Energy Requirements of San Diego's Light Rail Transit System

Thomas F. Larwin

Since the energy crises of 1973-1974 there has been extensive research into the relative energy requirements of alternative transportation modes. The energy issue is again prominent due to the significant short-term increase in the cost of automobile fuel, forecasts of energy supplies that show dwindling resources, and, most recently, reports from federal levels that discount the importance of energy with regard to public transportation.

During the San Diego Metropolitan Transportation Development Board's Guideway Planning Project of 1977-1978 and again as part of the recent East Line feasibility analysis, the energy intensiveness of the San Diego Light Rail Transit (LRT) system was evaluated. This report is an update and reexamination of the issue.

Larwin is Director of Planning, San Diego Metropolitan Transportation Development Board.

CONCLUSIONS

It is important to understand that the issue of energy intensiveness with regard to alternative transportation modes is a highly complex matter. To understand the factors necessary in order to have an energy-efficient transportation system, one must be aware of and recognize the many variables that go into the determination of energy intensiveness.

Based on a review of the research conducted and recognizing that the research is based extensively on average conditions and assumptions, it is possible to place the San Diego LRT system into this context. This reevaluation concludes: "By virtue of being a relatively low-cost system, the San Diego LRT line has expended a relatively small amount of construction energy in comparison with the rail systems as developed or being developed in San Francisco, Washington, Miami, Baltimore, and Buffalo."

With regard to operating energy efficiencies, resolution of the question comes down to the relative passenger load factors of the various transportation modes. For example, the energy efficiency of an automobile can range from very poor to very good depending on whether it has a single occupant or is a carpool with three or more people riding. The same holds true for bus and rail transit modes. The key to realizing energy-efficiency savings in transit is to reduce the number of vehicle miles being operated when passenger loads are low.

Another factor relative to operating energy efficiencies pertains to ongoing maintenance of the system. The design of the San Diego system includes functional stations that are essentially large shelters, no tunnels, and vehicles without air-conditioning. As a result, energy-efficiency gains are achieved. It is also important to note that the Metropolitan Transportation Development Board light rail vehicle is one that has been in operation for some time and has become increasingly efficient due to mechanical improvements. In contrast, newer buses have become no more energy efficient than those purchased in the 1950s and 1960s, and in some cases they have become even less energy efficient (i.e., fewer miles per gallon of fuel).

The overall conclusion is that the San Diego LRT system has been designed as an energy-efficient public transportation system. The practical, low-cost principles applied to construction and vehicle selection have proved prudent from an energy point of view.

It is important to stress, though, that the final conclusion on energy effectiveness will depend on use of the system. To achieve high energy efficiencies, high passenger loads must be encouraged in combination with a tailoring of the operating plan to provide service levels suited to those demands without operating unnecessary empty car miles.

DEFINITION OF ENERGY INTENSIVENESS

Based on a review of the research available a total view of energy requirements for the San Diego LRT system includes the following: propulsion energy required to operate the trains, station and maintenance energy, construction energy, vehicle-manufacturing energy, and factors related to use of the system that include average number of occupants per car, average trip length, mode of access to the system, length of access trip, and the source of the ridership (i.e., former bus or automobile users, or new trips being made).

As a basis for understanding San Diego LRT energy effectiveness, a comparison will be made with the research available for other modes of transportation that include automobiles, vanpools, buses, and various forms of rail transit systems. Some of the difficulties in making these comparisons are based on the average conditions assumed in the various studies. Just as the fuel efficiency of a Honda significantly differs from that of a Cadillac, the same thing is true for the various public transportation vehicles manufactured by different companies.

In addition, the investigation shows that the San Diego situation represents a completely different type of rail transit program than the others being developed in terms of construction, technology, and labor resource use. Finally, with regard to travel behavior, much of the data used in the other research is an average of situations that include northeastern urban areas along with other urban areas. There is a significant amount of variability in these assumptions and the San Diego situation is not directly comparable with any of these averages.

The basic unit of comparison for all these modes, since they do depend on different energy sources (petroleum and electrical), is Btu's per passenger or vehicle mile. The use of Btu's allows a comparison between a gallon of gasoline and the use of electrical energy. For example, a gallon of gasoline is usually estimated to contain about 125 000 Btu's.

ENERGY REQUIREMENTS FOR VARIOUS MODES

The figures in Table 1 show the comparison of the modal energy requirements for each of 11 primary modes of transportation plus the San Diego LRT system. As Table 1 shows, the research indicates quite a range in the comparative results. In general, however, it can be concluded that vanpools can offer the greatest energy efficiencies while the single-occupant automobile and dial-a-ride transit systems are perhaps the most energy inefficient. Bus and rail systems are all in the same general area of energy requirements with the two studies showing mixed conclusions—again, pointing out the variability of data.

