEAR	VOC	SOx	PM	NOx	CO
3 FPL	CANAVERAL PL	800	1986	17	924	106	3,740	
3		800	1987	28	2,540	262	7,090	518
3 FPL	PT EVERGLADE	800	1986	80	12,061	4,657	9,019	991
3		1820	1987	45	7,759	666	6,369	490
3 FPL	LAUDERDALE	1400	1986	3	258	66	2,313	802
3		1400	1987	4	230	39	1,531	168
3 FPL	SANFORD	1000	1986	27	3,748	314	2,130	158
3		1000	1987	7	1,271	170	560	39
3 FPL	RIVIERA	700	1986	28	3,040	297	6,190	453
3		700	1987	17	1,115	131	4,820	351
3 FPL.	TURKEY POINT	2450	1986	64	9,340	833	10,300	757
3	1600 NUCLEAR	2450	1987	50	7,360	655	9,000	661
3 FPL	MARTIN	1600	1986	21	2,199	217	3,219	236
3		1600	1987	73	71,772	563	9,490	697
3 FPL	FT MYERS	1600	1986	33	6,949	484	3,020	246
3		1600	1987	73	10,214	839	4,436	340
3 FPL	ST LUCY	1800	1986	0	0	0	0	0
3	NUCLEAR	1800	1987	0	0	0	0	0
3 FPL	MANATEE	1600	1986	161	32200	2660	14220	1062
		1600	1987	102	20890	1711		
REGION 3 TWO YEAR TOTAL		29,540		830	193,870	14,670	106,457	8,642
ONE YEAR AVERAGE		14,770		415	96,935	7,335	53,229	4,321
FACILITIES' CAPACITY FACTOR=.75								
MWH ANNUAL AVERAGE=97,038,900								
REGION 3 LBS OF EMISSION/MWH				0.009	1.998	0.151	1.097	0.089

REGION #2				VOC	SOx	PM	NOx	CO
2 ORLANDO	INDIAN RIVER	618	1986		4,540	188	3,100	227
2	COAL	618	1987		1,192	98	1,879	121
2 ORLANDO	STANTON CENTER	460	1986					
2	COAL	460	1987		848	42	2,087	
2 ORLANDO	BARTOW	200	1986	0	0	3	6	1
2		200	1987	0	0	80	15	1
2 LAKELAND	LAKELAND	400	1986		2,327	161		
2		400	1987		312	23	49	
2 LAKELAND	MCINTOSH	400	1986		4,561	325		
2		400	1987		4,522	213	3,977	
2 FLORIDA POWER	INTERCESSION	400	1986					
2		400	1987		64	13	173	
2 FLORIDA POWER	DELTONA	420	1986		2,382	53	773	
2		420	1987		2,347	97	620	
TOTAL 2 YEARS		5,796		0	18,302	1,133	11,113	350
ONE YEAR AVERAGE		2,898		0	9,151	567	5,557	175
POWER PLANT CAPACITY FACTOR=.75								
ANNUAL AVAILABLE MWH= 19,039,860								
				VOC	SOx	PM	NOx	CO
REGION 2 LBS OF EMISSIONS/MWH				0.000	0.961	0.060	0.584	0.018

REGION #1				VOC	SOx	PM	NOx	CO
1 FLORIDA POWER BARTOW		800	1986	14	23,069	480	3,719	
1		800	1987		18,550	523	2,607	
1 FLORIDA POWER HIGGINS		300	1986		1,983	44	665	
1		300	1987		2,254	67	637	
1 FLORIDA POWER BAYBORO		300	1986		1	11	142	
1		300	1987		42	5	70	
1 FLORIDA P. CRYSTAL RIVER		3,400	1986		84,564	1,524	41,306	
1 COAL & NUCLEAR (800)		3,400	1987		86,018	1,429	42,509	1,725
1 FLORIDA POWER ANCLOTE		1,200	1986		19,178	718	6,039	0
1		1,200	1987		17,742	1,123	5,521	557
1 TECO	HOOKER PT	250	1986	2	325	12	133	12
1	COAL	250	1987					
1 TECO	BIG BEND	1,880	1986	131	132,887	2,604	43,108	1,109
1	COAL	1,880	1987	160	152,151	2,770	48,404	1,347
1 TECO	GANNON	1,500	1986	77	44,584	1,663	39,810	647
1		1,500	1987	197	51,802	1,618	47,058	763
TWO YEAR TOTALS		19,260		581	635,150	14,591	281,728	6,160
ANNUAL AVERAGE		9,630		290	317,575	7,295	140,864	3,080
# MWH/YR 63,269,100								
ANNUAL FACILITIES CAPACITY FACTOR=.75				VOC	SOx	PM	NOx	CO
REGION 3 POUNDS OF EMISSIONS/MWH				0.009	10.039	0.231	4.453	0.097

SUMMARY	VOC	SOx	PM	NOx	CO
REGION 1 LBS/MWH-TAMPA	0.009	10.039	0.231	4.453	0.097
REGION 2 LBS/MWH-ORLANDO	0.009	0.961	0.060	0.584	0.097
REGION 3 LBS/MWH-SOUTH EAST FLORIDA	0.009	1.998	0.151	1.097	0.089

* CO AND VOC FOR REGION 2 AND VOC FOR REGION 3 ARE ADAPTED FROM REGION 1 DUE TO DATA

FHSRC AND TGV RAIL ALIGNMENT WITHIN EACH UTILITY REGION

HSR	CORRIDOR MILE	PERCENT OF TOTAL
TAMPA	30	9.09%
ORLANDO	220	66.67%
SOUTH	80	24.24%
TOTAL	330	100.00%*

	REGION 3 MW	REGION 3 PERCENT	REGION 2 MW	REGION 2 PERCENT	REGION 1 MW	REGION 1 PERCENT	ALL REGIONS MW	ALL REGIONS PERCENT
ANNUAL AVAILABLE MW CAPACITY	9,630	100%	2,898	100%	14,770	100%	27,298	100%
ANNUAL AVAILABLE NUCLEAR CAPACITY	3,400	35%	0	0%	800	5%	4,200	15%
ANNUAL COAL CAPACITY	2,130	22%	460	16%	6,150	42%	8,740	32%
ANNUAL OIL/NATURAL GA	4,100	43%	2,438	84%	7,820	53%	14,358	53%
TOTAL	9,630	100	2,898	100%	14,770	100%	27,298	100%

area, including all of the power stations of the Tampa Electric Company and some of those of the Florida Power Corporation. The second is the greater Orlando area, with power plants owned and operated by Orlando and Lakeland Utilities and some Florida Power Corporation facilities. The third and largest region is southeast Florida, containing all the generation capacity of Florida Power and Light. Table 7 presents data for the power plants within each region.

Next, a unique megawatt-hour (MWh) emissions factor was calculated for the five principal pollutants reported in the Florida Department of Environmental Regulation (FDER) and Environmental Protection Agency (EPA) air emissions inventory (*11*). They are volatile organic compounds (VOC), sulfur oxides (SO_x), nitrogen oxides (NO_x), total suspended particulates (TSP), and carbon monoxide (CO). In several cases, most notably VOC and CO, missing data were apparent for Regions 1 and 2. The VOC and CO emissions factors from Region 1 were used in these cases to avoid biased low emissions projections for these regions.

HSR and maglev mileage within each electrical generation service area was estimated. Then, each HSR and maglev system's energy requirements were calculated for each region. Total annual HSR and maglev MWh electrical demand for each system was combined with each unique region's emission factor to yield total system emission by region. The HSR and maglev transportation system emissions were then aggregated and finally compared with those of the automobile and airplane transportation emissions calculated earlier.

These regions and their unique fuel consumption mix also serve as the basis for estimation of fossil fuel consumption analysis, oil import demand differential, and net energy consumption estimation for the HSR and maglev modes.

