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Transportation Model of the World Energy Projection System Plus: Model Documentation 2011

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U.S. Energy Information Administration
Office of Energy Analysis
U.S. Department of Energy
Washington, DC 20585

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1. Introduction

Purpose of This Report

The Transportation Sector Model (generally referred to as the International Transportation Model or ITran) of the World Energy Projection System Plus (WEPS+) is a computer-based energy demand modeling system of the world transportation sector at a regional level. This report describes the version of the ITran that was used to produce the transportation sector projections published in the *International Energy Outlook 2011* (*IEO2011*). The ITran is one of many components of the World Energy Projection System Plus (WEPS+) energy modeling system, but the ITran can also be run as a separate, individual model. The WEPS+ is a modular system, consisting of a number of separate energy models that are joined together through the overall system model in order to communicate and work with each other. These models are each developed independently but are designed with well-defined protocols for system communication and interactivity. The WEPS+ modeling system uses a common and shared database (the "restart" file) that allows all the models to communicate with each other when they are run in sequence over a number of iterations. The overall WEPS+ system uses an iterative solution technique that allows for convergence of consumption and price to a simultaneous equilibrium solution.

This report documents the objectives, analytical approach and development of the WEPS+ Transportation Sector Model. It also catalogues and describes critical assumptions, computational methodology, parameter estimation techniques, and model source code. This document serves three purposes. First, it is a reference document providing a detailed description for model analysts, users, and the public. Second, it meets the legal requirement of the Energy Information Administration (EIA) to provide adequate documentation in support of its models (*Public Law 93-275*, *section 57.b.1*). Third, it facilitates continuity in model development by providing documentation from which energy analysts can undertake and analyze their own model enhancements, data updates, and parameter refinements for future projects.

Model Summary

The WEPS+ Transportation Model (ITran) for the *IEO2011* projects the amount of energy that is consumed to provide passenger and freight transportation services. This includes personal household on-road transportation in light duty vehicles, which is projected by the ITran rather than by the residential consumption model. This also includes fuel consumed by natural gas pipelines and small amounts of lubricants and waxes. The model projects transportation consumption for 14 energy sources in each of the 16 WEPS regions to the year 2035. The ITran provides an accounting framework that considers energy service demand (measured as consumption) and service intensity (measured as energy efficiency) for the overall stock of vehicles. Service demand is measured as the overall passenger miles for passenger services and overall ton miles for freight services. The service intensity is measured as the passenger miles per Btu (British thermal unit, a measure of energy consumption) for passenger services and as ton miles per Btu for freight services.

The ITran categorizes transportation services for passengers and freight in four modes: road, rail, water and air. These modes are also disaggregated into sub-modes (Table 1). The ITran projects overall service demand by fuel and service for a given stock of vehicles based on three drivers: economic activity, fuel prices, and a trend. The economic activity variable is quantified by gross domestic product (GDP), population, or GDP per capita and varies by service and region. Coefficients for each of the three drivers are determined by analyst judgment. An exogenous projection of service demand fuel shares for each service is used to allocate service demands by fuel type. The service intensity projection by service and fuel is exogenous to the model, and is read from an input file. Total consumption by fuel and service is calculated as service demand divided by service intensity.

Table 1. Transportation Sub-modes Included in the ITran Model

Transportation Modes	Transportation Sub-modes
1. Road	1a. Light Duty Vehicles
	1b. Two/Three Wheel Vehicles
	1c. Buses
	1d. Freight Trucks
	1e. Other Trucks
2. Rail	2a. Passenger
	2b. Freight Coal (Placeholder)
	2c. Freight Other (Currently, “All” Freight Rail)
3. Water	3a. Domestic
	3b. International
4. Air	4a. Passenger Air (Currently, “All” Air)
	4b. Freight Air (Placeholder)

The ITran obtains macroeconomic and price projections from the WEPS+ “restart file.” These projections have been previously calculated in the WEPS+ macroeconomic model and by various transformation and supply models. The model projects transportation energy consumption for a variety of energy sources and outputs them to the restart file for use by the other models.

Model Archival Citation

This documentation refers to the WEPS+ Transportation Sector Model (ITran) as archived for the *International Energy Outlook 2011*.

Model Contact

Victoria Zaretskaya
U.S. Energy Information Administration
Transportation Energy Consumption & Efficiency Analysis Team

EI-81/Forrestal Building
United States Department of Energy
1000 Independence Avenue, SW
Washington, D.C. 20585
Telephone: (202) 287-5501
E-mail: Victoria.Zaretskaya@eia.gov

Organization of This Report

Chapter 2 of this report discusses the purpose of the Transportation Sector Model (ITran); the objectives and the analytical issues it addresses; the general types of activities and relationships it embodies; the primary input and output variables; and the relationship of the model to the other models in the WEPS+ system. Chapter 3 of the report describes the rationale behind the ITran design, providing insights into further assumptions used in the model. Chapter 4 describes the model structure in more detail, including flowcharts, variables, and equations.

2. Model Purpose

Model Objectives

The WEPS+ Transportation Sector Model (the International Transportation Model or ITran) has three primary objectives. First, the model generates disaggregated projections of energy demand in the transportation sector for the period of 2009 through 2035 by fuel type, international region, mode/sub-mode, and service category. Second, the model is an analysis tool that can be used to assess the impact of policies and other changes in transportation modes through their service demands and service intensities. Third, as an integral component of the WEPS+ system, it provides consumption inputs to the various transformation and supply models of WEPS+ and contributes to the calculation of the overall energy supply and demand balance. The consumption inputs are also used by the Greenhouse Gases Model to calculate energy-related carbon dioxide emissions. The ITran calculates energy consumption for transportation as the product of two underlying components, energy service demand and energy service intensity.

As part of the WEPS+ system, the ITran provides projections for the 16 WEPS+ world regions. These regions consist of countries and country groupings within the broad divide of Organization of Economic Cooperation and Development (OECD) and non-OECD countries. The 16 regions are shown in Table 2.

Table 2. Regional Coverage of the World Energy Projections System Plus Model

OECD Regions	**Non-OECD Regions**
United States	Russia
Canada	Other Non-OECD Europe and Eurasia
Mexico/Chile	China
OECD Europe	India
Japan	Other Non-OECD Asia
Australia/New Zealand	Middle East
South Korea	Africa
	Brazil
	Other Central and South America

Model Inputs and Outputs

Inputs

As part of the WEPS+ system, the ITran uses macroeconomic and price projections that are input from the WEPS+ restart file. These projections are calculated prior to the execution of the ITran in the WEPS+ Macroeconomic Model and by various transformation and supply models (see Table 3).

Table 3. WEPS+ Models that Provide Input to the ITran through the Restart File

Transportation Model Input	Source
Gross domestic product	Macroeconomic Model
Population	Macroeconomic Model
Transportation motor gasoline retail price	Refinery Model
Transportation distillate (diesel) retail price	Refinery Model
Transportation residual retail price	Refinery Model
Transportation LPG retail price	Refinery Model
Transportation jet fuel retail price	Refinery Model
Transportation natural gas retail price	Natural Gas Model
Transportation coal retail price	Coal Model
Transportation electricity retail price	World Electricity Model
Transportation ethanol (E85) retail price	Refinery Model
Transportation biofuels retail price	Refinery Model
Transportation hydrogen retail price	(Placeholder)

A number of exogenous data series are also imported into ITran from the three input files shown in Table 4.

Table 4. Major Exogenous ITran Model Input Date Series

Source Input File	Model Input
TranBase.xml	Base year fuel by mode shares
	Base year fuel by mode by service shares
	Base year reference service intensity
	Base year regional efficiency multiplier for service intensity
	Base year regional load factor multiplier for service intensity
	Reference service intensity efficiency index projection
	Reference service intensity load factor index projection
	Regional service intensity efficiency index projection
	Regional service intensity load factor index projection
	Regional service demand shares projection
TranBXML.xml	Economic concept for service demand by sub-mode over time
	Economic elasticity for service demand by sub-mode over time
	Price elasticity for service demand by sub-mode over time
	Trend for service demand by sub-mode over time
TranMisc.xml	Coefficients for the U.S. transportation model
	Miscellaneous variables and coefficients for high world oil price case

Outputs

As part of the WEPS+ system, the ITran projects energy consumption for 14 energy sources, and write these projections to the WEPS+ restart file for use by the other models. Table 5 presents a list of these energy source outputs and the models that access them.

Table 5. ITran Model Outputs and the WEPS+ Models that Use Them

Transportation Model Output	Destination
Motor gasoline consumption	Petroleum and Refinery Models
Distillate (diesel) consumption	Petroleum and Refinery Models
Residual consumption	Petroleum and Refinery Models
LPG consumption	Petroleum and Refinery Models
Jet fuel consumption	Petroleum and Refinery Models
Sequestered petroleum consumption	Petroleum and Refinery Models
Other petroleum consumption	Petroleum and Refinery Models
Natural gas consumption	Natural Gas Model
Coal consumption	Coal Model
Electricity consumption	World Electricity Model
Ethanol (E85) consumption	Petroleum and Refinery Models
Other biofuels consumption	Petroleum and Refinery Models
Hydrogen consumption	(Placeholder)

In the course of computing the overall demand projections, the ITran also projects a variety of the components of demand – at a high level of detail – for each of the WEPS+ regions. Table 6 provides a summary of these output data series.

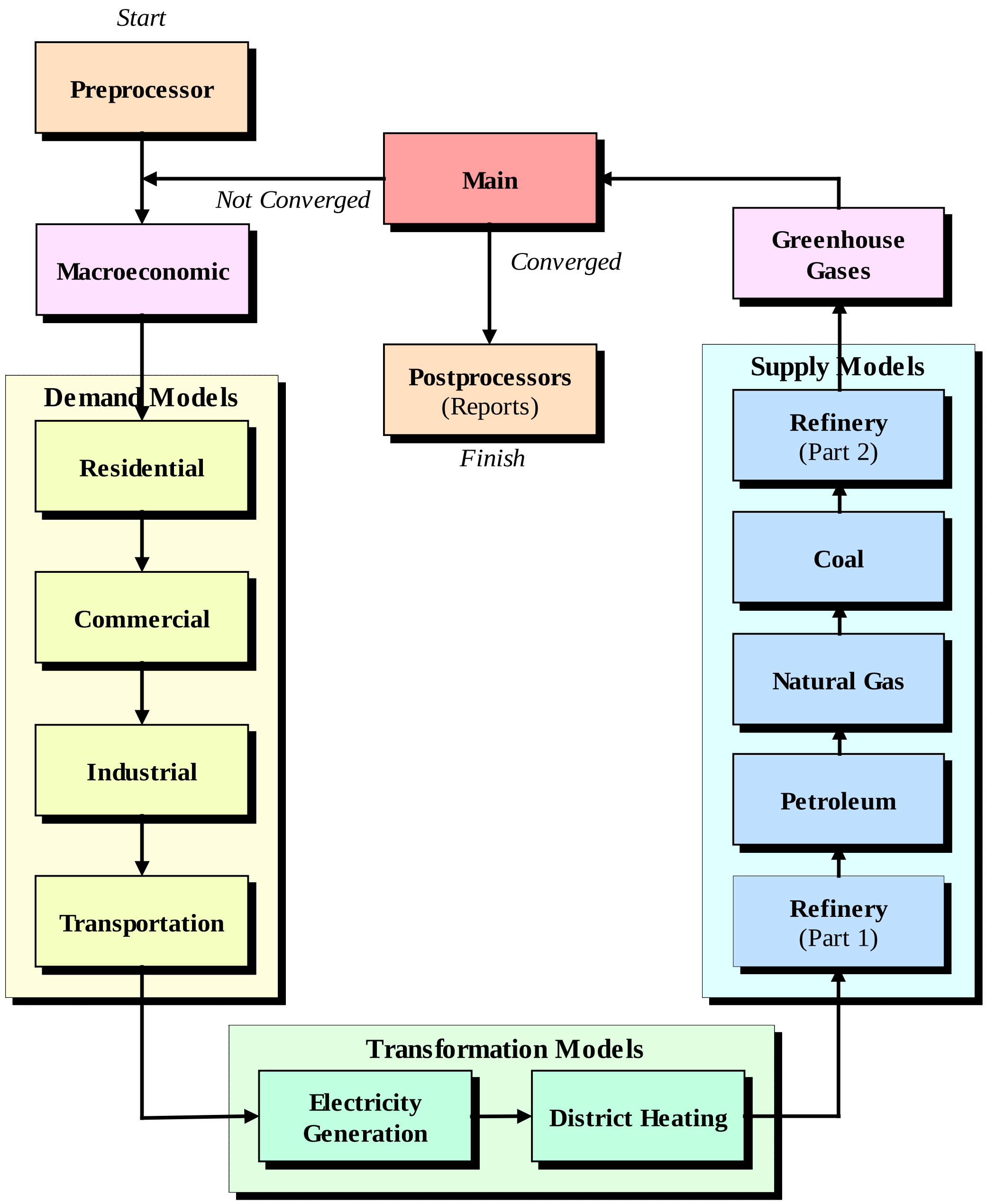
Table 6. Detailed ITran Output Data Series by Passenger and Freight Categories

Category	Model Output
Passenger	Service demand in passenger-miles by sub-mode, fuel, and region
	Service intensity in passenger-miles per Btu by sub-mode, fuel, and region
Freight	Service demand in ton-miles by sub-mode, fuel, and region
	Service intensity in ton-miles per Btu by sub-mode, fuel and region

Relationship to Other Models

The ITran is an integral component of the WEPS+ system, and depends on other models in the system for some of its key inputs (Figure 1). In turn, the ITran provides projections of transportation energy consumption, on which other models in the system depend (see Figure 1). A summary description of the models, flows, and mechanics of the WEPS+ system used for the *IEO2011* report is available in a separate *Overview* document.