Propulsion Energy

The energy to move a vehicle (i.e., propulsion energy) for the various modes is shown in Table 2. As shown in the table, these numbers represent ranges as obtained from the two primary references. Again, there is a significant variance in estimates from the two different references. For those vehicles that operate primarily on petroleum energy the numbers are fairly uniform, ranging from approximately 11 000 Btu's/vehicle-mile for an automobile to 30 000 Btu's/vehicle-mile for a bus.

On the other hand, for those vehicles that operate by using electrical energy, i.e., rail vehicles, there is considerable variation. The Congressional Budget Office (CBO) report (1) indicates, for example, that light rail vehicles require 50 000 to 100 000 Btu's/vehicle-mile, while the Polytechnic Institute study (2) indicates an average of 37 500 for light rail vehicles.

Just as there is no "typical" vehicle for automobiles, there are similar variations among rail vehicles. The Siemens-DuWag San Diego light rail vehicle has a known energy requirement based on the specific performance characteristics of the vehicle and the geographic and topographic characteristics of the South Line. Bechtel Corporation used these characteristics to estimate that there is a need for 17 300 kW hours per day, or 182 million Btu's, required to propel trains operating 4110 vehicle-miles/day. This results in an energy requirement of 44 280 Btu's/vehicle-mile. (This assumes two-car trains operating every 15 min during the hours of 7:00 a.m.-7:00 p.m. and every 30 min from 6:00 a.m.-7:00

Table 1. Modal energy requirements for various transportation modes (Btu's per passenger mile).

Mode	CBO	Polytechnic Institute of New York	
Single-occupant automobile	14 220	11 590	
Average automobile	10 160	8 280	
Carpool	5 450	4 820	
Vanpool	2 420	1 960	
Dial-a-ride	17 230	14 020	
Conventional bus	3 070	3 670	
Express bus	-	3 020	
Light rail	5 060	2 580	
Heavy rail (old)	3 990	2 200	
Heavy rail (new)	6 580	2 900	
Commuter rail	5 020	3 120	
San Diego LRT			1657-2617[a]

[a] Range as calculated in this paper shows variance between 28 000 riders per day (1657 Btu/passenger-mile of travel) and 15 000 (2617 Btu/passenger-mile of travel).

Table 2. Estimates of vehicle propulsion energy for urban transportation modes (BTU's per vehicle mile).

Mode	CBO	Polytechnic Institute of New York	
Automobile	10 400-11 100	11 000	
Vanpool	13 900-17 900	14 000	
Dial-a-ride	13 900-17 900	15 000	
Bus	26 100-32 900	30 000	
Heavy rail (new)	70 000-110 000	37 500	
Heavy rail (old)	50 000-95 000	30 500	
Light rail	50 000-100 000	37 500	
Commuter rail	100 000-150 000	52 500	
San Diego LRT			44 280

a.m. and from 7:00 p.m.-1:00 a.m. The actual operating plan could, in fact, reduce the number of hours of operation as well as tailor the train size to meet the demand and, therefore, have considerably fewer vehicle miles per day of operation. Thus, even the variability in the San Diego number is evident and could be considerably less than the 44 280 figure.)

Station and Maintenance Energy

The relative energy required to operate stations, ventilate systems in tunnels, and maintain vehicles and system facilities is small compared with propulsion energy requirements. In particular, the heavy rail systems require significant station energy due to the need for escalators, elevators, air-conditioning, heating, lighting, and ventilation systems. The San Diego system has functional station shelters and a modest shop building. The station shelters have minimal electrical requirements for lighting and ventilation systems. Maintenance requirements generally will depend on the age of the vehicle fleet with the expectation that newer vehicles will not have energy requirements as high as older systems. Again, for heavy rail systems, the maintenance energy requirements range from 2000 Btu's for new systems to 4100 Btu's per vehicle mile for older systems.

Conservatively, the San Diego LRT system would have to be on the extreme low end of the above ranges—and even somewhat lower than the station energy requirement cited above. In any event, for purposes of analysis, a figure in the low end of the range (5300 Btu's/vehicle-mile) will be assumed. In comparison, bus maintenance energy requirements are in the neighborhood of 800-1000 Btu's/vehicle-mile, while automobile maintenance requirements are approximately 1600 (1).

Construction Energy

Construction energy is a function of the energy needed to build the system and is related to the need to make and haul concrete, dig tunnels, and perform the other construction tasks. The construction energy is expended once and for purposes of this analysis is allocated over the life of the transportation facilities.