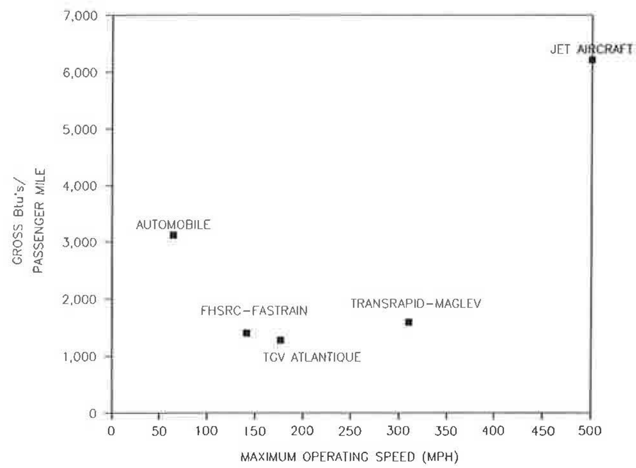

FIGURE 2 Comparative gross energy consumption per passenger mile for each transport mode considered.

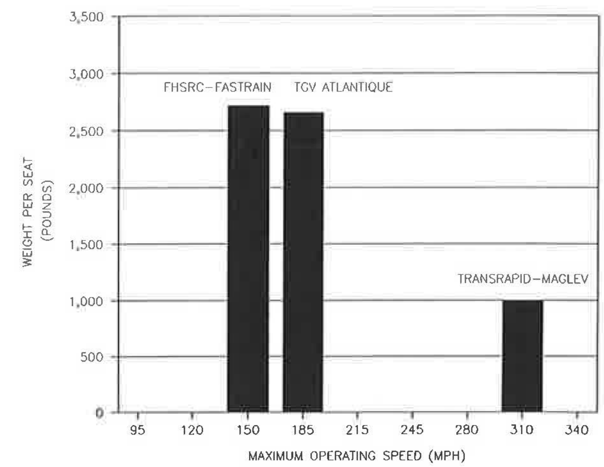

FIGURE 3 Weight per seat for the HSR and maglev transit systems.

ENERGY CONSUMPTION AND AIR POLLUTION EMISSIONS OF HSR AND MAGLEV COMPARED WITH OTHER TRANSPORTATION MODES AT FORECAST RIDERSHIP LEVELS

HSR and maglev systems generally have two to three times the gross energy efficiency of the automobile while offering average commuting speeds from three to six times faster. Comparably, HSR and maglev maintain considerable energy efficiency advantages over the airplane while offering competitive transportation time service levels. Florida HSR studies indicate that the HSR and maglev systems would enjoy a gross energy consumption (number of total Btu per passenger mile) efficiency between four and five times that of the airplane (*2*, *4*) (see Tables 5 and 6 and Figures 2 and 3).

As described earlier, the two proposed Florida HSR and maglev systems would consume 1,148 to 1,570 Btu per passenger-mile compared with 3,125 and 6,220 Btu per passenger-mile for the automobile and airplane, respectively. These efficiencies can vary according to the technology under examination, the average operating speed, occupancy rate, and a variety of other system characteristics. However, these general efficiency levels are most appropriate for the model reported in this paper, given the precise proposals designed for Florida-specific systems.

The total energy requirement to transport the 1.7 million FHSRC passengers annually is 0.53 trillion Btu. Comparable automobile and air modes would consume 1.57 trillion Btu. By contrast, to transport the proposed 5.2 million TGV passengers annually would require 0.86 trillion Btu in Florida. The same volume of passengers using automobile and air modes would require 2.46 trillion Btu. Total energy consumption for the HSR proposals and the existing modal shares of passenger volume is only one-third that of the automobile and air modes.

The Orlando maglev proposal indicates that total fossil fuel consumption for movement of as many as 8 million one-way trips would consume 0.251 trillion Btu of energy compared with the 0.526 trillion Btu consumed by the automobile annually. Total net energy savings for the HSR and maglev systems in Florida for 1999 would range from 1.35 to 1.875 trillion Btu.

These comparisons suggest that a substantial reduction in energy consumption would result from diversion of automobile and air travel to HSR and maglev systems. In addition, the following benefits would result:

1. Consumption of nonfossil fuels for transportation (15 percent in central and south Florida).

2. Consumption of less expensive (unrefined oil and coal) domestic and foreign sources of fossil fuels for transportation systems.

3. Consumption of more plentiful and less expensive domestic sources of fossil fuels for transportation systems (reducing U.S. economic dependence on foreign sources of energy).

4. Substantial reductions in air pollution emissions (because central station fossil fuel emissions can more efficiently remove pollution than numerous small nonpoint mobile sources such as automobiles and airplanes).

5. Transportation of passengers, goods, and services over the same distance for approximately the same energy consumption level in one-third to one-sixth the time.

6. Enhancement of overall high-technology growth of the economy by raising the quality of economic productivity and competitiveness.

HSR AND MAGLEV ECONOMIC BENEFITS

General Economic Benefits

The central thrust of much economic study is the examination of the distribution and use of scarce resources among competing demands. These scarce resources can be a natural resource like fossil fuel and iron ore for manufacturing or the scarce human resources of skilled labor and time itself. Each has a value and each contributes to the economic value of the nation's gross national product (GNP). More efficient use of these resources increases the nation's productivity, quality of life, and the GNP itself as the economy's given annual net scarce-resource assets go further and further in creating wealth and human well-being.

This phenomenon is easily grasped by recalling the enormous strides in productivity that this country and the developed world have made since the end of World War II. War-induced scientific discoveries and large-scale automation of industrial production led to substantial growth in U.S. manufacturing output in the five decades after World War II.

These technological enhancements were coupled with considerable improvement in the skill level of American workers. Many of these improvements were given an artificial boost by the necessities of war and its associated need for large numbers of highly trained technicians to operate and maintain the increasingly complex mechanisms of war. A comparable push on the home front propelled large numbers of untrained workers into technical support jobs designing, manufacturing, and maintaining the machines of war within American factories.

These war-stimulated technological discoveries and broad-based gains in formal educational attainments and skilled worker training were unprecedented in world history and reached across a broad base of the American work force. These trends, which continued into the decades after the war and up to the present, were the underpinning of the giant gains in economic growth and improvements in the quality of life that this nation has achieved during the past 45 years.

In recent years, with the advent of computer automation, gains in productivity and quality of life are readily apparent. Computers have enhanced productivity in manufacturing, office automation, research and design, communications, medicine, the home, and a number of other important areas.

Energy efficiency has also evolved as a critical issue for resource conservation in the wake of the tripling of oil prices by the Organization of Petroleum Exporting Countries over the period 1973 to 1977. American productive economies responded well to this resource challenge even though energy prices are now as inexpensive as at any time in the past few decades. Between 1973 and 1985, the amount of energy needed to produce one unit of GNP within the industrialized world fell by 20 percent. In the United States alone, GNP grew by 40 percent during that period, whereas consumption of energy stayed relatively constant (*15*).

Each time a scarce resource such as an hour of time or a kilowatt-hour of energy is saved (because of the enhanced productivity of the computer or other advances), that resource is also liberated for additional productive use within the economy. That additional hour of labor or kilowatt-hour of energy can add more to productivity elsewhere within the economy. The wealth of the nation's GNP and the national quality of life are commensurately enhanced.

So it is with HSR and maglev transportation systems that conserve natural and productive resources and travel time. The general economic efficiencies of HSR and maglev systems would enable the state and national economies to do more with expenditure of fewer resources.

