3.18 Energy

Energy is used during the construction and operation of transportation facilities. The energy that is used in the construction of various facilities is inclusive of the manufacture and transport of materials and equipment making up each alternative, as well as the operation of construction equipment. Operational energy consumption is the fuel and electricity used to power the vehicles using the transportation facility. This total energy is based on the vehicle mix and vehicle miles of travel (VMT) for each alternative being evaluated. Given average values of energy consumption for various vehicles based on available data, and knowing the number of VMT, it is possible to determine energy consumption per VMT and ultimately per day or per year. This is the approach taken for the Corridor alternatives.

> **Energy Issues**
> - Energy used during construction of transportation facilities – including manufacture and transport of materials and equipment, and operations of construction equipment.
> - Energy used during facility operation – fuel and electricity used to power vehicles using the transportation facility.

Considerable information is available regarding energy use, both in construction and especially in vehicle operations. Some can be calculated based on actual energy per unit consumed, such as a gallon of gasoline. Considerable information has been recorded by various agencies and has been presented in terms of VMT (or PMT, which is person miles of travel). Needless to say, differences exist between the various information sources, and an exact estimate of anticipated energy usage in any alternative is not possible nor is it absolutely necessary. However, using available information and adapting it consistently to all project alternatives will provide a reasonable comparison among alternatives. It should be noted that there are many variables, especially between Transit alternatives, that are difficult to quantify. It is known, for example, that spacing between transit stations can have a substantial effect on energy consumption, even for like vehicle types. Greater spacing reduces energy consumption.

Of particular interest is the question of how the major changes in elevation from Denver to the Continental Divide affect energy consumption. Moving a vehicle from less than 6,000 feet to 11,000 feet involves overcoming an elevation change of 1 mile, at grades as high as 7 percent; this situation is sure to have an impact on energy requirements. One cannot necessarily conclude that the additional effort to accomplish this is compensated by a corresponding decrease in energy needed on the descent part of the trip, especially as it applies to heavy trucks. However, electrical energy savings can be realized if regenerative braking systems are used on transit vehicles. The calculations required to make this determination with respect to vehicles on the roadway are likely to be complex and probably would not result in any defensible conclusions, although grades were taken into consideration in modeling the Transit components. Therefore, a simplistic approach, using data from previous studies, is taken for determining energy consumption (construction and operation) of the Corridor, at least as it applies to all nontransit vehicles. These data are then applied to projected construction costs and to the PMT/VMT that have been modeled for all alternatives.

3.18.1 Affected Environment

The Corridor stretches from the Denver metropolitan area to Glenwood Springs and serves as the only viable through route for surface transportation. Intermittent sections of frontage roads comprise parts of US 40 and US 6, but these serve mainly as distributor roadways and have no real significance in effectively serving through traffic. Traffic volumes vary considerably, with the higher concentration east of the Continental Divide, especially east of Empire Junction. However, there are high concentrations of traffic, with occasional congestion, in certain areas west of the Continental Divide, especially between Vail and Avon.

The Corridor, while generally in rural, mountainous terrain, passes through several highly developed areas, including most of Clear Creek County, Silverthorne/Frisco, Vail/Eagle-Vail/Avon, as well as Edwards, Eagle, and Gypsum. It also reaches the highest elevations on the entire Interstate system at the EMJT and at Vail Pass, and passes through scenic alpine terrain.

3.18.2 Methodology for Determining Energy Consumption

Common units of energy measurement are joules and British thermal units (BTU). One joule is the equivalent of 0.0009478 BTU. Conversely, 1 BTU equals 1,055 joules, which is the standard conversion factor. Because joules are very small units, energy usage is often expressed in terajoules (which is 1 trillion joules or 10 raised to the 12th power).

3.18.2.1 Construction

Estimating the number of terajoules for construction of transportation facilities is not straightforward. For the Corridor, this can be even more complex given the altitude, steep grades that have to be overcome, and abbreviated construction seasons that can result in reduced efficiencies. It was decided that these numbers would be developed using an accepted technique that approximates construction energy usage on the basis of construction cost. Data developed by *Engineering News Record* and Caltrans (1983) were used to apply, to this Corridor, an approximate construction energy consumption factor, adjusted to the year 2000, of 10 terajoules per million dollars in construction cost. While that value was based on urban freeway expansion, it was deemed reasonable for this Corridor because much of the construction will involve complexities that, while not identical to urban situations, will likely demand the expenditure of great amounts of energy.