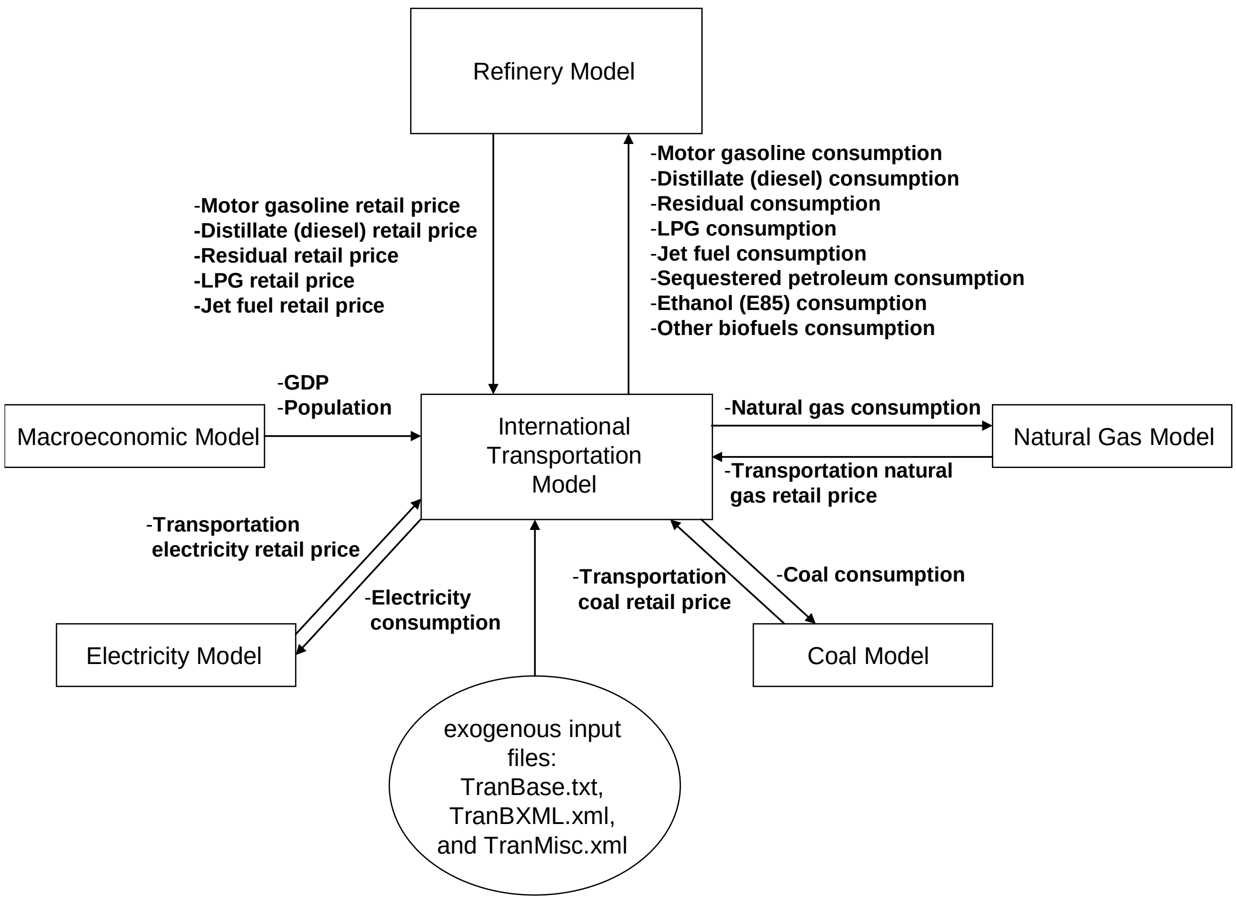
Figure 1. World Energy Projection System Plus (WEPS+) Model Sequence



Through the WEPS+ restart file, the ITran receives GDP and population projections from the Macroeconomic model, as well as a variety of transportation retail price projections from various supply models (Figure 2). In turn, the ITran provides consumption projections, through the system, back to the supply models.

Although the ITran is an integral part of the WEPS+ system, it can also be easily run as a standalone outside of the system. In standalone mode, the ITran uses macroeconomic and price projection inputs from the WEPS+ system "restart" file created in a previous full-system run.

Figure 2. Relationship Between the ITran Model and Other WEPS+ Models



3. Model Rationale

Theoretical Approach

The Transportation Sector Model (ITran) provides an accounting framework for projecting the energy consumed in providing travel services. Toward that purpose, the ITran looks at energy consumption as the product of two underlying components:

- Energy service demand (the amount of travel provided)
- Energy service intensity (measured as an energy efficiency)

For passenger modes and sub-modes, the service demand is measured as passenger-miles and the service intensity is measured as passenger-miles per Btu. Measuring service demand and service intensity in this fashion for passenger modes takes into account the passenger load factor. For freight modes and sub-modes the service demand is measured as ton-miles and the service intensity is measured as ton-miles per Btu. The ITran then estimates transportation energy consumption as the service demand divided by the service intensity.

The ITran projects annual transportation energy consumption for each of the 16 WEPS+ regions to the year 2035. To enhance readability, much of the discussion in this report omits the reference to regions and projection years. Subscripts indicating region and year are also suppressed in the equations. The ITran categorizes transportation services for passengers and freight in four modes: road, rail, water, and air (Table 7). Although pipeline natural gas is included in the transportation sector, projections of pipeline natural gas are projected in the Natural Gas Model and not in the ITran. As a result, the ITran currently considers 10 transportation services (though the structure includes two additional categories—one for air freight and one for coal rail freight—that could be incorporated should additional data become available).

Table 7. Transportation Services in the ITran

<table>
<tr><th>Mode</th><th>Units</th><th>Road</th><th>Rail</th><th>Air</th><th>Water</th></tr>
<tr><td rowspan="3">Passenger Service</td><td rowspan="3">Passenger-miles</td><td>Light-Duty (car, SUV)</td><td rowspan="3">Generic</td><td rowspan="5">Generic</td><td rowspan="3"></td></tr>
<tr><td>2 and 3 Wheel</td></tr>
<tr><td>Bus</td></tr>
<tr><td rowspan="2">Freight Service</td><td rowspan="2">Ton-miles</td><td>Heavy Truck</td><td rowspan="2">Generic</td><td>Domestic</td></tr>
<tr><td>Other Truck</td><td>International</td></tr>
</table>

Model Assumptions

As noted above, the ITran assumes an accounting framework for projecting both the amount of travel provided and the intensity (measured as an energy efficiency) of that travel. This reflects the overall assumption that the total amount of energy consumed by transportation services is determined by the total amount of service provided (passenger-miles or ton-miles) along with the average efficiency of the service (passenger-miles or ton-miles per Btu). This is summarized in the following two equations:

For passenger services:

$$TotalConsumption = \frac{TotalPassengerMiles}{PasssengerMiles / Btu}$$

For freight services:

$$TotalConsumption = \frac{TotalTonMiles}{TonMiles / Btu}$$

Embedded in these assumptions is the concept of passenger miles and ton-miles. The calculation of passenger-miles and ton-miles incorporates the load factor, which is a common usage with freight services, but is less common for passenger services. It is incorporated in the ITran to better reflect the relationships that exist, particularly in developing, non-OECD regions, between passenger-miles in services such as buses versus light duty vehicles. The number of passenger-miles is the number of miles traveled multiplied by the average load factor (average passengers per vehicle):

$$TotalPassengerMiles = TotalMilesTraveled * AverageNumberOfPassengersPerVehicle$$

For freight services:

$$TotalTonMiles = TotalMilesTraveled * AverageNumberOfTonsOfFreightPerVehicle$$

The ITran assumes that changes in total service demand for both passenger and freight services are related to three drivers: changes in economic activity (measured by GDP and/or population), energy prices, and—in some regions—a trend. The measure of economic activity (GDP, population, or GDP per capita) varies by service and region.

Each of the three drivers of service demand is implemented as an elasticity in the ITran. The sensitivity of the service demand to the cost of energy service is assumed to be the same as the sensitivity of service demand to the price of a representative fuel used to provide that service. For example, the sensitivity of taxi service demand to changes in taxi fares may be represented by the elasticity of taxi service demand to motor fuel prices. The representative fuel price is calculated as the weighted average of the price of the fuels consumed for that service (using the consumption in the previous year for weights). Fuel prices are only one of the factors determining the cost of an energy service, so the ITran cannot evaluate policies beyond those that impact a fuel price directly. For example, the effect of a subsidy on the purchase price of a vehicle cannot be analyzed.

Although the words “demand” and “consumption” are often used interchangeably, they refer to different but related concepts. Demand is the behavioral result of real-life conditions of income and prices but it can often be partly unrealized because of other constraints. Consumption is the amount of the demand that is realized. A consumer, for example, may demand one level of passenger miles given the level of income and fuel prices, but since the roads are heavily congested and/or full of potholes, the consumer may actually consume less.

The ITran projects transportation energy consumption. The ITran elasticities associated with transport services are adjusted, where possible, to account for demand constraints. In this document, the terms “demand” and “consumption” are interchangeable.

4. Model Structure

Structural Overview

The main purpose of the ITran is to estimate annual transportation sector energy consumption by region, service, and fuel type annually for 2009 to 2035. The transportation energy consumption calculations are based on service demand and service intensity estimates. Consumption is estimated for each of the 16 WEPS+ regions for 12 different services and 13 energy sources (including petroleum, non-petroleum liquids such as ethanol, other biofuels, and hydrogen fuel and natural gas used in pipeline transportation).

The basic structure of the ITran model is illustrated in Figure 3. A call from the WEPS+ interface to the ITran initiates importation of the supporting information needed to complete the projection calculations. The model then executes the Tran subroutine, the major component of the model, which performs all model computations. The subroutine then exports all projections to the restart file for use by other WEPS+ models.

A call from the ITran Main Model initiates the Tran subroutine (Figure 4), which, in turn, calls the Tinput subroutine (Figure 5). Tinput imports data from two exogenous data sources, the tranBXML.xml and tranBase.txt data files.

TranBXML.xml includes basic model identifiers (region names, fuel names, service names, etc.) as well as indices that are used throughout the computations to map services with transport modes (road, air, rail, and water) and purposes (passenger and freight). This file also includes the economic and price elasticities associated with regions, services and years, as well as multiplicative and additive factors associated with each service, projection year, and region.

TranBase.txt includes historical information about the fuel share of total liquid fuel consumption by region, mode, and service. It also includes a historical reference and future assumptions for service intensity by fuel and service, as well as historical reference and future assumptions of regional service efficiency and regional load factor multipliers for service intensity by fuel. The exogenous data provided in TranBase.xml are only available in five year increments. The Tinput subroutine therefore converts these data, after importation, to annual data series by interpolating between years to 2035.