Integration of technological advances can dramatically reduce the amount of energy required to produce a given level of goods and services and simultaneously reduce energy demands worldwide. Innovations like HSR and maglev can enhance energy efficiency and help reduce American dependence on foreign sources of fossil fuel without sacrificing economic growth (*15*) or quality of life.

As Europeans know, the technical and commercial productivity for HSR systems is much higher than that of conventional train operations. In a recent report (*16*), the European HSR community indicated that HSR operation makes much more efficient use of rolling stock fleets. HSR rolling stock can operate over two to three times the distances of conventional rolling stock annually. Where conventional rolling stock operates over 100,000- to 200,000-km routes (60,000 to 120,000 mi) per year, HSR rolling stock can operate over 300,000- to 400,000-km routes (180,000 to 240,000 mi) annually.

Furthermore, fleet uniformity and specialized maintenance equipment enable the rolling stock to be more efficiently maintained and keep the existing stock in better condition and more available than average conventional train sets. Finally and most important, the high speed of the service enables much higher productivity of train crews, operational and commercial staff, and other administrative and technical support. Much more route, equipment, and passenger mileage per unit of labor is possible with the HSR systems than with conventional systems. As a result, productivity and profits are both considerably higher than for conventional systems.

HSR and maglev systems provide the safest and highest quality, time-efficient transportation services with a time savings factor of three to six times that of the automobile at one-third to one-half the level of energy and other resource consumption of the automobile and one-fifth that of the airplane. Stated differently, the HSR systems can transport three times as many persons or goods to any given destination on average three times faster than the automobile, using the same amount of energy. Maglev can deliver twice as many persons or goods

any distance at over five times the speed for equivalent energy. These savings of energy, time, money, and reductions in accident costs and vehicle wear can be released for other productive purposes within the economy and further stimulate the GNP. Furthermore, these gains would enhance the quantity and quality of leisure time and thereby add to the economy's quality of life and general productivity.

The value of a number of these benefits can be quantified and are the basis of some of the economic benefits projected and reported here for the HSR and maglev systems proposed for Florida.

Travel Time Savings

Tables 5 and 6 itemize the proposed HSR and maglev annual 1999 passenger miles traveled and list the travel mode splits for these passengers without high-speed systems. These travel levels are estimated and do not include induced ridership for any of the systems examined. The proposed TGV stations in the greater Orlando area involve the same market as the maglev system. Therefore, a net reduction of 241,000 TGV passengers in that market segment were removed from the TGV passenger estimates to avoid double-counting potential passenger miles when the systems are combined.

The average TGV passenger trip is 125 mi, whereas the FHSRC average length is 230 mi. This estimated length (derived from actual proposed length from origin to destination and passenger volume) is from each technology's respective travel forecasts in Florida. The FHSRC excluded all short-distance trips and induced ridership. The TGV included both long and short trips and induced ridership. Again, induced ridership was removed from the TGV projections to ensure comparability in evaluation of benefits. The average one-way travel length for the maglev rider is approximately 18 mi.

Researchers often equate the hourly value of time savings and the per capita earning potential of the traveler, which for Floridians in 1990 is \$8.43. The value of travel time is the basis of estimated economic savings in this analysis. This 1990 estimate of value of time is likely conservative for a variety of reasons. First, a large segment of the HSR travelers are business-related travelers, and they and the recreational traveler would both have higher-than-average earning potential. Second, a number of travelers for either system would be out-of-state visitors. Again, such travelers would have considerably higher income, on average, than the Florida per capita level. Finally, AASHTO estimates that the annual savings for the traveling public should be \$9.27 per hour saved (*17*). This AASHTO estimate and a higher FAA (*18*) estimate are also frequently used for such benefit estimation and were the basis for the original Barton-Aschman Florida HSR study (*6*). The conservative nature of the lower value used in these estimates helps understate the potential value of these time savings benefits.

The value of saved traveling time on each of the HSR and maglev systems is presented in Table 8. The additive value of time savings when the maglev system is combined with each HSR system is also presented in Table 8. Figures 4 and 5 show bar graphs of the value of the combined HSR and maglev system time savings benefits. All estimates include standard access time, en route time, and egress time determined by Barton-Aschman (*6*). The time savings values shown in Figure 4 are most dependent on access time, travel time, and number of passengers. FHSRC ridership levels have considerably less time savings because the number of passengers initially estimated for the FHSRC system is less than half that for the TGV system.

The TGV potential time savings value exceeds \$77 million for 1999. Comparatively, the FHSRC time savings benefit for that year is 46 percent of that, or \$33 million. Finally, the maglev time savings value is estimated at \$59 million for 1999. Thus, travelers within Florida could receive between \$92 and \$136 million in travel benefits in 1 year alone from implementation of HSR and the maglev systems within the state.

Reduced Automobile Maintenance and Vehicle Wear

A second very important area of potential economic savings would result from reduced wear and tear and maintenance costs for millions of personal automobiles across the state. These estimated gross wear and maintenance costs are exclusive of any fuel costs, which are addressed elsewhere in this paper. Related reduced deterioration of existing roadways and other infrastructure (such as bridges) is also a potential area of savings but is beyond the scope of this analysis.

It is difficult, if not impossible, to estimate the costs of less wear and tear from substitution of the proposed HSR and maglev systems at these proposed levels of ridership, because neither system is operational within Florida, but clearly the magnitude of the expense of individual automobile deterioration far exceeds those of the proposed systems. Although the gross estimated automobile vehicle wear and maintenance costs may overstate the true net benefit of replacement of the automobile, other potential benefits not included (such as savings in roadway and other infrastructure wear costs) tend to make this estimate conservative.

These unknown benefit levels may very well balance out, and until more precise information is available, the AASHTO automobile wear and maintenance projection provides the best possible estimate of the benefits of lower automobile deterioration costs attributable to implementation of HSR and maglev systems in Florida (*17*). AASHTO estimates \$0.165/mi for vehicle operating cost. One-fourth of this cost is fuel related; therefore, \$0.118/mi is the final cost for automobile maintenance and wear.

Automobile operation and maintenance costs are estimated to be \$34.3 and \$25.5 million less for the TGV and FHSRC proposals, respectively, for the year 1999 alone (see Table 9 and Figures 4 and 5). The maglev proposal will lower automobile maintenance expenses for 1999 by an additional \$9.9 million.

Statewide potential benefits from lower automobile wear and maintenance expenses for 1999 from a combined HSR and maglev system would range from \$35.4 to \$44.2 million for 1999 alone.

Fewer Automobile Accidents and Reduced Property and Injury Losses

Another important category of potential economic benefits would result from reduced automobile accidents and property

TABLE 8 MAGLEV VALUE OF TRAVEL TIME DIFFERENCE OVER THE AUTOMOBILE

		TRIP HOURS ENROUTE	ACCESS TIME BOTH TRIP ENDS	# HOURS ENROUTE	# HOURS ACCESSING MODE	# HOURS ENROUTE & ACCESSING	TRAVEL TIME CONSUMER COS
AUTO SPEED IN MPH	40	0.45	1.25	3,600,000	10,000,000	13,600,000	$114,648,000
MAG LEV AVERAGE SPEED	250	0.07	0.75	576,000	6,000,000	6,576,000	$55,435,680

MAGLEV TRAVEL TIME SAVINGS= $59,212,320

# PERSONS	8,000,000
TIME VALUE PER HOUR TRAVEL	$8.43
AVERAGE TRIP LENGTH (MILES)	18

Time Travel Savings/Maglev Trip = $7.40

FLORIDA HIGH SPEED RAIL CORP VALUE OF TRAVEL TIME DIFFERENCE OVER THE AUTOMOBILE AND AIRPLANE

	TRANSPORT MODE AVER SPEED (MPH	TRIP HOURS ENROUTE	ACCESS TIME BOTH TRIP ENDS	# HOURS ENROUTE	# HOURS ACCESSING MODE	# HOURS ENROUTE & ACCESSING	TRAVEL TIME CONSUMER COS
AUTOMOBILE MODE	45	5.11	0.75	6,177,458	906,475	7,083,932	$56,124,471
AIRCRAFT MODE	400	0.51	1.75	252,319	863,917	1,116,236	$9,414,334
FHSRC HSR SYSTEM	135	1.53	0.75	2,610,038	1,276,649	3,886,688	$32,780,324