Obviously, a system like the BART system or the Washington METRO system, requires significantly more construction energy than the one in San Diego. In these two heavy rail systems, tunneling and structure construction require a significant energy expenditure. The San Diego system, on the other hand, being primarily a rehabilitation of an existing at-grade right-of-way with little heavy construction, requires a relatively small proportion of that used for heavy rail systems.

Bechtel has estimated that, by the time the construction of the San Diego LRT line has been completed, 158 billion Btu's will have been expended. In comparison, the BART system required 164 trillion Btu's for construction (3). Thus, the construction energy used for the San Diego system will be 0.1 percent of what was expended for the BART system.

Based on the estimated life of construction (40 years) and a constant number of vehicle miles of service (as used above), the construction energy requirements for the San Diego line work out to be 2633 Btu's/vehicle-mile. This figure is actually higher than the one cited for light rail in the CBO report but will be used in order to remain conservative.

Vehicle-Manufacturing Energy

The energy required to manufacture the vehicles is similar to construction energy in that it is spent at one time and has to be allocated over the life of the vehicle. For the San Diego system, this energy is spent in West Germany; even so, we will use the CBO estimate of 2000 Btu's/vehicle-mile since we do not have a good idea of the exact energy requirements from the Siemens-DuWag manufacturing plant. The CBO report points out that vehicle-manufacturing energy for bus and rail transit vehicles is essentially equal.

Travel Behavior Factors

Factors, such as average trip length, access mode to transit, average trip length of the access trip, circuity of travel, and the source of new transit ridership, all influence the total energy consumed in using the particular transportation mode. For instance, there will be certain energy requirements to use the light rail system in addition to those occasioned by the system itself because a certain number of people will arrive by bus and by automobile.

Furthermore, the load factor or passengers per vehicle is an important energy consideration. Seating capacity, itself, is a poor index of ridership. Instead, passenger miles (1 passenger mile equals 1 passenger going 1 mile) per vehicle mile is the best common index for relating load factors of all transportation modes.

For the San Diego system, the travel characteristics were based on demand estimates made by San Diego Association of Governments (SANDAG) and Caltrans. The ridership on a daily basis of 28 000 trips was estimated to have an average trip length of 7.17 miles. This works out to 48.8 passenger miles per vehicle mile (28 000 x 7.7 ÷ 4110).

With regard to the other characteristics, the following statistics resulted from the demand estimates:

1. Mode of arrival = 45 percent by bus, 38 percent by walking, and 17 percent by automobile;
2. Percentage of trip devoted to access = 15 percent (the CBO report indicates a range of 10-20 percent is typical);
3. Circuity factor = 1.2 (which means that the trip is actually 20 percent longer than "as the crow flies"); and
4. Previous mode of travel—50 percent from bus, 35 percent from automobile, and 15 percent new trips.

The above factors, along with the average trip length and the energy use of each access mode, are used to calculate the energy required to access the system. This requirement is equal to 547 Btu's/passenger-mile.

TOTAL MODAL ENERGY REQUIREMENTS

Intuitively, research has shown that the San Diego LRT system should be far more energy efficient than comparable heavy rail systems or even some of the light rail systems that are currently being built that have elevated sections and subway portions (e.g., Edmonton, Calgary, and Buffalo). This conclusion is borne out by the above energy figures that add up as follows:

Factor	Btu's per Vehicle Mile
Propulsion	44 280
Station, maintenance	5 300
Construction	2 633
Vehicle manufacturing	2 000
Total (excluding access energy)	54 213

Next, taking into consideration the expected load factor, the energy (excluding access energy) requirement results in a figure of 1110 Btu's/passenger-mile. As an indication of the importance of the load factor, at a reduced passenger figure of 15 000 passengers/day, the energy consumption (excluding access energy) per passenger mile would be 2070 Btu's.

To arrive at the total modal energy requirement for the San Diego LRT system, it is necessary to include the energy expended to access the system (547 Btu's/passenger-mile). Added to 1110 Btu's/passenger-mile for propulsion, maintenance, and construction, the total modal energy requirement is 1657 Btu's/passenger-mile. Adding 547 to the figure based on ridership of 15 000 passengers/day, the total energy consumption per passenger mile would be 2617 Btu's.

In conclusion, comparison with the figures noted in Table 1 shows that the range of energy requirements for the San Diego LRT system places it in a very favorable position relative to well-used vanpools, buses, and carpools.

REFERENCES

1. Congressional Budget Office. Urban Transportation and Energy: The Potential Savings of Different Modes. U.S. Government Printing Office, Sept. 1977.
2. The Energy Advantages of Public Transportation. Polytechnic Institute of New York, March 1980.
3. Charles A. Lave. Transportation and Energy: Some Current Myths. Policy Analysis, Univ. of California, 1978.