After the Tinput subroutine has executed, the Tran subroutine begins to compute total transportation energy consumption. First, several computations are made using the historical data series to prepare the data for the projection calculations. For each WEPS+ region in each historical year, Tran performs the following preliminary calculations:

- adjust historical price data by adding any carbon price increment to the by-fuel prices provided through the restart file.
- computes average annual percent growth in GDP, population, GDP per capita
- computes percent changes in transportation prices (by fuel and averaged across fuels)

- aggregates the historical residual, sequestered petroleum, and ‘other’ petroleum consumption estimates

- subtracts pipeline natural gas from total transportation natural gas use

- aggregates consumption estimates for ethanol and other biofuels

- calculates transportation energy consumption, service intensity, and service demands by region, fuel, and service for each historical year.

Once the historical data series are readied, the Tran subroutine computes projected transportation service intensity (passenger and ton miles per Btu) by region, fuel, and service. Next, the Tran subroutine begins computing transportation service demand (passenger and ton miles) over the projection period by region, fuel and, service. These estimates are the building blocks of the consumption projections, as described above.

If the scenario is a High Oil Price case, the Tran subroutine calls two special subroutines, THWOPA and THWOPB. The THWOPA subroutine (Figure 6) is executed immediately after the historical data are prepared. In this subroutine, price elasticity multipliers from the tranMisc.xml data file are imported for each service and region. These multipliers are applied for each year to the existing Reference case price elasticities to ensure that demand is more sensitive to the higher prices assumed in the High Oil Price case. The recomputed price elasticities are then used to calculate projected transportation service demand by region, fuel, and service.

After projected levels of service demand are recalculated for the High Oil Price case, Tran calls the THWOPB subroutine (Figure 7). From the tranMisc.xml file, this subroutine imports service intensity target improvements that would be initiated under a high price regime. These improvements are targeted for implementation by 2030 and are specified by region and service. TranMisc.xml also provides penetration rates for alternative vehicles that exceed those provided in the Reference case assumptions. Once the data are imported, THWOPB re-computes transportation energy service intensities and, using the new intensities, it re-computes transportation energy consumption by projection year, service, region, and fuel type. Finally, THWOPB estimates the effects of additional alternative vehicles (hybrid electric, plug-in hybrid electric, and CNG vehicles) on projected total motor gasoline and diesel demand by year and region. THWOPB then projects total service demand by year, region, and fuel (motor gasoline and diesel/distillate fuel) and returns the projections to the Tran subroutine.

The Tran subroutine then re-computes regional consumption of motor gasoline and diesel to capture any impact of additional alternative vehicles. Next, it approximates a projection of U.S. transportation energy consumption as a placeholder for the *Annual Energy Outlook 2011* projections. Finally, Tran calculates total liquids consumption by region and benchmarks the projections to regional *Short-Term Energy Outlook* projections through 2012.

The Tran subroutine generates several output files and returns them to the main ITran routine, which then executes the WriteRestart subroutine. Write Restart provides projections to the restart file for use by other WEPS+ models, notably the refinery model. These output data series include projections of regional transportation energy use by fuel.

Flow Diagrams

Figure 3. Flowchart for the ITran Model

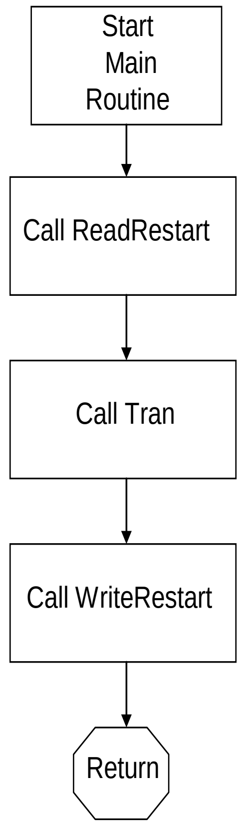
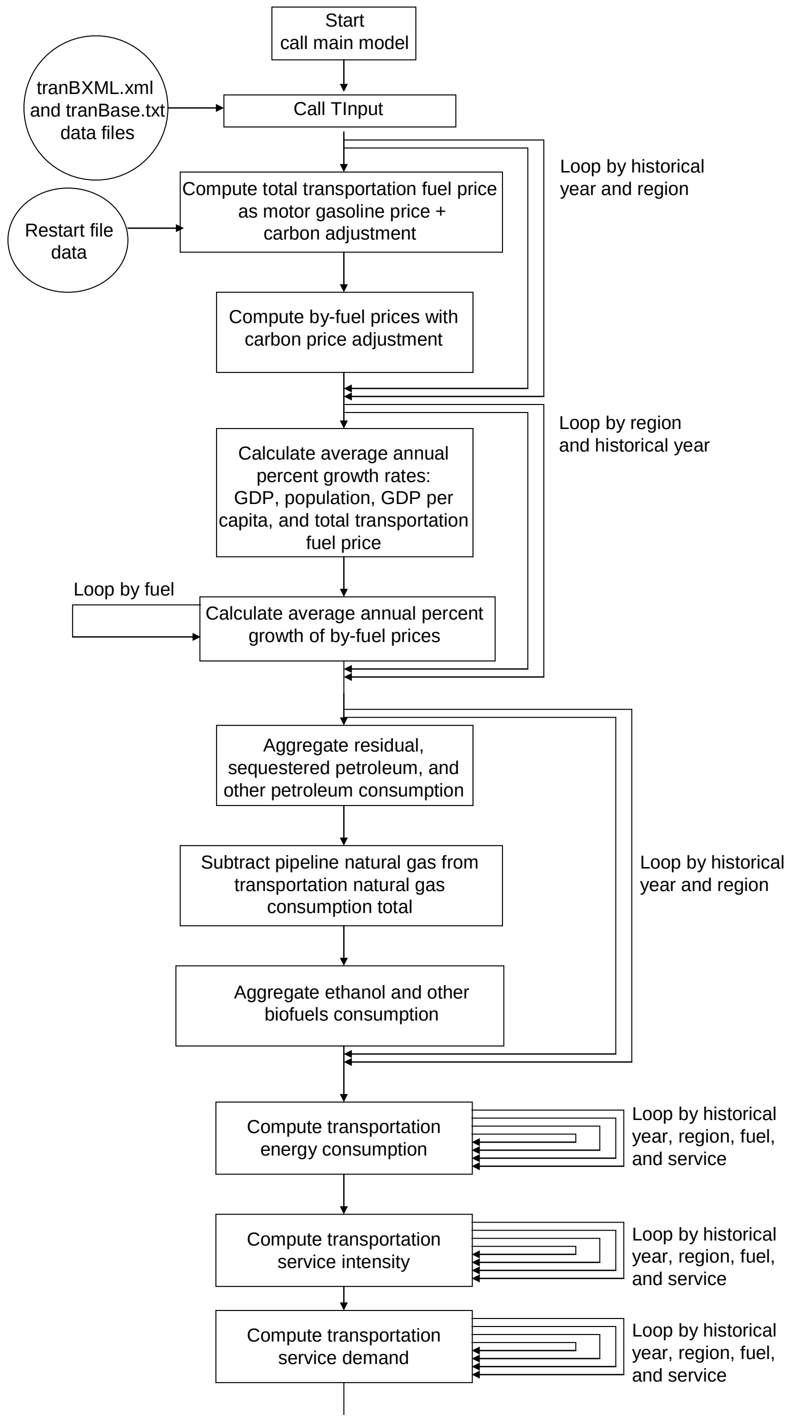


Figure 4. Flowchart for the Tran Subroutine



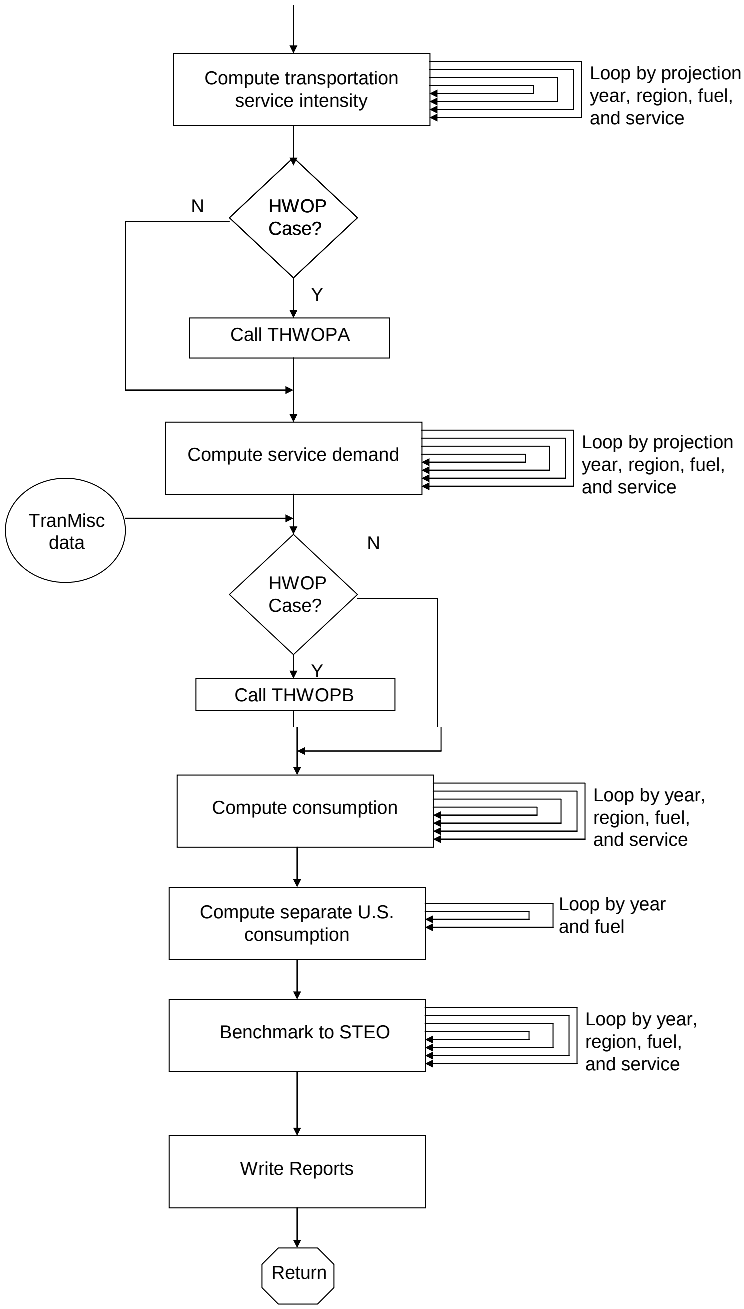

Compute transportation service intensity
Loop by projection year, region, fuel, and service
N
HWOP Case?
Y
Call THWOPA
Compute service demand
Loop by projection year, region, fuel, and service
TranMisc data
N
HWOP Case?
Y
Call THWOPB
Compute consumption
Loop by year, region, fuel, and service
Compute separate U.S. consumption
Loop by year and fuel
Benchmark to STEO
Loop by year, region, fuel, and service
Write Reports
Return