MAGLEV TRAVEL TIME SAVINGS= $32,758,480

# AUTO PERSON TRIPS/YEAR	1,208,633	
# HSR PERSON TRIPS/YEAR	1,702,199	
# AIRPLANE PERSON TRIPS/YEAR	493,667	
TIME VALUE PER HOUR TRAVEL	$8.43	
AVERAGE TRIP LENGTH (MILES)	230	AUTO

Time Travel Savings/HSR Trip = $19.24*

THE TGV OF FLORIDA VALUE OF TRAVEL TIME DIFFERENCE OVER THE AUTOMOBILE AND AIRPLANE

	TRANSPORT MODE AVER SPEED (MPH	TRIP HOURS ENROUTE	ACCESS TIME BOTH TRIP ENDS	# HOURS ENROUTE	# HOURS ACCESSING MODE	# HOURS ENROUTE & ACCESSING	TRAVEL TIME CONSUMER COS
AUTOMOBILE MODE	45	3.13	0.75	12,406,500	2,977,560	15,384,060	$129,749,162
AIRCRAFT MODE	400	0.31	1.75	328,913	1,841,910	2,170,823	$18,308,717
THE TGV HSR SYSTEM	135	0.93	0.75	4,650,556	3,766,950	8,417,506	$70,993,242

TRAVEL TIME SAVINGS $77,064,637 **

# AUTO PERSON TRIPS/YEAR	3,970,080
# HSR PERSON TRIPS/YEAR	5,022,600
# AIRPLANE PERSON TRIPS/YEAR	1,052,520
TIME VALUE PER HOUR TRAVEL	$8.43
TRIP LENGTH EACH WAY=	125

Time Travel Savings/HSR Trip = $15.34*

TOTAL HSR AND MAGLEV TIME SAVINGS

FHSRC & MAGLEV	$91,970,800
TGV & MAGLEV	$136,276,957

* Savings per trip are higher for the FHSRC than the TGV Company based predominantly on longer average trip length of the FHSRC estimates.

** The TGV Company total time savings values are higher than those of the FHSRC because of the considerably larger number of passenger trips estimated for the TGV system.

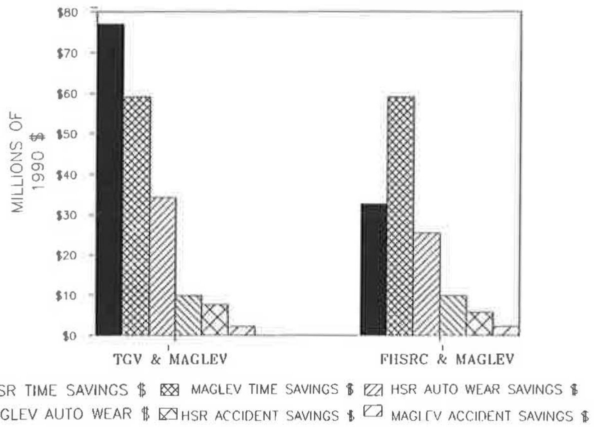

FIGURE 4 Comparison of individual economic benefits of operating the HSR and maglev systems in Florida for 1999.

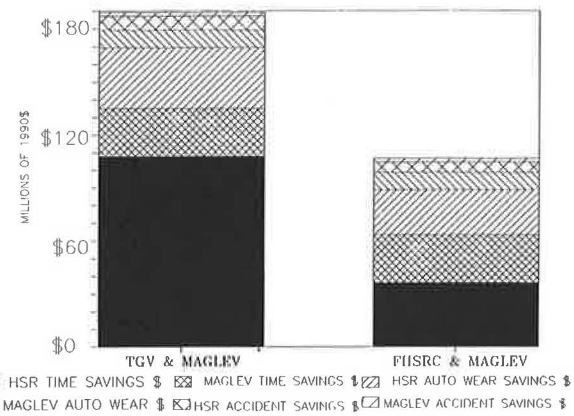

FIGURE 5 Comparison of total economic benefits of operating the HSR and maglev systems in Florida for 1999.

and injury losses. AASHTO estimates (using 1990 dollars) the per mile cost of automobile accident damage and injury costs at $0.0252 (*19*). Automobile accident cost savings (system benefits) for 1999 are presented in Table 10 and Figures 4 and 5 for each proposed HSR and maglev system. The TGV system's proposed highest system ridership again provides the highest level of potential benefits, $7.6 million annually by 1999; that for FHSRC is somewhat less at $5.7 million, and the maglev proposal savings is $2.2 million. Combining the HSR and maglev systems results in an annual 1999 statewide savings in automobile accident costs of $7.9 to $9.9 million.

Reduced Highway Infrastructure Expenditures in Florida

Florida, like America's other major areas of growth, is facing overwhelming increases in demand for transportation infrastructure. This demand, when combined with serious constraints on budgets and physical capacity to fulfill needed airport and roadway expansion, is one of the most serious issues that Americans collectively face. HSR and maglev may offer a workable alternative to help address these ever-increasing demands that must be met with shrinking resources. A recent study in Florida that examined demands for state

TABLE 9 AUTOMOBILE WEAR AND MAINTENANCE SAVINGS

	Savings ($)	
	TGV-Maglev	FHSRC-Maglev
HSR	34,276,145	25,499,389
Maglev	9,915,789	9,915,789
Total	44,191,934	35,415,178

TABLE 10 AUTOMOBILE ACCIDENT SAVINGS

	Savings ($)	
	TGV-Maglev	FHSRC-Maglev
HSR	7,672,317	5,707,742
Maglev	2,216,000	2,216,000
Total	9,888,317	7,923,742

public infrastructure estimated that the cost for the next 10 years for future growth alone will exceed $53 billion.

Transportation entails the largest share of that demand—a 1989 Florida Department of Transportation (FDOT) study that measures traffic volume by comparing the number of cars and paved miles in Florida indicated that vehicles per highway mile in Florida have increased by 50 percent in the last 8 years alone. For every paved mile in the state 8 years ago, there were two cars on the road. Now there are three. Highway capacity construction cannot keep up with the demand. HSR and maglev would complement other modes of travel in Florida by predominantly serving the intermediate-haul markets, whereas the automobile and airplane would dominate the short- and long-haul (over 300 mi) markets, respectively. Construction of a statewide HSR system could potentially save many millions and perhaps billions of public-sector dollars in highway capacity construction. For example, FDOT estimated that a $1 billion savings in highway capacity construction will result when the statewide HSR system is completed.

No comparable estimate is available for the Orlando maglev system, but after an established ridership develops, this system is also expected to result in local infrastructure savings.

Increased Employment and Income

Potential employment and income gains related to HSR and maglev may be viewed as transfers from other sectors of the Florida economy. It can be argued that if the HSR system were not completed, the monies would be expended elsewhere within the state's economy and would entail those of the same resources for other purposes. For example, these funds might be used for construction of new roads, tourist attractions, and service jobs to operate such facilities. Although the argument contains a certain logic, in this setting it is fundamentally flawed. Both the HSR and maglev systems are completely new concepts and would draw to the state both new financial resources and new bases of high-technology manufacturing and research. Most of the resources expended on these projects would not simply be reallocated within the

state if the systems were not built: The resources simply would not exist, because many of the dollars to construct these facilities would originate from sources outside the United States. It is therefore meaningful and important to examine the potential economic impact of increased employment and income resulting from construction and operation of the HSR and maglev systems.