In determining energy consumption during construction of transit systems, reference is again made to Caltrans (1983). An estimate of 21 terajoules per track-mile was used and applied to the Corridor. This includes the installation of track and power systems. For dual track, the factor was doubled although, due to economies of scale, the actual consumption may be less than double. Other civil construction costs associated with Transit alternatives and not directly attributable to transit vehicles, track, and power systems (such as viaducts, walls, or earthwork) were treated the same as highway construction costs in terms of calculating energy consumption. That is, energy consumption for construction of those elements was based on 10 terajoules per million dollars in construction costs. Therefore, all alternatives having a Transit component were evaluated as to their construction energy consumption in terms of both track mileage and construction costs.

3.18.2.2 Operations

Operational energy consumption by vehicles operating on the roadway is directly proportional to the number of miles driven. Variables that can be considered are vehicle type, speeds, roadway grades, and fuel economy. Average gas mileage for all vehicles in the traffic stream can be converted to a measurement of energy. Most sources seem to agree that 1 gallon of gasoline is equivalent to about 125,000 BTU. With an average fuel economy of 25 mpg (the *I-405 Corridor Program, NEPA/SEPA Draft Environmental Impact Statement and Draft Preliminary Section 4(f) Evaluation*) in Washington state used a range of 23.8 to 25.6 mpg, or an average of 24.7 mph), the amount of energy used per VMT is 5,000 BTU. This can then be converted to energy consumption per PMT by dividing by the vehicle occupancy. For example, if occupancy is 1.6, the energy per PMT is 3,125. This then results in a conversion from VMT to actual energy usage when PMT and vehicle occupancy are known for each alternative. Such is the case for the Corridor, where the projected annual occupancy rate varies from 1.71 to 1.73.

An alternative to manually calculating this energy consumption rate per PMT is to use published data directly. The US Department of Energy (DOE) has such data readily available in its *Transportation*

Energy Data Book. That document includes a table relating passenger travel and energy use in the US for the year 2000 for various modes of transportation, including automobiles, buses, and rail. That information suggests a fuel economy of about 22 mph for cars, which may be more realistic than 25 mpg considering the elevation and long, steep grades along the Corridor. The energy consumption for automobiles in that report is 5,669 BTU per VMT (or 3,543 BTU per PMT based on an occupancy rate of 1.6). The slightly higher occupancy rates projected for the Corridor would result in energy consumption rates per PMT that are somewhat lower. This correlates well with a number of other data sources found over the Internet, such as the US DOT, which gives a rate of 3,467 BTU per PMT (apparently based on a national vehicle occupancy rate of 1.6). Having assimilated all of this information, and recognizing the empirical nature of this subject and unknown impacts due to other variables, it was decided to use an energy consumption rate of 125,000 BTU per gallon of gasoline and an average gas mileage of 22 mpg. This then yields a rate of 5,682 BTU per vehicle mile, which is consistent with the DOE data. This was then converted to terajoules in accordance with the conversion factors given above.

Energy consumption for the transit elements of each alternative was calculated on various bases. Transit energy usage consists of electrical energy expressed in kilowatt-hours and fuel consumption expressed in gallons of diesel fuel. All Transit alternatives would include a certain amount of diesel fuel consumption. The Bus in Guideway alternatives would use both the diesel bus and the dual-mode bus (off the guideway) for propulsion. The IMC portion of the Rail with IMC alternative also would rely on diesel fuel for propulsion. The Rail with IMC and AGS alternatives would also experience a certain amount of diesel fuel consumption due to the feeder bus components associated with these.

For the Rail with IMC and AGS elements, electrical energy consumption was calculated on the basis of Railsim 7® Train Performance Calculator (TPC) simulation output. This proprietary software was used to model overall train (and Dual-Mode Bus in Guideway) performance in the Corridor, including speeds, travel time, and energy consumption. However, with regard to the AGS alternative, the TPC calculated only the propulsion and on-board energy requirements, not the energy required to levitate the trains. That was derived from another study and was then added to the propulsion energy calculated in this section. The diesel consumption for the Diesel Bus in Guideway portion was also calculated using the TPC. The model uses train and bus performance parameters in conjunction with ridership demand. This particular TPC has gained recognition within the industry as one of the most comprehensive simulators used today as a planning and costing tool.