Figure 5. Flowchart for the Tinput Subroutine

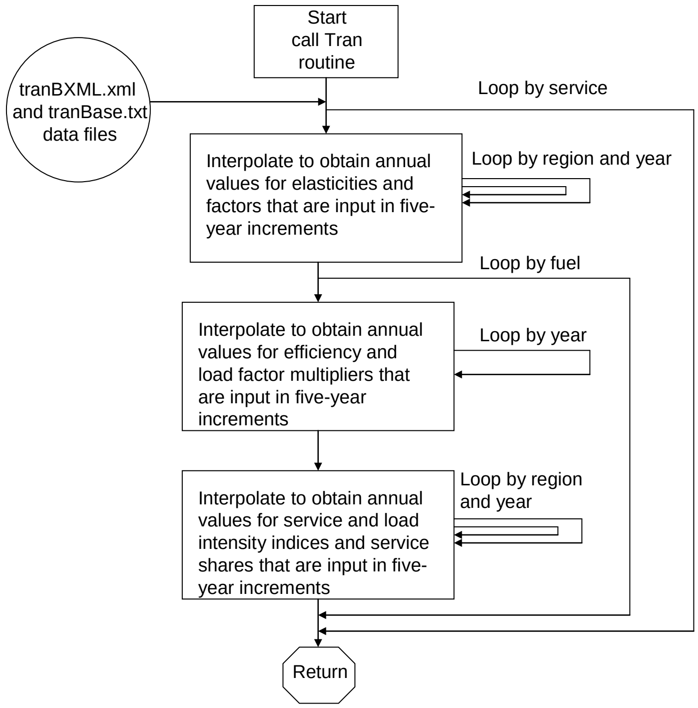


Figure 6. Flowchart for the THWOPA Subroutine

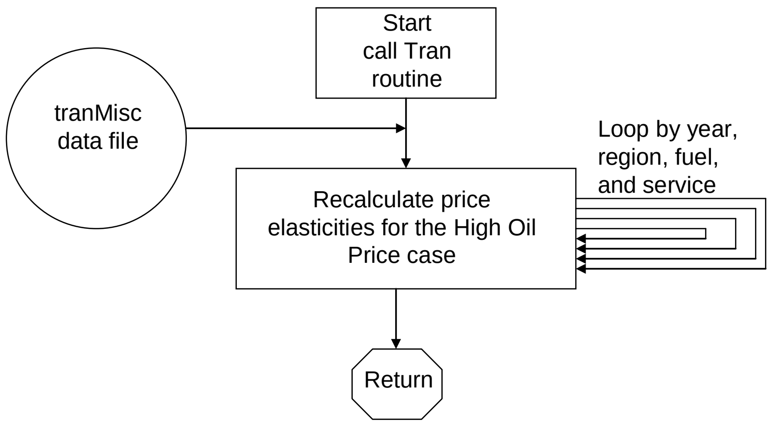
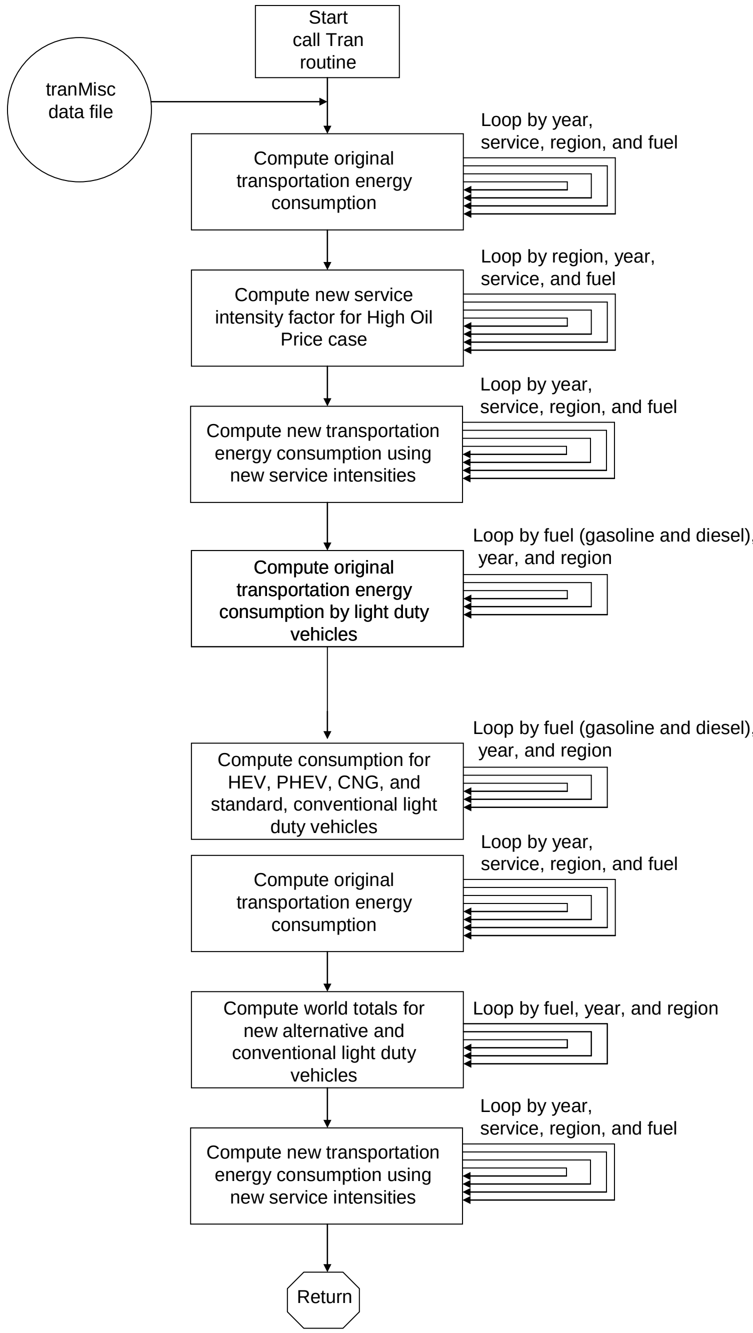


Figure 7. Flowchart for the THWOPB Subroutine



Key Computations

The International Transportation Model (ITtran) of the WEPS+ modeling system projects energy used for passenger and freight transportation services. Personal household on-road transportation in light duty vehicles is included in the ITran Model rather than in the Residential Model of WEPS+. For each of the 16 WEPS+ regions, the ITran projects annual transportation energy consumption, through 2035, for the following 13 energy sources:

- Motor Gasoline
- Distillate
- Residual
- Liquefied Petroleum Gas (LPG)
- Jet Fuel
- Sequestered Petroleum
- Other Petroleum
- Natural Gas
- Coal
- Electricity
- Ethanol (E85)
- Other Biofuels
- Hydrogen

The ITran provides an accounting framework for projecting both the amount of travel provided and the energy consumed in providing travel services. For the sake of readability, much of the discussion in this report omits the reference to regions and projection years. The ITran categorizes passenger and freight transportation services into four modes: road, rail, water, and air. The modes are further disaggregated into a total of 10 transportation services, as shown in Table 8.

Table 8. Transportation Services Currently Modeled in the ITran

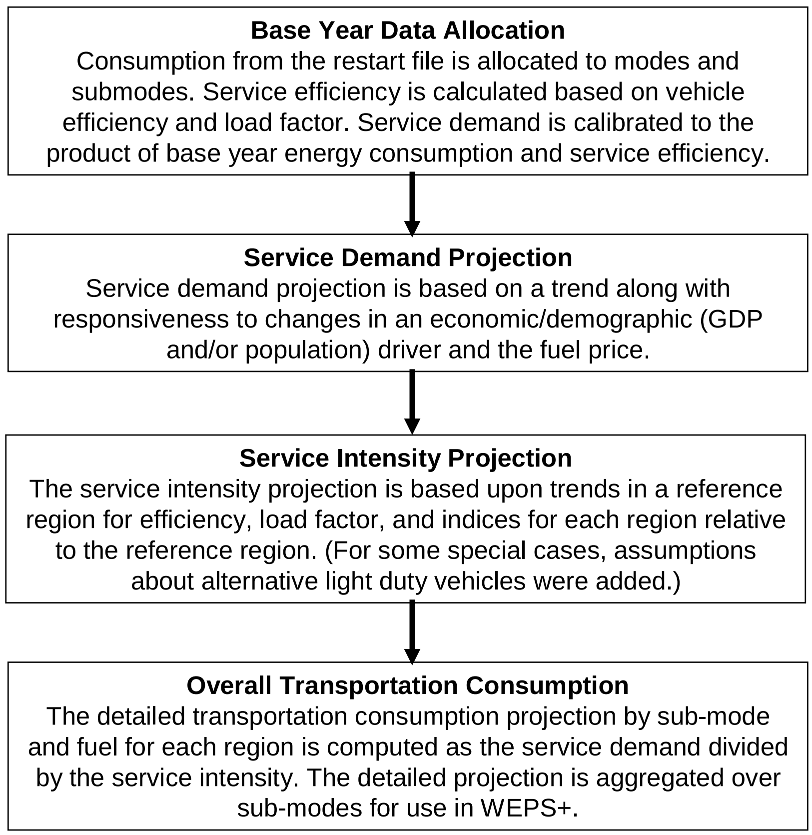
Transportation Mode	Units	Road	Rail	Air	Water
Passenger Service	Passenger-miles	Light-Duty (car, SUV)	Generic	Generic	
		2 and 3 Wheel			
		Bus			
Freight Service	Ton-miles	Heavy Truck	Generic		Domestic
		Other Truck			International

Services in the ITran are measured in units of passenger-miles for each of the passenger services, and in ton-miles for each of the freight services. The average efficiency characteristics of each fuel category may change over the projection period by user specification, but the model does not track the stock or vintage of vehicles. For the air transportation mode, Itran combines freight and passenger services and reports them in passenger-miles.

Figure 8 provides a flowchart of the major computations of the ITran. Each of these routines is discussed in greater detail in the subsequent text. The overall activity of the model can be exemplified by a single sub-mode, such as light duty vehicles (LDVs). The total level of the base-year LDV service demand provided by all fuel categories is the sum of the service provided by each fuel category. For LDVs ITran adds up service provided in gasoline-powered vehicles, diesel-powered vehicles, ethanol-powered vehicles, and so on.

Over the projection period, the number of passenger miles provided by light duty vehicles changes relative to the base year. The Itran estimates the changes based on changes in demographic and economic explanatory variables and on explicit, time-dependent elasticities of service demand with respect to these explanatory variables. Itran projects fuel consumption estimates based on projected service level demand, technology fuel shares, and the efficiency with which fuel is converted to passenger miles using each fuel technology. In the model specification, service demand elasticities, technology fuel shares, and technology efficiencies all may vary over time.

Figure 8. Major ITran Functions



For each model iteration, the ITran imports the following information from the WEPS+ shared restart file:

- Projected fuel prices (all years and all regions)
- Macroeconomic and demographic drivers
- Historical transportation energy consumption levels—the base year for model calibration is the most recent year for which historical data are available

After making its calculations, the ITran outputs the resulting transportation fuel consumption projections, by region and year, to the restart file for use by other WEPS+ models. Within the ITran, transportation fuel consumption levels are more disaggregate (over fuel technologies) and are modeled in the following level of detail:

- Projected level of service (service demand)
- Fuel technology share
- Fuel use per unit of service (service intensity or efficiency)

For example, diesel fuel used in providing heavy truck ton-miles is the product of the projected level of heavy truck ton-miles, the diesel share of heavy truck ton-miles, and the diesel use per heavy truck ton-mile. Diesel (distillate) consumption estimates used in WEPS+ are aggregates of distillate consumption estimates for: light duty vehicles; 2 and 3 wheel vehicles; buses; heavy trucks; other trucks; passenger rail; freight rail; and international and domestic shipping.

Base Year Model Calibration

In the ITran base year calibration, the model disaggregates the WEPS+ base year transportation energy consumption estimates to the finer level of detail used in the ITran projection calculations. The process described here uses petroleum products as an example. The ITran base year model calibration processes for transport electricity, natural gas, and coal consumption, are essentially the same as the one described here for petroleum.

The ITran transportation model begins by importing the historical data that are contained in the common, shared restart file. These historical data are compiled from the International Energy Agency's transportation sector energy consumption data from the *Extended Balances and Statistics* database (IEA/Paris data). The data are calibrated to the more aggregated international data series that are available from the Energy Information Administration's *International Energy Statistics Database*. These calibrations have been processed at an earlier point, and put into the restart file to provide a common starting point for all the WEPS+ models. For the *IEO2011*, the ITran used the data available to it for 2005, 2006, 2007, and 2008 for each of the 16 regions and each of the 13 energy sources (hydrogen use is currently zero in the initial data and the transportation model projections). The model grabs this data and puts it into its own variables.

Allocate Regional Consumption to Transport Modes. The ITran models transportation energy use in each of four modes: road, rail, air, and water. The shares for each mode are from the IEA/Paris data. Table 9shows the values that were used for the *IEO2011* for modal shares of transport consumption in China. In this example, all gasoline consumption has been allocated to road use (implicitly assuming no small pleasure craft, for example) and all electricity consumption has been allocated to rail (implicitly assuming no plug-in hybrid electric cars). The user can specify fuels for the mode shares within each region.