The TGV of Florida proposal indicates that its system would typically generate employment of 4,558 persons, 29,980 man-years of direct construction employment, and secondary employment of 186,499 induced from construction.

The system proposed by TGV of Florida would typically generate $291 million annually in direct and indirect operations employment income, $800 million in total direct construction income, and $19.5 billion indirect income from construction.

The proposal submitted by Maglev Transit indicates that development and operation of their maglev system in Florida would typically result in $300 million in direct local expenditures, $75 million in indirect regional income, $15 million in state and local taxes, and $45 million in annual operating and maintenance costs. This system would also result in 1,500 construction jobs, 5,000 indirect full-time jobs, and 350 permanent jobs.

No comparable employment and income information is available from the FHSRC at this time, but the impacts would be considerable, long term, and of the same magnitude as those of the two other systems.

Reduced Dependence on Fossil Fuels for Transportation

Important to the HSR and maglev economic efficiency issues are the kind, source, and cost of competing energy supplies used in producing electricity to power the HSR and maglev technologies. Domestic sources of coal and nuclear-powered electrical energy enjoy a considerable economic advantage over predominantly imported residual fuel oil sources of power (*7*). The United States has sufficient coal reserves to fuel the economy for the next 260 years (*15*). In south and central Florida, 32 percent of the electrical energy produced is generated from domestic coal, whereas 15.4 percent is from nuclear power (*7*) (see Table 7 and Figure 6). Combining this advantage with the fact that HSR and maglev are two to three times more energy efficient at three times the service (speed) levels of the automobile and five times as efficient as the airplane at comparable travel times provides an insight into the technology's principal economic energy advantages.

As an example, to transport all of the proposed TGV-HSR and maglev passengers in 1999 by automobile and airplane would require up to $33.4 million in fossil fuels. To transport the same number of passengers the equivalent distance by maglev and HSR would cost only $3.1 million in fossil fuels. This translates into a potential fossil fuel savings within the economy of $30.3 million.

Although these are accurate facts in contemporary America, greater promise of substantial advances in areas of electrical energy production are on the horizon (*20*). These and other advances hold great promise of further accentuating the economic, environmental, and energy advantages of HSR and

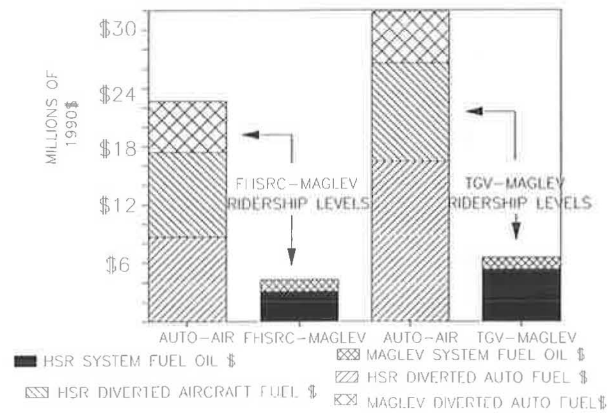

FIGURE 6 Comparison of oil import needs for the airplane and automobile versus the HSR and maglev transportation modes.

maglev over conventional transportation systems (*21*). This greater fossil fuel efficiency can be put to more productive use elsewhere in the economy and would result in even greater primary and secondary economic returns from the net national wealth.

Hand in hand with the HSR and maglev increased economic and energy efficiencies and related reliance on more diverse sources of energy production is the potential for substantial reduction in reliance on foreign sources of fossil fuels for U.S. transportation systems. Again, this would result because much of the HSR and maglev energy supply relies on non-oil-based fossil and nonfossil fuels for operation. Almost half, or 47.4 percent, of electrical power in central and south Florida is either coal fired or nuclear generated.

Development of an HSR and maglev system on the scale being examined in Florida would result in displacement of need for 14 to 20 million gal of expensive imported and then refined fuel oil for 1999 alone. Development of the HSR and maglev systems could reduce oil imports by well over 20 million gal annually by 2020 for Florida alone. These savings would translate into reduced purchases of foreign fossil fuels and therefore a reduced balance of payments of $24.3 and $31.5 million. Modal shifts to the new system offer prospects of annual foreign debt reductions in the future exceeding $50 million by 2020.

This substantial reduction in foreign imports would result in

1. Strengthening U.S. energy independence,
2. Helping to equalize the international negative balance of payments,
3. Increasing domestic security, and
4. Reducing the vulnerability of the American economy to international economic fluctuation such as oil price variations.

Reduced Negative Environmental Externalities

Concurrent with enhanced productivity are the systems-associated benefits of reductions in air and water pollution emissions, quantified in the other sections of this paper. These emission reductions would likely result in a reduction in fac-

tors associated with higher automobile emissions, such as respiratory illness, materials and crop damage, and a variety of other ecological stresses. These economic cost factors, called "negative economic externalities," are undesirable byproducts of pollution. As an example, it is estimated that acid rain-induced materials damage alone in the United States exceeds $16.25 per person annually (*22*).

Such projections are beyond the scope of this analysis given the complexity of developing air pollution dispersion models and risk assessment analysis of the individuals and receptors at risk. This paper does not attempt to estimate the potential range of the benefits from HSR and maglev on environmental externalities because of the complexity of such an undertaking. Nor does this paper attempt to examine some other potential environmental risks associated with these technologies, such as electromagnetic field exposures. Only net air pollution emissions tradeoffs among the transportation technologies are examined.

However, reduced negative externalities represent real HSR and maglev potential economic benefits. These benefits are achieved by substituting the lower HSR and maglev net per-passenger emissions for the higher automobile and airplane emissions. Because these benefits are not quantified, they are discussed qualitatively within the context of each reduction in air pollution emission estimated.

HSR and Maglev Elasticities and Growth in Economic Benefits

Needless to say, the economic benefits of the HSR and maglev systems grow as rapidly as the ridership of these systems expands. A logical question, then, is what principal factors influence the growth of these societal (ridership-related) benefits and at what rate do these benefits grow?

A detailed answer to these questions is beyond the scope of the analysis in this paper. Nevertheless, it is an important issue, and it is possible to creditably address these issues from a macroeconomic perspective with a brief discussion of system elasticities. An elasticity measures the amount of change in one dependent variable, such as ridership or revenue, as an independent variable, such as trip time, changes. Usually, ridership studies examine how much ridership and ridership-related revenue change as trip times increase or decrease by 10 percent.

Response to this issue is of special interest because both HSR applicants completed separate analyses in a competitive environment, and they concluded with very similar ridership elasticities. The conclusions of these ridership studies were completed by two consultants who specialize in ridership studies. (FHSRC employed Charles River Associates and the TGV employed Peat Marwick Main & Company.) The conclusions offer the clearest empirical insight into the benefits of increases in HSR and maglev ridership for markets in Florida and elsewhere in the United States. Maglev markets particularly seem to hold great promise if the ridership-trip time arc elasticity relationships discussed here continue to hold over the 185- to 300-mph speeds and over intermediate (100- to 500-mi) distances.

The TGV analysis demonstrates highly sensitive trip time ridership and revenue elasticities (*23*). TGV reports a positive ridership elasticity of +35 percent increase in ridership for every 20 percent improvement (reduction) in travel time. Even more striking is the projected +54 percent increase in ridership revenues with a 20 percent improvement (reduction) in trip travel times. TGV estimated trip time between Tampa and Miami is 160 min.

A ridership elasticity of −23 percent and a −32 percent ridership revenue elasticity were estimated for the TGV HSR system, assuming that it experienced an average 20 percent slowdown (increases in trip times) over proposed en route times.