For purposes of determining fuel consumption by the buses (both diesel and dual-mode) off the guideway, a fuel consumption rate of 2.6 mpg was used for the diesel bus and 2.0 mpg for the dual-mode bus. Running time and distance for the segments off the guideway were based on simulations conducted using the VisSim™ software.

Once the total numbers of kilowatt-hours were calculated using these techniques, they were converted into terajoules for purposes of this section and are presented in Table 3.18-2. The conversion factors that were used were 0.0001465 terajoules per gallon of diesel fuel and 0.0000036 terajoules per kilowatt-hour of electricity. These were then combined with the energy usage for passenger vehicles on the roadway to arrive at total energy consumption estimates for each alternative.

3.18.3 Environmental Consequences

3.18.3.1 Construction Impacts

These impacts would be the direct result of the operation of construction equipment, as well as delivery of materials to the site. The amount of energy consumed was calculated on the basis of construction costs, as well as the number of track miles for those alternatives having a transit component, as earlier described. Because the No Action alternative would involve no expenditures of capital costs, it is assumed that no construction-related energy would be consumed. Table 3.18-1 summarizes the estimated energy consumption for construction of each alternative. The capital costs shown for each alternative would be for the civil construction costs only, not the total capital cost of each alternative, because energy consumption estimates for rail construction are based not on costs but on track miles of rail and associated electrification, as described above. It should be noted that, while the construction energy consumption may appear high, these are one-time values and are not time dependent regardless of when the construction actually takes place and/or its duration. By contrast, average daily operational energy consumption, when expanded over a 25-year horizon, for example, would be considerably higher.

Table 3.18-1. Construction Energy Consumption

Alternative	Number of Transit Track Miles	Civil Construction Energy Consumption (Terajoules)	Track Construction Energy Consumption (Terajoules)	Total Construction Energy Consumption (Terajoules)
No Action	N/A	N/A	N/A	N/A
Minimal Action		13,080		13,080
Rail with IMC	147	27,010	3,087	30,097
AGS	236	36,730	4,956	41,686
Dual-Mode Bus in Guideway		22,350		22,350
Diesel Bus in Guideway		22,350		22,350
Six-Lane Highway 55 mph		17,450		17,450
Six-Lane Highway 65 mph		22,800		22,800
Reversible/HOV/HOT Lanes		18,590		18,590
Combination Six-Lane Highway with Rail and IMC	147	41,030	3,087	44,117
Transit with Highway Preservation	147	35,550	3,087	38,637
Highway with Transit Preservation		22,240		22,400
Combination Six-Lane Highway with AGS	236	55,750	4,956	60,706
Transit with Highway Preservation	236	53,850	4,956	58,806
Highway with Transit Preservation		22,100		22,100
Combination Six-Lane Highway with Dual-Mode Bus in Guideway		27,000		27,000
Transit with Highway Preservation		24,710		24,710
Highway with Transit Preservation		22,490		22,490
Combination Six-Lane Highway with Diesel Bus in Guideway		27,000		27,000
Transit with Highway Preservation		24,710		24,710
Highway with Transit Preservation		22,490		22,490

3.18.3.2 Operational Impacts

Energy use during operations of any alternative would be directly related to the gasoline consumption of automobiles, trucks, and buses, as well as to the propulsion energy generated for powering transit vehicles. Table 3.18-2 summarizes energy consumption for each alternative, broken down by both transit travel and vehicles on the roadway; the latter in any alternative represents the great majority of impacts in terms of energy usage. The variation in total operational energy consumption among the alternatives, as compared to the No Action alternative, ranges from 1 percent lower than the No

Action alternative in the case of the Rail with IMC and AGS alternatives, to 15 percent higher in the case of the Combination Six-Lane Highway with Diesel Bus in Guideway alternative.

The total energy consumption in Table 3.18-2 is calculated on the basis of annual PMT (or VMT) for each mode and alternative, reduced to an average daily rate, as previously described. The variations thus calculated are not expected to be substantial enough to have any effect on total energy usage or fuel availability along the Corridor or in the region. However, this analysis does not take into consideration provisions for actually supplying the required energy in terms of fuel distribution; it was simply assumed that buses would be fueled at garages supplied by a fuel distributor. However, it does include provisions for high-voltage power transmission capacity through placement of transmission lines and appropriately spaced substations along the Corridor. The energy required to increase the overall generating capacity within the power grid, should that be required, was not taken into consideration.