Table 9. Initial Mode Consumption Shares by Fuel for China

Region	Transport Fuel	Mode	Share
China	Gasoline	Road	1.000
China	Distillate	Road	0.613
China	Distillate	Rail	0.222
China	Distillate	Water	0.165
China	Jet Fuel	Air	1.000
China	Heavy Fuel Oil	Water	1.000
China	LPG	Road	1.000
China	Coal	Rail	1.000
China	Electricity	Rail	1.000
China	Natural Gas	Road	1.000
China	Renewable	Road	1.000

Allocate Regional Consumption to Services within Modes. The ITran further disaggregates transportation energy consumption from the four modes to the ten sub-modes or services shown in Table 8. The shares for each service are based on available data from a variety of sources and analyst judgment. As an example, Table 10 shows how distillate consumption in China is allocated to services within modes. Because airplanes do not consume distillate fuel, the distillate shares for road, rail, and water add to 1 (see Table 9). In Table 10, for example, 3 percent of the distillate consumption for road vehicles is allocated to light duty vehicles in the base year. The ITran performs similar service-level (sub-mode) allocations for all fuels in all modes and regions.

Table 10. Initial Service Consumption Shares for Distillate Fuel in China

Region	Fuel	Mode	Service	Share
China	Distillate	Road	Light Duty	0.030
China	Distillate	Road	Two Three Wheel	0.030
China	Distillate	Road	Bus	0.280
China	Distillate	Road	Heavy Truck	0.450
China	Distillate	Road	Other Truck	0.210
China	Distillate	Rail	Rail Passenger	0.150
China	Distillate	Rail	Rail Freight	0.850
China	Distillate	Water	Water Domestic	0.953
China	Distillate	Water	Water International	0.047
China	Distillate	Air	All Air	0.000

ITran allocates regional fuel consumption for the base year 2008 to the modes and services by applying factors representing mode-level and service-level (within mode) shares:

Where *BaseQty(f,r,y*=2008*)* = estimated 2008 consumption of fuel *f* in region *r*

BYFuelByMode(m,f,r,y=2008*)* = 2008 share of fuel *f* used in mode *m*

BYFuelByModeByServ(m,s,f,r,y=2008*)* = 2008 share of fuel *f* used for service *s* within mode *m* and region *r*

TrnQty(m,s,f,r,y=2008*)* = 2008 consumption of fuel *f* for service *s* within mode *m* in region *r*

The end result of this base year model calibration sharing routine is a more detailed level of base year consumption at the sub-mode for each fuel and in each region. An example of fuel consumption for light duty vehicles in China is shown in Table 11.

Table 11. Base Year Light Duty Fuel Vehicles Consumption in China, **2008**

Service	Fuel	Fuel Consumption (trillion Btu)
Light Duty Vehicle	Motor Gasoline	878
	Distillate Fuel	63
	Liquefied Petroleum Gas	20
	Natural Gas	6
	Electricity	0
Total		967

Service Intensity and Service Demand by Sub-Mode. Estimates of base year service intensity provide the link between fuel consumption and service demand by fuel. Service intensity is defined as the level of transport service provided per unit of energy consumed. In the ITran, the units for service intensity are billion passenger-miles per trillion Btu for passenger transport and billion ton-miles per trillion Btu for freight transport. Service intensity in the ITran is calculated as the product of two elements that are explicit in the ITran: vehicle efficiency and vehicle load factor. Both vary by region and over time. The initial value of service intensity is specified as a reference value for a generic or “reference” region. This is then multiplied by factors for vehicle efficiency and for the vehicle load factor for the reference region. Finally, resulting value is multiplied by factors for vehicle efficiency and by a vehicle load factor for each region. The equation for the initial service intensity is given by:

Where *BYRefServ(s,f,y*=2008*)* = 2008 service intensity for service *s* and fuel *f*

FYRefServEFM(s,f,y=2008*)* = 2008 reference vehicle efficiency index for service *s* and fuel *f*

FYRefServLDM(s,f,y-2008*)* = 2008 reference vehicle load factor index for service *s* and fuel *f*

FYRegServEFM(s,f,r,y=2008*)* = 2008 vehicle efficiency index for service *s* and fuel *f* in region *r*

FYRegServLDM(s,f,r,y=2008*)* = 2008 vehicle load factor index for service *s* and fuel *f* in region *r*

TrnSI(s,f,r,y=2008*)* = 2008 service intensity for service *s* and fuel *f* in region *r*

Initial base year service demand is calculated as the product of base year consumption and base year service intensity. By definition, the energy consumption level is the service demand divided by the service intensity; if two of the items are known, the value for the third can be calculated:

Where, for service *s* and fuel *f* in region *r,*

TrnQty(s,f,r,y=2008*)* = 2008 energy consumption (Btu)

TrnSI(s,f,r,y=2008*)* = 2008 service intensity (passenger or ton miles per Btu)

TrnSD(s,f,r,y=2008*)* = 2008 = estimated service demand (passenger or ton miles)

Table 12illustrates the process of calculating base year transport service demand for a single service (or sub-mode), light duty vehicles, in a single region, China. The same basic logic is used to estimate base year service levels for all regions and for all services. The first column lists the fuel technologies that can provide the service. (The ITran does not account for different technologies that consume the same fuel, such as a conventional gasoline vehicle and a gasoline hybrid.) The second column shows fuel consumption for the service or sub-mode (a result of the sharing allocation process).

The third column shows an estimate (based on analyst judgment) of the average fleet vehicle efficiency (for the entire stock of vehicles of that type) in the base year. This is estimated for a reference region in the base year and then adjusted using regional factors. The fourth column is an estimate (based on analyst judgment) of the base year load factor in passenger-miles per vehicle mile. This is estimated for a reference region in the base year and adjusted using regional factors.

The fifth column is the product of the vehicle efficiency (column 3) and the load factor (column 4). It is the efficiency with which the fuel technology provides the transport service. For example, a diesel bus carrying 50 passengers has a service intensity that is ten times the service intensity of the same bus holding 5 passengers each vehicle mile.

The sixth column is the product of the service energy intensity (billion passenger miles per trillion Btu) and the fuel consumption (trillion Btu), which is the level of light duty vehicle service demand (billion passenger miles) provided by each fuel in the base year. This is the starting point for the ITran projections.

Table 12. Initial Service Energy Intensity and Service Demand Example for Light Duty Vehicles in China

Fuel	Consumption	Vehicle Technology Efficiency	Load factor	Service Energy Intensity	Service
	(trillion Btu)	(billion vehicle miles per trillion Btu)	(passenger miles per vehicle mile)	(passenger miles per trillion Btu)	(billion passenger miles)
Gasoline	878	0.279	1.23	0.344	301.9
Distillate	63	0.336	1.23	0.414	25.6
LPG	20	0.254	1.23	0.313	6.3
Natural Gas	6	0.262	1.23	0.323	2
Total	967				336

The energy intensity/efficiency parameters assumed for the reference region in the base year are shown in Table 13 for all transport services. Note that the efficiency (intensity) in the third column is shown as miles per gallon and can be converted to billion vehicle miles per trillion Btu by multiplying by 0.008049. Table 14 provides a sample of sub-mode factors by fuel for a single region, Africa. The ITran first determines the service efficiency and service demand for a reference region and then uses regional adjustment factors to extend them to each of the 16 WEPS+ regions.

The service energy intensity of a gasoline bus provides a useful example of the base year calculations. As shown in Table 13, the reference region gasoline bus in the base year has a vehicle energy intensity of 8.0 miles per gallon and a load factor of 12.0 (average occupancy of a bus). Together, these figures mean that, for the reference region, the service energy efficiency of the gasoline bus (service per unit of energy) in the base year is 0.773 billion passenger-miles per trillion Btu of gasoline. As shown in Table 14, bus vehicle efficiency in Africa is 18 percent higher, while the load factor is twice as high. The bus vehicle efficiency in Africa is the product of 8.0 and 1.18 for a value of 9.4 miles per gallon and the load factor is the product of 12.0 and 2.00 for a value of 24.0 passengers per average bus. The resulting service intensity associated with these values is 1.84 billion passenger-miles per trillion Btu.

Table 13. Reference Region Energy Intensity/Efficiency Assumptions, 2008

Fuel	Service	Vehicle Energy Intensity	Load Factor	Service Energy Intensity
		(miles per gallon)	(passenger miles per vehicle mile)	(passenger Miles per trillion Btu or billion ton miles per trillion Btu – freight)
Gasoline	Light_Duty	19.6	1.5	0.237
Gasoline	Two_Three_Wheel	50.0	1.0	0.403
Gasoline	Bus	8.0	12.0	0.773
Gasoline	Heavy_Truck	5.7	8.0	0.367
Gasoline	Other_Truck	10.0	4.0	0.322
Distillate	Light_Duty	1.0	1.5	0.296
Distillate	Two_Three_Wheel	1.0	1.0	0.403
Distillate	Bus	7.0	15.0	0.760
Distillate	Rail_Passenger	1.0	1.0	1.011
Distillate	Heavy_Truck	5.7	11.0	0.454
Distillate	Other_Truck	10.0	4.0	0.290
Distillate	Rail_Coal	1.0	1.0	2.910
Distillate	Rail_Other_Freight	1.0	1.0	2.910
Distillate	Water_Domestic	1.0	1.0	2.400
Distillate	Water_International	1.0		2.400
Jet_Fuel	Air_Passenger	55.7	1.0	0.413
Jet_Fuel	Air_Freight	1.0	1.0	1.000
Heavy_Fuel_Oil	Water_Domestic	1.0	1.0	2.400
Heavy_Fuel_Oil	Water_International	1.0	1.0	2.400
Liquid_Petroleum_Gas	Light_Duty	1.0	1.5	0.230
Liquid_Petroleum_Gas	Two_Three_Wheel	1.0	1.0	0.403
Liquid_Petroleum_Gas	Bus	1.0	1.0	0.773
Liquid_Petroleum_Gas	Heavy_Truck	7.2	5.0	0.290
Liquid_Petroleum_Gas	Other_Truck	8.56	2.0	0.138
Coal	Rail_Passenger	1.0	1.0	1.011
Coal	Rail_Coal	1.0	1.0	2.910
Coal	Rail_Other_Freight	1.0	1.0	2.910
Electricity	Rail_Passenger	1.0	1.0	1.011
Electricity	Rail_Coal	1.0	1.0	1.000
Electricity	Rail_Other_Freight	1.0	1.0	2.910
Natural_Gas	Light_Duty	1.0	1.5	0.237
Natural_Gas	Two_Three_Wheel	1.0	1.0	0.403
Natural_Gas	Bus	1.0	1.0	0.773
Natural_Gas	Heavy_Truck	7.2	5.0	0.290
Natural_Gas	Other_Truck	8.56	2.0	0.138
Renewables	Light_Duty	1.0	1.5	0.237
Renewables	Two_Three_Wheel	1.0	1.0	0.403
Renewables	Bus	1.0	1.0	0.773
Renewables	Heavy_Truck	1.0	1.0	0.367
Renewables	Other_Truck	1.0	1.0	0.322

Table 14. Example of Regional Service Energy Intensity Factors for Africa, 2008

Region	Fuel	Service	Region Efficiency Factor	Region Load Factor
Africa	Gasoline	Light_Duty	1.00	1.25
Africa	Gasoline	Two_Three_Wheel	2.00	1.50
Africa	Gasoline	Bus	1.18	2.00
Africa	Gasoline	Heavy_Truck	0.80	0.80
Africa	Gasoline	Other_Truck	0.80	0.80
Africa	Distillate	Light_Duty	1.00	1.25
Africa	Distillate	Two_Three_Wheel	2.00	1.50
Africa	Distillate	Bus	1.18	2.00
Africa	Distillate	Heavy_Truck	0.80	0.80
Africa	Distillate	Other_Truck	0.80	0.80
Africa	Distillate	Rail_Passenger	0.85	2.00
Africa	Distillate	Rail_Coal	0.85	1.00
Africa	Distillate	Rail_Other_Freight	0.85	1.00
Africa	Distillate	Water_Domestic	1.00	1.00
Africa	Distillate	Water_International	1.00	1.00
Africa	Jet_Fuel	Air_Passenger	1.00	0.90
Africa	Jet_Fuel	Air_Freight	1.00	1.00
Africa	Heavy_Fuel_Oil	Water_Domestic	1.00	1.00
Africa	Heavy_Fuel_Oil	Water_International	1.00	1.00
Africa	Liquid_Petroleum_Gas	Light_Duty	1.00	1.25
Africa	Liquid_Petroleum_Gas	Two_Three_Wheel	2.00	1.50
Africa	Liquid_Petroleum_Gas	Bus	1.00	2.00
Africa	Liquid_Petroleum_Gas	Heavy_Truck	1.00	1.00
Africa	Liquid_Petroleum_Gas	Other_Truck	1.00	1.00
Africa	Coal	Rail_Passenger	1.00	2.00
Africa	Coal	Rail_Coal	1.00	1.00
Africa	Coal	Rail_Other_Freight	1.00	1.00
Africa	Electricity	Rail_Passenger	1.00	2.00
Africa	Electricity	Rail_Coal	1.00	1.00
Africa	Electricity	Rail_Other_Freight	1.00	1.00
Africa	Natural_Gas	Light_Duty	1.00	1.25
Africa	Natural_Gas	Two_Three_Wheel	1.50	1.50

Region	Fuel	Service	Region Efficiency Factor	Region Load Factor
Africa	Natural_Gas	Bus	1.00	2.00
Africa	Natural_Gas	Heavy_Truck	1.00	1.00
Africa	Natural_Gas	Other_Truck	1.00	1.00
Africa	Renewables	Light_Duty	1.00	1.25
Africa	Renewables	Two_Three_Wheel	2.00	1.50
Africa	Renewables	Bus	1.00	2.00
Africa	Renewables	Heavy_Truck	1.00	1.00
Africa	Renewables	Other_Truck	1.00	1.00

Projections of Transportation Energy Components

The ITran projects annual transportation service demand (in passenger or ton miles) for each fuel and sub-mode (service), described earlier, in each of the WEPS+ regions through 2035. ITran computes energy consumption projections as products of projected service demand and service efficiency.