Given the elasticity estimations of potential increases in societal benefits examined in this paper, HSR and maglev ridership revenues (private benefits) are straightforward. For instance, the distance between Miami and Tampa is approximately 315 mi. Both FHSRC and TGV estimate the total trip time between these points to be approximately 160 min. The TGV analysis assumes five intermediate stops of 6 min (2 min each for deceleration, dwell time, and acceleration). Therefore, the average en route trip speed is approximately 145 mph.

Figure 7 is a comparative bar graph of potential percentage changes in ridership and revenues as a result of increases or decreases in average transport trip speeds. These estimates indicate that if a steel wheel or maglev system could increase average trip speeds by 34 percent, to 195 mph, the ridership and societal benefits reported in this paper would all increase by 60 percent. Ridership revenues would jump by 93 percent.

This estimate assumes that the arc ridership and revenue elasticities reported by the TGV hold into the upper speed ranges, but they should, because they are in part predicated on the airplane, which offers even faster en route trip times. Presumably then, a maglev system operating at an average trip speed of 255 mph would anticipate a 132 percent increase in ridership and 205 percent increase in ridership revenue over the current proposed TGV Florida forecast.

Figures 8 and 9 provide ridership and revenue curves extrapolated from the proposed TGV Florida base case of 5.2 million riders and $152 million (1990 dollars) of ridership

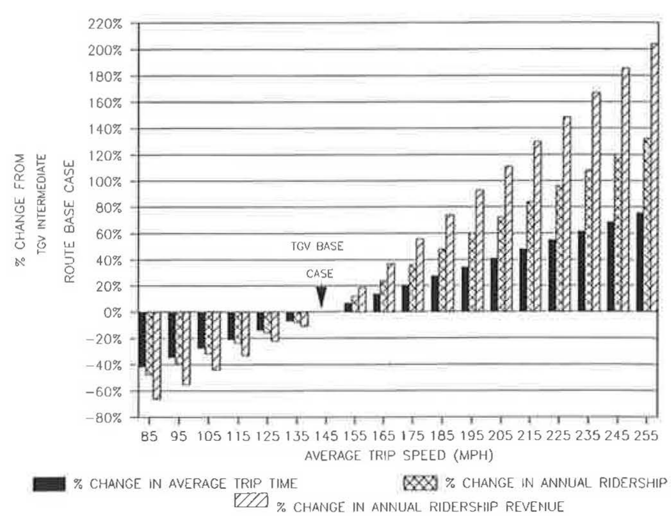

FIGURE 7 HSR and maglev potential changes in ridership and system revenues in Florida at different average trip speeds.

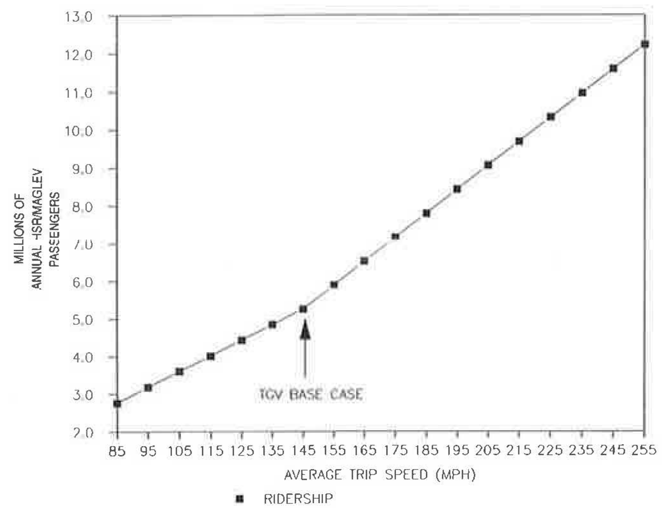

FIGURE 8 Annual ridership potential as a function of average trip speed using TGV estimated revenue elasticities.

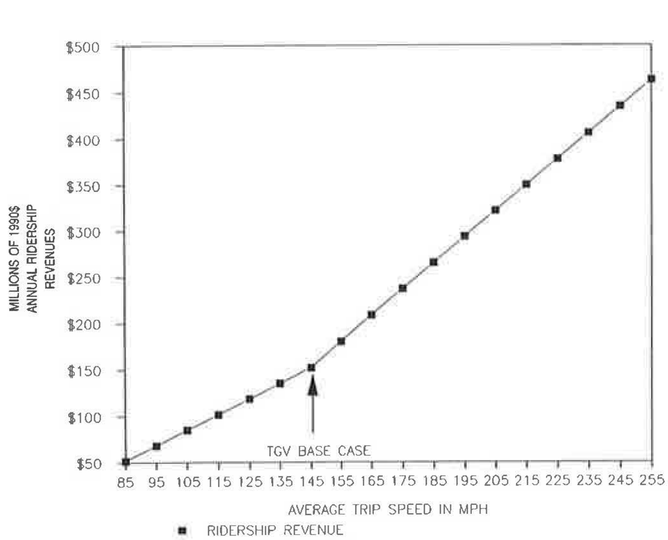

FIGURE 9 Potential HSR and maglev revenue versus speed projections extrapolated from TGV revenue elasticities.

revenue forecast for 1990. The bend at 145-mph average speed results from the higher elasticity rate of ridership and revenue gains above the TGV base case of 145 mph than below that value. Again as an example, annual average passenger levels would increase from 5.2 to 12.2 million in 1999 if a maglev system capable of operating at 255 mph were in place. The growth in ridership revenues would increase from the annual base case of $152 to more than $463 million for 1999 in such a system. This forecast seems to hold considerable promise for substantial increases in societal and ridership revenue benefits for any system offering a reasonable increase in speed.

This information is especially timely because the TGV Atlantique reported that it established a new world speed record of 299.9 mph in France during December 1989. TGV asserts it will be offering conventional passenger service with top speeds of 200 mph within the foreseeable future.

Societal benefits reported in this paper are also directly dependent on the HSR and maglev ridership levels. Therefore, each economic benefit estimated and reported in this paper would also increase by approximately 132 percent, the magnitude of ridership increase, if a maglev system operating at average trip speeds of 250 mph were in place in Florida.

For competitive reasons, the FHSRC does not report (as of this writing) as extensively on ridership elasticities as TGV. Nevertheless, when it does offer an insight into ridership modeling, the ridership elasticity is close to that of the TGV.

FHSRC alludes to an equivalent powerful trip time and ridership relationship (*1*). It indicates that a ±10 percent change in HSR travel time was found to result in ±13 percent change in HSR ridership. These estimates suggest that an increase of 20 percent change in trip time would result in a 26 percent increase in ridership. Although not as large as the TGV 35 percent ridership response, this elasticity does indicate strong concurrence with the direction and magnitude of the TGV HSR ridership study.

The obvious implication is that significant increases in HSR and maglev societal (and private sector) benefits are possible with any measurable improvements (reductions) in average trip times. These conclusions are drawn from several sources in a Florida context, and are corroborated by competing sources in a private enterprise setting. These findings are believed to be among the most significant to evolve from the Florida HSR and maglev proposals under review. These findings hold great promise for other transportation markets within the United States.

Air Pollution Emission Differences

Volatile Organic Carbons

VOCs consist of hydrocarbons, which are of local concern in many urban areas. HCs, along with NO_2 and CO, are major precursors of ozone, which is another principal local-area pollutant plaguing American urban areas.

The proposed Florida HSR and maglev transportation systems would result in reductions of between 671 and 749 tons of hydrocarbons per year by 1999. Another way to view these differences is to realize that virtually all of the estimated automobile hydrocarbon pollutants generated by the 1.7 to 5 million HSR and 4 million maglev passengers would be removed if these systems were in place in Florida (see Table 11 and Figures 10 and 11).