Table 3.18-2 does not list the preservation alternatives because these alternatives are presumed to have the same energy consumption as their respective base alternatives. By contrast, the energy consumption during construction of the preservation alternatives would be different from that of their base alternatives because construction costs would be different.

Table 3.18-2 also provides estimated operational energy costs associated with each alternative based on three components: electrical, diesel, and gasoline. Electrical cost rates were based on local prevailing energy rates with an allowance for some escalation due to recent fossil fuel price increases. Accordingly, it is assumed that $0.10 per kilowatt-hour of electricity is a reasonable estimate of current rates for this source. Diesel fuel and gasoline costs are widely variable across the country and fluctuate considerably from week to week and even day to day. To provide a defensible unit cost for these forms of energy, it was decided to use data published by the Energy Information Administration of the US Department of Energy. This agency maintains a website that provides up-to-date costs per gallon for these fuels in various regions of the country, including the Rocky Mountain Region. These costs are updated weekly, and the costs recorded for the week beginning October 25, 2004, for the Rocky Mountain Region were used herein. These costs were determined to be $2.007 per gallon for gasoline and $2.278 per gallon for diesel. The differences in percentages relative to the No Action alternative when comparing energy consumption against energy costs result from variations in electrical versus diesel/automotive fuel usage (and their unit costs) among the alternatives.

3.18.4 Mitigation Measures to Reduce Energy Consumption

Measures to reduce energy consumption during construction could include limiting the idling of construction equipment; encouraging employee carpooling or vanpools for construction workers; locating construction staging areas close to the actual work sites; and implementing traffic management schemes that minimize motorist delays and thus vehicle idling.

Operational energy consumption is not as easily controlled because it is directly related to travel demand. However, strategies could be implemented, such as carrying out maintenance activities (especially those that involve reducing the number of through lanes, such as striping activities) during periods of reduced traffic volumes; encouraging greater use of transit through measures such as incentive programs; working with chambers of commerce or tourist organizations to encourage resort operators to offer incentives for visitors who use transit; and promoting carpooling for regular users of the facility.

Table 3.18-2. Daily Operational Energy Consumption

Alternative	Total Transit Energy Use per Day (kwh)	Total Transit Energy Use per Day (Gal)	Daily Transit Energy Consumption (Terajoules)	Daily Vehicle Miles on Roadway	Daily Gasoline Consumption (Gal)	Total Daily Energy Consumption (Terajoules)	Total Daily Energy Operations Cost*	Change in Energy Consumption Relative to No Action	Change in Energy Cost Relative to No Action
No Action				6,841,419	310,974	41.0	$624,124	N/A	N/A
Minimal Action				6,901,237	313,693	41.4	$629,581	1%	1%
Rail with IMC	306,860	4,109	1.7	6,516,355	296,198	40.8	$634,515	-1%	2%
AGS	416,805	1,487	1.7	6,485,977	294,817	40.6	$636,766	-1%	2%
Dual-Mode Bus in Guideway	241,609	15,148	3.1	6,656,466	302,567	43.0	$665,919	5%	7%
Diesel Bus in Guideway		35,950	5.3	6,656,735	302,579	45.2	$689,170	10%	10%
Six-Lane Highway 55 mph				7,225,208	328,419	43.3	$659,136	6%	6%
Six-Lane Highway 65 mph				7,225,208	328,419	43.3	$659,136	6%	6%
Reversible/HOV/HOT Lanes				7,242,073	329,185	43.4	$660,675	6%	6%
Combination Six-Lane Highway with Rail and IMC	329,373	4,371	1.8	6,930,363	315,017	43.4	$675,132	6%	8%
Combination Six-Lane Highway with AGS	433,174	1,487	1.8	7,001,180	318,235	43.7	$685,404	7%	10%
Combination Six-Lane Highway with Dual-Mode Bus in Guideway	194,310	12,114	2.5	7,065,304	321,150	44.8	$691,574	9%	11%
Combination Six-Lane Highway with Diesel Bus in Guideway		32,142	4.7	7,114,764	323,398	47.4	$722,279	15%	16%

Note: The preservation alternatives are not listed here because they would have the same energy consumption as their respective base alternatives.

** Electrical energy cost for transit is based on $0.10 per kwh. Diesel energy cost for transit and gasoline cost for cars are based on per gallon costs for the Rocky Mountain Region as posted on the US Department of Energy, Energy Information Administration, website (http://www.tonto.eia.doe.gov/oog/info/gdu/gasdiesel.asp).*

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