Projections of Transportation Service Demand

The next three tables provide examples of the Itran calculations used for projecting service demand levels (passenger or ton miles) in each region. The assumptions are made for each of the services and for each projection year at 5-year intervals. (The transportation model interpolates to get values for each year in between these 5-year intervals for making model projections.) For each service, the model allows alternative drivers to be used for the projection. These include GDP, GDP per capita, or population and are shown in Table 15. There is an economic elasticity associated with the particular economic/demographic driver that is shown in Table 16.

The elasticity of service demand with respect to the price of the service is shown in Table 17. The ITran does not estimate the cost of energy services associated with the fuel prices, but rather assumes that the sensitivity of the service demand to the price of the service is the same as the sensitivity of service demand to the price of a representative fuel used to provide that service. The representative fuel price is calculated as an average price for the fuels consumed in providing that service, weighted by the previous year’s energy consumption figures. Fuel prices are only one of the factors determining the cost of an energy service, and the ITran cannot evaluate policies beyond those that impact the fuel price directly. For example, the effect of a subsidy on the purchase price of a vehicle cannot be analyzed.

Table 15. Service Demand Economic Elasticity Concepts for China, 2010-2035

		2010	2015	2020	2025	2030	2035
Road							
	Light Duty Vehicles	GDP_Pop	GDP_Pop	GDP_Pop	GDP_Pop	GDP_Pop	GDP_Pop
	Two/Three Wheel	GDP_Pop	GDP_Pop	GDP_Pop	GDP_Pop	GDP_Pop	GDP_Pop
	Bus	GDP_Pop	GDP_Pop	GDP_Pop	GDP_Pop	GDP_Pop	GDP_Pop
	Heavy Truck	GDP	GDP	GDP	GDP	GDP	GDP
	Other Truck	GDP	GDP	GDP	GDP	GDP	GDP
Rail							
	Passenger	GDP_Pop	GDP_Pop	GDP_Pop	GDP_Pop	GDP_Pop	GDP_Pop
	Freight	GDP	GDP	GDP	GDP	GDP	GDP
Air							
	Passenger	GDP_Pop	GDP_Pop	GDP_Pop	GDP_Pop	GDP_Pop	GDP_Pop
	Freight	GDP	GDP	GDP	GDP	GDP	GDP
Water							
	Domestic	GDP	GDP	GDP	GDP	GDP	GDP
	International	GDP	GDP	GDP	GDP	GDP	GDP

Table 16. Service Demand Economic Elasticities for China

		2010	2015	2020	2025	2030	2035
Road							
	Light Duty Vehicles	1.35	1.35	1.35	1.35	1.35	1.35
	Two/Three Wheel	0.75	0.60	0.45	0.40	0.30	0.30
	Bus	0.50	0.50	0.50	0.50	0.50	0.50
	Heavy Truck	1.20	1.20	1.20	1.20	1.20	1.20
	Other Truck	1.20	1.20	1.20	1.20	1.20	1.20
Rail							
	Passenger	0.75	0.75	0.75	0.75	0.75	0.75
	Freight	1.10	1.10	1.10	1.10	1.10	1.10
Air							
	Passenger	1.40	1.40	1.40	1.40	1.40	1.40
	Freight	0.80	0.80	0.80	0.80	0.80	0.80
Water							
	Domestic	0.72	0.72	0.72	0.72	0.72	0.72
	International	0.70	0.70	0.70	0.70	0.70	0.70

Table 17. Service Demand Price Elasticities for China

		2010	2015	2020	2025	2030	2035
Road							
	Light Duty Vehicles	-0.10	-0.20	-0.30	-0.33	-0.35	-0.35
	Two/Three Wheel	-0.05	-0.10	-0.10	-0.10	-0.10	-0.10
	Bus	-0.05	-0.10	-0.10	-0.10	-0.10	-0.10
	Heavy Truck	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10
	Other Truck	-0.10	-0.12	-0.15	-0.17	-0.19	-0.19
Rail							
	Passenger	0.00	0.00	0.00	0.00	0.00	0.00
	Freight	0.00	0.00	0.00	0.00	0.00	0.00
Air							
	Passenger	-0.05	-0.10	-0.15	-0.20	-0.25	-0.25
	Freight	-0.10	-0.15	-0.20	-0.25	-0.25	-0.25
Water							
	Domestic	-0.05	-0.10	-0.10	-0.10	-0.10	-0.10
	International	-0.05	-0.10	-0.10	-0.10	-0.10	-0.10

In each projection year, the level of transport service produced may change because of changes in economic and/or demographic conditions, changes in the price of the energy service, and the assumed elasticities. If there are no changes in the explanatory variables (or if the elasticities are zero), then the Itran projects no change in the level of the transport service. The service demand is projected at an overall level for each service (a total for all fuels for that service) and then allocated to fuels based on service demand fuel shares. The fuel price used to calculate the overall service demand is an average fuel price for that service, weighted by the service demand fuel shares. The model calculates an adjustment factor to represent the effect of each explanatory variable.

The Itran uses either the GDP, the population, or the GDP per capita as the explanatory variable representing economic/demographic conditions. This explanatory variable will be referred to as the "economic concept," For example, when the economic concept is the GDP, the adjustment factor calculated to represent the effect of change in economic conditions on service *s* in region *r* from year *y*-1 to *y* is

$$EconMlt(s,r,y) = FYEconElas(s,r,y) * (\frac{GDP(r,y)}{GDP(r,y-1)} - 1)$$

Where *FYEconElas(s,r,y)* = economic elasticity for service *s* and region *r* in year *y*

GDP(r,y) = gross domestic product for region *r* in year *y*

EconMlt(s,r,y) = growth rate due to the economic variable for service *s* in region *r* and year *y*

The Itran calculates the price growth rate (factor) by multiplying a price elasticity parameter by an estimate of the percentage change in average prices, weighted by service demand shares.

$$PrcMlt(s,r,y) = FYPrcElas(s,r,y) * (\frac{WtAvgPrc(r,y)}{WtAvgPrc(r,y-1)} - 1)$$

Where *FYPrcElas(s,r,y)* = price elasticity for service *s* in region *r* and year *y*

WtAvgPrc(r,y) = weighted average price for services in region *r* and year *y*

PrcMlt(s,r,y) = factor representing growth rate due to price variability for service *s* in region *r* and year *y*

In the final projection equation, the Itran combines the projected growth rate factors for the economic concept and price effects. Service demand projections can also incorporate a trend projection; this allows for exogenous technology or efficiency changes, or other trend factors.

$$OverallSD(s,r,y) = OverallSD(s,r,y-1) * (1 + EconMlt(s,r,y)) * (1 + PrcMlt(s,r,y)) * (1 + FYMultFac(s,r,y))$$

Where, for service *s* in each region *r* and year *y*,

OverallSD(s,r,y) = overall service demand

EconMlt(s,r,y)= growth rate due to changes in the economic concept variable

PrcMlt(s,r,y) = growth rate due to price changes

FYMultFac(s,r,y) = growth rate due to the trend

The model uses the base year service demand fuel shares to allocate the overall service demand to each fuel used for each service:

$$TrnSD(s,f,r,y) = OverallSD(s,r,y) * FYShrServ(s,f,r,y)$$

Where, for fuel f and service s in region r and year y,

FYShrServ(s,f,r,y) = service demand share

TrnSD(s,f,r,y) = projected service demand

For the *IEO2011*, the base year service demand fuel shares were assumed constant over the projection period. Future ITran enhancements may include efforts to approximate fuel technology shares as endogenous functions of the relative cost of providing the different services with each fuel technology.

Projections of Transportation Service Efficiency/Intensity

In the ITran, the service energy intensity (or efficiency) is the product of vehicle efficiency and on the intensity with which the vehicle provides service:

For example, an average gasoline passenger bus in the United States may have a vehicle efficiency of 7 miles per gallon. An average (much older) gasoline bus in India may go only 4 miles per gallon of gasoline. Obviously, the U.S. bus has the greater vehicle efficiency (more vehicle miles per gallon). India's bus, however, is likely to carry roughly 10 times as many passengers and therefore provide much greater energy service efficiency. Economic development often brings both the use of newer, more efficient vehicles *and* an increased use of private vehicles rather than public transit—resulting in an overall decrease in energy service efficiency.

The projections of service intensity in ITran are calculated as the products vehicle efficiency and vehicle load factor. Both factors are explicit in the model and vary by region and year. The initial value of service intensity is specified as a reference value for a reference region. This is then multiplied by factors representing vehicle efficiency and vehicle load factor for the reference region in the projection year. Finally, the value is multiplied by factors for vehicle efficiency and for vehicle load factor for the specific region in the projection year. (The process is the same process as that used for the base year, except that it is carried out over the projection period.) The equation for the service intensity projections:

$$\begin{aligned} TrnSI(s, f, r, y) = {} & BYRefServ(s, f) \\ & * FYRefServEFM(s, f, y) * FYRefServLDM(s, f, y) \\ & * FYRegServEFM(s, f, r, y) * FYRegServLDM(s, f, r, y) \end{aligned}$$

Where *BYRefServ(s,f)* = base year reference service intensity for and service *s* and fuel *f*

FYRefServEFM(s,f,y) = reference vehicle efficiency index for service *s* and fuel *f* in projection year *y*

FYRefServLDM(s,f,y) = reference vehicle load factor index for service *s* and fuel *f* in projection year *y*

FYRegServEFM(s,f,r,y) = vehicle efficiency index for service *s* and fuel *f* in region *r* and projection year *y*

FYRegServLDM(s,f,r,y) = projected vehicle load factor index for service *s* and fuel *f* in region *r* and projection year *y*

TrnSI(s,f,r,y) = service intensity for service *s* and fuel *f* in region *r* and projection year *y*

The calculations for gasoline and diesel in the region of Africa provide an illustrative example. Table 18 shows the service intensity projections for gasoline sub-modes in Africa. Table 19 shows an example of the service intensity projections for diesel sub-modes

As shown in Table 18, the original gasoline service intensity in 2005 for buses is 0.773 billion passenger-miles per trillion Btu in a generic or "reference" region. In that reference region, from 2005 to 2035 the gasoline bus efficiency index increases by 6 percent while the load factor index stays constant. This causes the overall service energy intensity in the reference region to increase by a total of 6 percent from 0.773 to 0.819 billion passenger-miles per trillion Btu.

Table 18 also illustrates how the values for the reference region are modified by the indices to apply to a specific region. In the table, the example region shown is Africa. The indices shown for Africa are relative to the values in the reference region. Continuing the example for the gasoline bus service intensity, the 2035 value for the reference region is 0.819. This reference value is multiplied by the vehicle energy intensity index of 1.060 for 2035 and by the load factor index of 2.000 for 2035. The result is the 2035 regional service energy intensity of 1.736 for Africa. In this example of gasoline bus service in Africa, the 2005 vehicle efficiency for Africa is 18 percent higher than for the reference region. In the year 2035, however, it is only 6 percent higher.