Carbon Monoxide

Carbon monoxide (CO) is another of the principal local-area pollutants of concern in many urban areas. Again, it is a precursor of ozone.

HSR and maglev transportation systems operating in 1999 in the reported passenger range would result in reductions of 3,724 to 5,417 tons of CO per year. Again, an HSR system in Florida would virtually eliminate these estimated levels of automobile and aircraft CO emissions for the passenger levels under consideration. This improvement is due to the much more complete burn associated with power plant fuel consumption than fuel conserved in automobile engines (see Table 11 and Figures 10 and 11).

TABLE 11 HSR AND MAGLEV TOTAL EMISSIONS REDUCTIONS (TONS/YEAR)

	VOC	CO	CO2	NOx	TSP	Tire TSP	SOx
MAGLEV	169	981	12,167	242	19	18	(41)
TGV	579	4,437	50,638	1,108	78	73	(160)
TOTAL	749	5,417	62,805	1,350	97	90	(201)
	VOC	CO	CO2	NOx	TSP	Tire TSP	SOx
MAGLEV	169	981	12,167	242	19	18	(41)
FHSRC	502	2,744	50,061	801	51	43	(118)
TOTAL	671	3,724	62,228	1,043	70	61	(163)

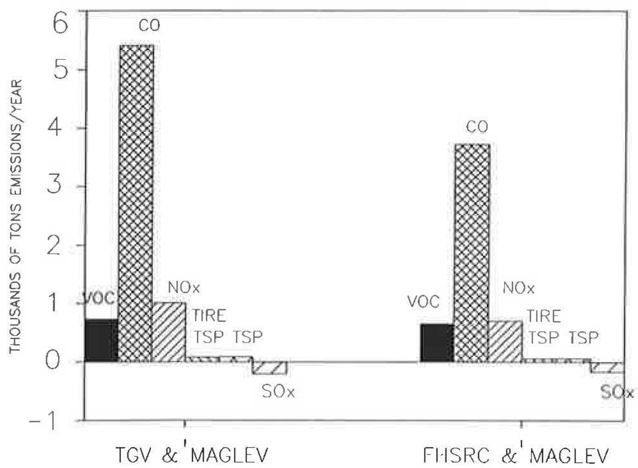

FIGURE 10 Florida net emissions reductions (excluding CO_2) resulting from HSR and maglev development.

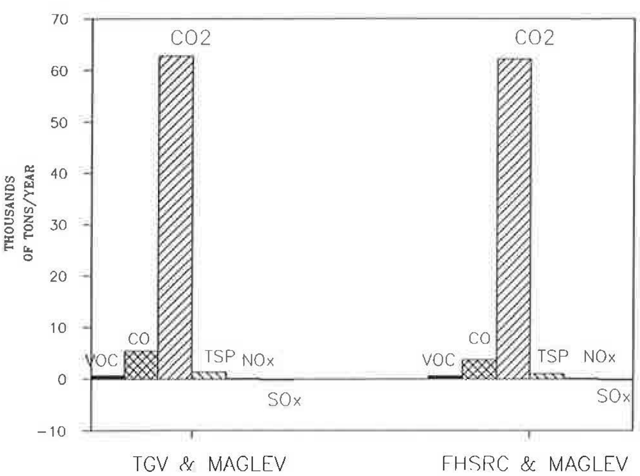

FIGURE 11 Florida net emissions reductions resulting from HSR and maglev development.

Total Suspended Particulates

Like hydrocarbons and CO, a serious concern in many urban areas in Florida (and elsewhere) is the level of total suspended particulates.

HSR and maglev transportation systems operating in the 1999 projected passenger range would reduce TSP emissions from the aircraft and automobile modes by 70 to 97 tons/year for 1999 alone. TSP, like the other pollutants examined, is a concern both as a localized pollutant and as a regional pollutant in many parts of Florida and throughout the United States (see Figures 10 and 11).

Here again, automobiles are widely recognized as one of the principal sources of this pollution. Aircraft operations are also a recognized important source of TSP in the vicinity of airports.

Suspended Particulates Related to Tire Wear

An HSR transportation system operating in the 1.7 to 5 million passenger range combined with the 8 million maglev passengers would produce no tire emissions because the systems are transported along the fixed guideway with no rubber-wheel–road friction or wear.

Automobiles and trucks again are widely recognized as the principal source of tire wear particulate pollution. Tire wear emissions within Florida could be reduced by 61 and 90 tons annually by 1999 if the HSR and maglev systems transported the projected passenger ranges in place of the automobile and airplane (see Table 11 and Figures 10 and 11).

Carbon Dioxide

CO_2 represents the largest quantified emission release from each of the transportation systems examined. CO_2 has only relatively recently become a pollution emission of some concern. Serious concerns about the links between CO_2 emissions and the greenhouse effect have gained growing acceptance in the world scientific community.

Gases such as CO_2, ammonia, and water vapor are relatively transparent to incoming short-wave radiation, but relatively opaque to outgoing long-wave radiation. The greenhouse effect occurs because these gases are radiatively active (*24*). Changes in their concentrations can alter the thermal balance of the earth's atmosphere. CO_2, in particular, though virtually transparent to incoming solar radiation, absorbs outgoing terrestrial infrared radiation that would otherwise escape to space. This trapping of radiation at the lower levels of the atmosphere results in a greenhouse effect caused by the increase in surface temperatures and cooling of upper levels of the atmosphere.

These concerns of global warming are creating intensified worldwide interest in CO_2 emissions. Proposals to examine

the effects and reduce the anthropogenic sources of CO_2 have taken on new prominence in the environmental sciences across the world. Combustion of fossil fuels is the primary source of CO_2. Efforts to shift from more fossil fuel and energy-intensive transportation modes, like the automobile and airplane, to less fossil-fuel-intensive modes, such as HSR and maglev, can significantly contribute to reductions in massive loading of CO_2 into the atmosphere.

The airplane and automobile transportation systems currently in place emit about 80,000 tons/year of CO_2 in transporting passengers at the levels proposed for the Florida HSR and maglev systems. By contrast, these advanced HSR and maglev transportation systems would emit only about 17,600 tons/year of CO_2. So although electrical generation facilities used to power these high-speed ground transport systems do emit CO_2, net state emissions could be reduced by as much as about 62,800 tons/year if an HSR and maglev system were implemented in Florida.

This HSR and maglev system combination is 35 to 58 percent more CO_2 efficient than the automobile and airplane transportation modes at similar passenger loadings. Clearly, this is potentially one of the largest emission reduction benefits that would result from implementation of the HSR and maglev systems in Florida (see Table 11 and Figures 10 and 11).

Nitrogen Oxides

Like the other pollutants, NO_x compounds are viewed as a principal concern in many urban areas across America. NO_x is also one of the principal precursors of acid rain. As mentioned earlier, NO_x compounds are also precursors of ozone.

Nitrogen oxides are a concern both as a localized pollutant and as a precursor to acidic deposition in many parts of this country. Automobiles are widely recognized as the principal and growing source of this pollution. Although power plants emit NO_x, implementation of the HSR and maglev systems in Florida would result in substantial reductions of this pollutant. For example, an HSR transportation system operating in the 1.7 to 5 million annual passenger level combined with the 4 million maglev passengers would reduce annual NO_x emissions statewide by 1,045 to 1,350 tons/year (see Table 11 and Figures 10 and 11).

Sulfur Oxides

Much like nitrogen oxides, sulfur oxides are a concern both as a localized pollutant and as a precursor to acidic deposition in Florida and many other parts of the country. Fossil fuel power plants are generally recognized as one of the principal sources of sulfur oxides.

SO_2 emissions are the single transportation-related pollutant that is estimated to increase somewhat if the HSR and maglev systems were developed in Florida. Although this potential increase in emissions may be of limited concern, several related and important points need to be considered with this projection to keep the potential increase in perspective.