Table 18. Service Intensity Projection Example for Motor Gasoline

Light Duty Vehicles		2005	2015	2025	2035
Reference Region					
	Energy Intensity Index	1.000	1.051	1.150	1.252
	Load Factor Index	1.000	1.000	1.000	1.000
	Service Energy Intensity	0.237	0.249	0.272	0.296
Africa (Region)					
	Energy Intensity Index	1.000	1.160	1.320	1.485
	Load Factor Index	1.250	1.210	1.170	1.130
	Service Energy Intensity	0.296	0.349	0.420	0.497
Two/Three Wheel Vehicles		**2005**	**2015**	**2025**	**2035**
Reference Region					
	Energy Intensity Index	1.000	1.000	1.000	1.000
	Load Factor Index	1.000	1.000	1.000	1.000
	Service Energy Intensity	0.403	0.403	0.403	0.403
Africa (Region)					
	Energy Intensity Index	2.000	1.900	1.700	1.506
	Load Factor Index	1.500	1.400	1.300	1.202
	Service Energy Intensity	1.209	1.072	0.890	0.729

Table 18. Service Intensity Projection Example for Motor Gasoline in Africa (continued)

Buses		2005	2015	2025	2035
Reference Region					
	Energy Intensity Index	1.000	1.020	1.040	1.060
	Load Factor Index	1.000	1.000	1.000	1.000
	Service Energy Intensity	0.773	0.788	0.804	0.819
Africa (Region)					
	Energy Intensity Index	1.180	1.140	1.100	1.060
	Load Factor Index	2.000	2.000	2.000	2.000
	Service Energy Intensity	1.824	1.797	1.768	1.736
Heavy Trucks		**2005**	**2015**	**2025**	**2035**
Reference Region					
	Energy Intensity Index	1.000	1.027	1.037	1.042
	Load Factor Index	1.000	1.000	1.000	1.000
	Service Energy Intensity	0.367	0.377	0.381	0.382
Africa (Region)					
	Energy Intensity Index	0.800	0.860	0.920	0.981
	Load Factor Index	0.800	0.860	0.920	0.981
	Service Energy Intensity	0.235	0.279	0.322	0.368
Other Trucks		**2005**	**2015**	**2025**	**2035**
Reference Region					
	Energy Intensity Index	1.000	1.026	1.055	1.072
	Load Factor Index	1.000	1.000	1.000	1.000
	Service Energy Intensity	0.322	0.330	0.340	0.345
Africa (Region)					
	Energy Intensity Index	0.800	0.860	0.920	0.981
	Load Factor Index	0.800	0.860	0.920	0.981
	Service Energy Intensity	0.206	0.244	0.288	0.332

Table 19. Service Intensity Projections Example for Distillate Fuel in Africa

Light Duty Vehicles		2005	2015	2025	2035
Reference Region					
	Energy Intensity Index	1.000	1.030	1.070	1.131
	Load Factor Index	1.000	1.000	1.000	1.000
	Service Energy Intensity	0.296	0.305	0.317	0.335
Africa (Region)					
	Energy Intensity Index	1.000	1.080	1.160	1.241
	Load Factor Index	1.250	1.210	1.170	1.130
	Service Energy Intensity	0.370	0.398	0.430	0.469
Two/Three Wheel Vehicles		**2005**	**2015**	**2025**	**2035**
Reference Region					
	Energy Intensity Index	1.000	1.000	1.000	1.000
	Load Factor Index	1.000	1.000	1.000	1.000
	Service Energy Intensity	0.403	0.403	0.403	0.403
Africa (Region)					
	Energy Intensity Index	2.000	1.900	1.700	1.506
	Load Factor Index	1.500	1.400	1.300	1.202
	Service Energy Intensity	1.209	1.072	0.890	0.729
Buses		**2005**	**2015**	**2025**	**2035**
Reference Region					
	Energy Intensity Index	1.000	1.020	1.040	1.060
	Load Factor Index	1.000	1.000	1.000	1.000
	Service Energy Intensity	0.760	0.776	0.791	0.806
Africa (Region)					
	Energy Intensity Index	1.180	1.140	1.100	1.060
	Load Factor Index	2.000	2.000	2.000	2.000
	Service Energy Intensity	1.795	1.769	1.740	1.710

Table 19. Service Intensity Projections Example for Distillate Fuel in Africa (continued)

Heavy Trucks		2005	2015	2025	2035
Reference Region					
	Energy Intensity Index	1.000	1.038	1.122	1.161
	Load Factor Index	1.000	1.000	1.000	1.000
	Service Energy Intensity	0.454	0.472	0.509	0.527
Africa (Region)					
	Energy Intensity Index	0.800	0.860	0.920	0.981
	Load Factor Index	0.800	0.870	0.970	1.031
	Service Energy Intensity	0.291	0.353	0.455	0.533
Other Trucks		**2005**	**2015**	**2025**	**2035**
Reference Region					
	Energy Intensity Index	1.000	1.026	1.055	1.072
	Load Factor Index	1.000	1.000	1.000	1.000
	Service Energy Intensity	0.290	0.297	0.306	0.311
Africa (Region)					
	Energy Intensity Index	0.800	0.860	0.920	0.981
	Load Factor Index	0.800	0.870	0.970	1.031
	Service Energy Intensity	0.185	0.222	0.273	0.314
Passenger Rail		**2005**	**2015**	**2025**	**2035**
Reference Region					
	Energy Intensity Index	1.000	1.010	1.020	1.030
	Load Factor Index	1.000	1.000	1.000	1.000
	Service Energy Intensity	1.011	1.022	1.032	1.042
Africa (Region)					
	Energy Intensity Index	0.850	0.890	0.930	0.970
	Load Factor Index	2.000	2.000	2.000	2.000
	Service Energy Intensity	1.719	1.818	1.919	2.023

Table 19. Service Intensity Projections Example for Distillate Fuel in Africa (continued)

Freight Rail		2005	2015	2025	2035
Reference Region					
	Energy Intensity Index	1.000	1.010	1.020	1.030
	Load Factor Index	1.000	1.000	1.000	1.000
	Service Energy Intensity	2.910	2.939	2.969	2.999
Africa (Region)					
	Energy Intensity Index	0.850	0.890	0.930	0.970
	Load Factor Index	1.000	1.000	1.000	1.000
	Service Energy Intensity	2.474	2.616	2.761	2.910
Domestic Water		**2005**	**2015**	**2025**	**2035**
Reference Region					
	Energy Intensity Index	1.000	1.020	1.041	1.062
	Load Factor Index	1.000	1.000	1.000	1.000
	Service Energy Intensity	2.400	2.449	2.498	2.549
Africa (Region)					
	Energy Intensity Index	1.000	1.000	1.000	1.000
	Load Factor Index	1.000	1.000	1.000	1.000
	Service Energy Intensity	2.400	2.449	2.498	2.549
International Water		**2005**	**2015**	**2025**	**2035**
Reference Region					
	Energy Intensity Index	1.000	1.020	1.041	1.062
	Load Factor Index	1.000	1.000	1.000	1.000
	Service Energy Intensity	2.400	2.449	2.498	2.549
Africa (Region)					
	Energy Intensity Index	1.000	1.000	1.000	1.000
	Load Factor Index	1.000	1.000	1.000	1.000
	Service Energy Intensity	2.400	2.449	2.498	2.549

Projections of Transportation Energy Consumption

For each fuel, service, region, and year, ITran computes energy consumption by dividing the service demand by the service intensity. Service consumption values are aggregated across services to provide total consumption projections for each fuel, region, and year for WEPS+. Currently, the ITran inputs are specified for five year increments, starting in 2005 and continuing through the projection period to 2035. Because the transportation model for the *IEO2011* computes service demand, service intensity and consumption for each individual year, the model interpolates the inputs to fill in data for the intervening years. For the *IEO2011,* the algorithm provides annual estimates of service demand, service intensity, and consumption for 2009 through 2035.

Consumption is estimated as the service demand divided by the service intensity (efficiency):

$$TrnQty(s, f, r, y) = \frac{TrnSD(s, f, r, y)}{TrnSI(s, f, r, y)}$$

Where, for each service *s*, fuel *f*, region *r*, and year *y*,

TrnSD(s,f,r,y) = service demand (passenger or ton miles)

TrnSI(s,f,r,y) = service intensity (passenger or ton miles per Btu)

TrnQty(s,f,r,y) = consumption (Btu)

Heavy Oil

One of the consumption categories in ITran is a petroleum category for heavy oil. Although modeled as a single category, heavy oil actually consists of residual oil, sequestered petroleum, and other petroleum. The total consumption estimates for heavy oil are allocated to the various components based on their initial base year shares.

Pipeline Natural Gas

In the *IEO2011* analysis, the reporting of transportation energy consumption includes projections of pipeline natural gas. The consumption of pipeline natural gas is projected elsewhere in the WEPS+ system (in the Natural Gas Model) and then added to the transportation natural gas totals in the ITran. Because the ITran does not project pipeline natural gas endogenously, it is necessary to subtract out the pipeline natural gas from the historical data at the beginning, run the model, and then add it back in at the end.

Renewable Fuels

Originally, the transportation model did not include a projection of renewable fuels such as ethanol (E85) and biodiesel. Although Itran does not currently project renewable fuels or hydrogen, they are in the system as placeholders. A basic method included in the transportation model assumes that consumption of these "miscellaneous" fuels (ethanol, biodiesel, and hydrogen) grows at a rate related to the rate of GDP growth:

$$MiscQty(f, r, y) = MiscQty(f, r, y = 2008) * \left[1 + \left(\frac{GDP(r, y)}{GDP(r, y = 2007)} - 1\right) * OLRate(f, r)\right]$$

Where *GDP(r,y)* = gross domestic product for region *r* in year *y*

OLRate(f,r) = fraction of the GDP growth rate applied for renewable fuel *f* in region *r*

MiscQty(f,r,y) = projected consumption of fuel *f* in region *r* and year *y*

The values of *OLRate(f,r)* were determined by analyst judgment.

Calibration of Transportation Consumption to *STEO*

The ITran model for *IEO2011* uses historical data up to the base year 2008 and projects transportation energy consumption for 2009 through 2035. In addition to the *IEO* modeling using WEPS+, EIA publishes short-term international energy projections of overall consumption of liquid fuels. The EIA *Short-Term Energy Outlook* (*STEO*) currently provides monthly projections extending to 2011, including projections of total world liquids consumption for seven international regions and for eight individual countries within these regions. The *STEO* regions do not correspond exactly to the WEPS+ regions, and the *STEO* consumption projections are for total liquids with no sector or product differentiation. The *IEO2011* total liquids consumption projections (aggregate projections of liquids consumption across all sectors and all liquids) are adjusted to be consistent with the *STEO* values for all the years through 2012.

Independent of the ITran, the Main Model in WEPS+ reads an input file that contains the aggregate levels of liquids consumption for nine *STEO* regions. The Main Model then inputs current WEPS+ region and sector-level liquids consumption projections from the restart file. Next, it allocates the nine *STEO* region consumption levels to the 16 WEPS+ region consumption levels, based on the sub-regional consumption shares. Within each region, it then allocates the liquids consumption to end-use sectors, based on sector-level consumption shares.

An exception to the sector-level allocation step is the electric power sector, where liquids-fired generation is not included. The reason for this exception is that electricity generation is a small liquids-consuming sector, and it is much more complicated in terms of its transformation of energy. Instead, the amount of liquids consumed in the electricity generation sector is subtracted from the total *STEO* liquids consumption. After that, the remaining amount of liquids consumption is allocated to the remaining sectors, based on the remaining share of liquids consumption. These quantities are then exported to the restart file so for use by each of the WEPS+ models for calibration to *STEO*. Note that the sector allocation step is performed by the Main Model for each WEPS+ iteration so that the consumption projections adapt to changes in sector-level consumption shares as the model converges toward the equilibrium solution.

For each iteration of a WEPS+ run, the Itran imports the regional-level *STEO* projections of liquids consumption for 2009 through 2012 from the WEPS+ restart file. Itran aggregates its own projections of liquid fuel consumption by region and year and benchmarks the Itran projections to the *STEO* projections through a regional adjustment factor computed for each year 2009 through 2012,

$$STEOFac(r,y) = \frac{STEOQty(r,y)}{TotalModelQty(r,y)}$$

Where for each region *r* and year *y*,

> *STEOQty(r,y)* = benchmark *STEO* liquids consumption for transportation from the Main WEPS+ Model
>
> *TotalModelQty(r,y)* = ITran total liquids consumption projection
>
> *STEOFac(r,y) = STEO* calibration factor

Within each region and year, Itran applies the *STEO* calibration factor to the consumption projections for each liquids component (petroleum products and biofuels). In effect, this means that the *STEO* consumption projection is allocated to each component based on its share of the total, as estimated by Itran.