The central point is that these potential increases are likely to diminish as new and more emission-efficient power plants are added to the Florida power plant grid, because of three important factors.

First, new power plants are required to meet stringent SO_2 (and other) pollution emission levels. These federally mandated New Source Performance Standards are resulting in increasingly cleaner total emissions per megawatt-hour as new capacity is added to the existing power plant mix and older facilities are retired.

Second, in addition to building more new power plants with the most stringent emission controls available to serve new and growing capacity, existing old dirty systems are also being replaced (*7*) or directed to operate at increasingly cleaner levels (*25*). These older plants with their historically authorized higher pollution emission levels are increasingly being either removed from service or replaced and upgraded by plants with cleaner emissions than the historic levels.

Third, and perhaps most important, new energy technologies that are both more energy and environmentally efficient are beginning to emerge in Florida and elsewhere across the country (*20*).

For example, improvements in emission controls and electrical generation capability from clean sources such as photovoltaics, other solar energy sources, nuclear sources, and clean-coal technologies are rapidly emerging. Solar markets in recent years are expanding significantly as price of production continues to decrease. Photovoltaics, although more expensive than conventional methods, cost \$0.30/kWh and are common in small-source or isolated-source areas. In February 1990, a solar thermal plant is expected to generate power for less than \$0.08/kWh, still greater than the \$0.03/kWh fossil fuel price, but prospects for continuing declines are imminent.

Perhaps of more immediate interest and pertinence is the surge in recent years of the growth in highly efficient coal-burning technologies. Such is the case with fluidized-bed combustion and coal gasification technologies. Fluidized-bed combustion, which suspends coal in a stream of air, results in more efficient complete combustion, dramatically reduced emissions, and generation of inert byproducts from the burn. Both technologies are under active consideration in Florida and elsewhere for large-scale development. The first 300-mw fluidized-bed cogeneration power plant permitted in Florida will undergo final review during 1990–1991 (*8*).

The City of Tallahassee is also the site of a 120-mw fluidized-bed combustion plant, which is the largest of 13 clean-coal technology projects approved by the Department of Energy for 1990. It will reduce sulfur emissions by 99 percent. It is being built jointly by Tampa Electric (TECO) and CRSS Capital Inc. with the cooperation and support of the City of Tallahassee (*26*).

Finally, the potential increases in SO_2 must also be considered in the context of equivalent offsetting of net gains achieved elsewhere in net reductions of other air pollutants from HSR and maglev systems. Although substantial potential reductions exist in every other air pollution category, the considerable potential reductions in NO_x levels deserve special consideration at this juncture.

As described earlier, NO_2 and SO_2 are both of concern as sources of local and longer-range pollution. Both pollutants are also the principal precursors of acid rain (both wet and dry acidic deposition). Also, no well-accepted or highly efficient technology currently exists to control NO_x emissions. Meanwhile, literally billions of dollars of investment in equipment and substantial progress have been achieved with SO_x

emission reduction in Florida and elsewhere in the United States and in the world.

Therefore, it is both reasonable and desirable to support achievement of a substantial reduction in NO_x pollution at a slight cost of potentially moderate increases in SO_x emissions. This tradeoff is exactly what would result if HSR and maglev transportation systems were implemented in Florida and elsewhere to the extent that these modes would supplant trips by automobile and air.

Specifically, in the Florida setting the potential annual increase of 163 to 201 tons/year of SO_2 can be compared with the projected decrease of 1,043 to 1,350 tons/year of NO_x. A net reduction of localized and long-range pollutant and acid rain precursors could exceed 1,149 tons/year from the combination of these two pollutants (see Table 11 and Figures 10 and 11).

Again, this result would be provided by the development of the HSR and maglev proposed systems in the state of Florida alone. Stated differently, every potential ton of SO_2 emission increase would be matched with a 6.4- to 6.7-ton NO_x emission reduction. From a net environmental efficiency perspective, this tradeoff is desirable.

Total Annual Pollutants Emissions from Transportation

Simply stated, an HSR and maglev system would considerably improve net loadings of all pollutants (except SO_x) to the extent that it is implemented and diverts passengers from the automobile and airplane modes. HSR local area pollutants of CO, HC, NO_x, TSP, and SO_x estimated from these Florida studies are 6 to 16 percent of the automobile and airplane transportation technologies (see Table 11 and Figures 10 and 11).

Although these localized pollution emission loadings are important, of equal or of even greater long-run importance may be the net reductions in long-range pollutants of acid rain precursors (net reductions in the sum of NO_x and SO_x) and larger-scale CO_2 emissions that contribute to the greenhouse effect.

Reduction in these aggregate emission loadings, both localized and long-distance pollutants, could also have other, secondary environmental benefits from improvements in water quality (*27*). Potential reductions in levels of pollutant loadings, acid rain, and air pollution are the most directly visible environmental benefits of implementing such systems.

Other pollutants (such as heavy metals), however, can also contribute to lowering the quality of ambient water and potentially adversely affect other parts of the ecosystem. To the extent that HSR is substituted for the other transportation modes, these benefits would accrue to the environment.

Again, the total potential reduction in all pollutants including CO_2 from implementation of an HSR and maglev system is evident. Total automobile and airplane emissions exceed HSR and maglev emissions (excluding CO_2) by a factor of 14 and total emissions including CO_2 by a factor of 2. This magnitude of improvement can, if implemented in large scale, provide a significant contribution to improving ambient air quality in America's urban areas.

In the final analysis, the air and water environmental benefits of large-scale magnetic levitation technology substantially surpass the others evaluated in virtually every category examined.

CONCLUSION

The results of this Florida-specific analysis conclude that implementation of an HSR proposal and the maglev system would annually result in the following benefits.

Economic and Energy Benefits

- Time savings valued to $136 million.
- Automobile wear and maintenance savings valued to $44 million.
- Property and injury loss savings valued to $10 million.
- Reduction in annual transportation energy consumption of 1.35 to 1.875 trillion Btu.
- Reduced dependence of $33.4 million on fossil fuel to power the U.S. transportation systems.
- Reduction of $31.5 million in imported oil, thereby strengthening the U.S. domestic economy by (a) reducing the negative balance of payments, (b) increasing reliance on domestic sources of energy, and (c) increasing domestic security.
- Reduction in the annual economic damages (externalities) from transportation air pollution emissions.

In addition, HSR and maglev systems would provide the following benefits:

- Savings in new highway construction costs exceeding $1 billion.
- Up to 217,979 man-years of direct and indirect construction employment.
- Up to $20 billion in indirect construction income.
- As much as 9,908 annual permanent operations jobs created both directly and indirectly.
- Over $300 million annually in direct and indirect operation employment income.
- Enhanced transportation productivity by a factor of 3 over current modes.

Environmental Benefits

- Annual reductions of 671 to 749 tons/year of volatile organic carbon emissions.
- Annual reductions of 3,724 to 5,417 tons/year of carbon monoxide.
- Annual reductions of 62,228 to 62,805 tons/year of carbon dioxide.
- Annual reductions of 1,043 to 1,350 tons/year of nitrogen oxides.
- Annual reductions of 70 to 61 tons/year of total suspended particulate matter.
- Annual reductions of 61 to 90 tons/year of particulate matter due to tire wear.

- Annual increases of 163 to 201 tons/year of sulfur oxides.
- Total non-CO_2 automobile and airplane emissions exceed HSR and maglev emissions by a factor of 14.
- Total automobile and airplane emissions (including CO_2) that exceed HSR and maglev emissions by 200 percent.

Growth in Overall Benefits

All of these HSR and maglev social benefits would increase by a factor of 1.75 times any percentage of improvement in trip times, whereas ridership revenues to system owners could increase by a factor of 2.7.

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