For each year 2009 through 2012,

$$CalibQty(f, r, y) = OrigQty(f, r, y) * STEOFac(r, y)$$

Where, for fuel *f* in region *r* and year *y*,

> *OrigQty(f,r,y)* = original Itran consumption projection
>
> *CalibQty(f,r,y) = STEO*-calibrated consumption projection

The *STEO* calibration factors are applied directly to the Itran consumption projections for 2009 through 2012, so Itran projects the overall total *STEO* consumption levels for these years. Because the calibration adjustment for 2012 can be significant, projections for subsequent years are smoothed to prevent a break in the series. Modified *STEO* calibration factors are applied to the Itran estimates for each of the next 10 projection years. Over the 10-year period, the adjustment factors gradually approach 1.0.

As a hypothetical example, if the 2011 STEO calibration factor was calculated to be 1.10, the original consumption projection for 2012 would be multiplied by 1.09. Consumption for 2013, in turn, would receive a factor of 1.08, and so on. For 2020 and subsequent years, the STEO adjustment factors would return to 1.0, indicating no further STEO calibration. The modified adjustments provide a smooth transition from the *STEO*-calibrated period to the remaining years of the WEPS+ series. For three regions: Mexico, South Korea, and the Middle East, the transition was not very smooth in the *IEO2011* so the transition back to 1.0 was carried out over a period of 20 years. The benchmark adjustments were also applied to the service demand projections.

Projections of U.S. Transportation Consumption

For the purpose of scenario analysis, the Itran includes a routine to project the consumption of transportation fuel in the United States. Originally, there was no attempt to make assumptions within ITran for service demand and service intensity for the United States because those projections are made in the National Energy Modeling System (NEMS). The NEMS projections are used to overwrite the transportation values for the publication of the *IEO2011*. A U.S. model is needed for a run in which the U.S. values vary based on GDP and price projections (for example for analysis of carbon cases).

A simple elasticity model was built, using parameter values calibrated to replicate the Reference case projection of NEMS for the *Annual Energy Outlook*. The model projects annual transportation energy consumption by fuel for each year in the projection period. To estimate change in consumption from the base period levels, it uses three explanatory variables: GDP, energy prices, and a trend. The GDP and energy prices have elasticities and lags that are determined from the NEMS Reference case run, and the trend is calculated to calibrate the projections to the 2035 value in the Reference case.

The model estimates U.S. consumption of fuel *f* in projection year *y* (denoted *USQty(f,y)*) by multiplying the consumption level of fuel *f* in year *y*-1 by a factor representing the multiplicative year-to-year change. The factor representing change from year *y*-1 to *y* is the product of three indexes, representing the effects of GDP, prices, and the trend:

The three indexes are computed as follows:

GDP Change Index:

$$GDPIdx(f,y) = \left(\frac{GDP(y)}{GDP(y-1)}\right)^{GDPElas(f)} * \left(GDPIdx(f,y-1)\right)^{GDPLag(f)}$$

Where *GDP(y)* = gross domestic product in year *y*

GDPElas(f) = estimated effect (elasticity) of GDP change on consumption of fuel *f*

GDPLag(f) = lag coefficient for the GDP index for fuel *f*

GDPIdx(f,y) = GDP index (multiplier) for fuel *f* in year *y*

Price Change Index:

$$PrcIdx(f,y) = \left(\frac{Prc(f,y)}{Prc(f,y-1)}\right)^{PrcElas(f)} * \left(PrcIdx(f,y-1)\right)^{PrcLag(f)}$$

Where *Prc(f,y)* = price of each fuel *f* in year *y*

PrcElas(f,y) = price elasticity for fuel *f* in year *y*

PrcLag(f) = lag coefficient for the price index for fuel *f*

PrcIdx(f,y) = price index (multiplier) for fuel *f* in year *y*

Trend Change Index:

$$TrendIdx(f, y) = TrendIdx(f, y-1) * (1 + TrendGR(f))$$

Where *TrendGR*(f) = trend growth rate for fuel *f*.

Extended Transportation Modeling for Special Cases

The structure of the Transportation Model was extended in order to allow the simulation of additional policy options, e.g., for the high world oil price case and for carbon cases. The modifications fall into three categories: additional elasticity for projecting service demand, additional stock efficiency levels for projecting service efficiency, and a stock/flow approach for modeling alternative light duty vehicle (LDV) technology penetration.

Service Demand Elasticity

In order to represent different behavioral patterns that may result from changes in energy markets and technologies, the transportation model can simulate greater responsiveness of service demand to fuel prices (i.e., higher responsiveness than that represented by the existing model price elasticities). Although the higher elasticities are not tied to a specific policy option, they represents a world in which there may be additional disincentives to consume transport services, such as an additional tax on gasoline. The miscellaneous input file provides multipliers that can be applied to the current service fuel price elasticities. The multipliers are specified by the eleven services or sub-modes and for each of the regions. They increase from 1.0 in 2010 to their full level in 2030. In the case of the *IEO2011*, for example, the multipliers increased to 1.25 for all passenger services in each region.

Service Efficiency Targets

It was also desired to have the ability to increase the service efficiency or intensity, in order to represent a policy such as a mile-per-gallon standard. Note that because the ITran is not a stock/flow model, and looks only at the stock of vehicles, a change in the level of service efficiency is actually a change for the entire fleet or stock of vehicles. This functionality was implemented by adding to the miscellaneous input file multipliers that are applied against the current assumed projection levels for service efficiency. The multipliers are specified by the eleven services or sub-modes and for each of the regions. They ramp up from 1.0 in 2010 to their full level in 2030, where they remain through the end of the projection period. In the case of the *IEO2011*, for example, for passenger light duty vehicles in each region, the multipliers increased to 1.05.

Alternative Light Duty Vehicle Technology Penetration

A third modification allows Itran to simulate increased penetration of alternative LDV technologies, representing both a consumer choice (under increased fossil fuel prices) increase and the possibility of government policies (e.g., subsidies) to encourage use of alternative vehicles. A small slate of alternative vehicle technologies was added to the model, including hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV), and compressed natural gas (CNG) vehicles. These vehicle types are included only for the LDV service or sub-mode. For gasonline and diesel fuels, Itran can simulate the substitution of alternative LDVs for conventional LDVs over the projection period, from 2011 through 2035. The characteristics of the vehicles and the penetration rates are specified exogenously in an input file.

Because ITran is not a stock/flow model, and the alternative vehicles penetrate as new vehicles and slowly work themselves into the stock, it was necessary to build some sort of basic vintage structure into the ITran stock model. For this purpose, service demand was used as a proxy for the number of new vehicles, and the service efficiency was used as a proxy for the new vehicle efficiency. For example, consider two vintages and a total service demand:

1. Remaining (existing) – Total service demand (passenger miles) for the first simulation year (2010)
2. New – New service demand added in the current projection year
3. Total – Total service demand (remaining plus new) in the current projection year

For motor gasoline and light duty vehicles, Itran reads from the input file a variety of user assumptions, including retirement rates for the existing vehicle stocks and penetration rates (for 2011 through 2030) for HEVs, PHEVs, and CNG vehicles. For these alternative vehicles, the input file also provides ratios representing the alternative vehicle type's service intensity relative to the service intensity of the existing gasoline and diesel vehicles. For the PHEV technology these ratios are given for gasoline, diesel, and electricity. Table 20 gives typical values for some of these input parameters.

Table 20. Parameters Associated with High Penetration of Alternative Vehicles in a High Oil Price Case

Parameter	Value
Existing Service Demand Retirement Rate (RetRate)	5.0% per year
Penetration Rate for New HEVs in 2030 (HEVPen)	13.5% per year
Penetration Rate for New PHEVs in 2030 (PHEVPen)	17.0% per year
Penetration Rate for New CNG in 2030 (CNGPen)	10.5% per year
Service Intensity Ratio for HEV Gasoline (HEVRat)	1.50
Service Intensity Ratio for PHEV Gasoline (PHEVRat)	4.00
Service Intensity Ratio for PHEV Electric (PHEVERat)	3.00
Service Intensity Ratio for CNG Natural Gas (CNGRat)	1.00

Itran begins by projecting the total stock of vehicles for the current year, including the vehicles remaining from the previous year and the number of new vehicles added in the current year. Assumptions are made about vehicle retirement rates to determine these two values. Note that the model considers gasoline-fueled and diesel-fueled light duty vehicles (LDVs) as two separate categories, so the alternative vehicles are modeled within each of these categories. For the sake of brevity and clarity, the section below discusses only the process for the gasoline LDVs. (The index *f* below represents gasoline and diesel light duty vehicle categories.)

The model first uses a survival rate to determine how much of the service demand for the stock of gasoline LDVs from the previous year remains in the current year. As noted earlier, the service demand is in units of passenger-miles. In the stock/flow model, the survival rate is imported only to retire actual vehicles. However, applying the survival rate to the service demand achieves the same purpose, because the service demand is the product of the number of vehicles, the vehicle miles per vehicle, and the load factor (person miles per vehicle mile).

$$RemFromPrevYear(f,r,y) = LDVSD(f,r,y-1) * (1 - RetRate(f))$$

Where,for fuel *f* in region *r* and year *y*,

RemFromPrevYear(f,r,y) = service demand from year *y*-1 remaining in year *y*

LDVSD(f,r,y) = light duty vehicle service demand

RetRate(f) = retirement rate (assumed constant across regions and years)

After estimating the remaining total stock—the stock remaining from the previous year—Itran estimates the service demand associated with new vehicles in the current projection year by subtracting the remaining demand from the total demand:

$$NewThisYear(f,r,y) = LDVSD(f,r,y) - RemFromPrevYear(f,r,y)$$

Factors representing the penetration of new alternative vehicles (within each vehicle fuel category) are included in the exogenous input for each projection year. These factors are applied to the estimates of new vehicle service demand to determine the new service demand due to added vehicles in each of the alternative vehicles categories. The added service demand for conventional vehicles is then computed as a residual from the total new service demand.

$$NewHEV(f,r,y) = NewThisYear(f,r,y) * HEVPen(f,y)$$

$$NewPHEV(f,r,y) = NewThisYear(f,r,y) * PHEVPen(f,y)$$

$$NewCNG(f,r,y) = NewThisYear(f,r,y) * CNGPen(f,y)$$

$$NewSTD(f,r,y) = NewThisYear(f,r,y) - NewHEV(f,r,y) - NewPHEV(f,r,y) - NewCNG(f,r,y)$$

Where *NewHEV*, *NewPHEV*, *NewCNG*, and *NewSTD* represent service demand attributed to additional HEV, PHEV, CNG, and conventional vehicles, respectively.

The new alternative vehicles (actually in terms of passenger miles) are added to those that are remaining from the previous year to get the total number of vehicles in the current projection year. The system does not currently use retirement rates for the alternative vehicles, because of the short period of time in which they have been available. Some retirements will likely occur in the later projection years. The model estimates total service demand for conventional vehicles as a residual from the total service demand across all light duty vehicles (conventional and alternative).

$$TotHEV(f,r,y) = TotHEV(f,r,y-1) + NewHEV(f,r,y)$$

$$TotPHEV(f,r,y) = TotPHEV(f,r,y-1) + NewPHEV(f,r,y)$$

$$TotCNG(f,r,y) = TotCNG(f,r,y-1) + NewCNG(f,r,y)$$

$$TotSTD(f,r,y) = LDVSD(f,r,y) - TotHEV(f,r,y) - TotPHEV(f,r,y) - TotCNG(f,r,y)$$

Where *TotHEV(f,r,y)*, *TotPHEV(f,r,y)*, *TotCNG(f,r,y)*, *LDVSD(f,r,y)* and *TotSTD(f,r,y)* are service demand totals (proxies for the stocks of vehicles) using fuel *f* in region *r* and year *y*.

The model imports service intensity or efficiency ratios for each type of alternative vehicle. The ratios, which are assumed constant across regions and years, represent the service intensity (passenger miles per trillion Btu) of the alternative vehicle type relative to that of conventional vehicles. Itran estimates service intensity for the alternative vehicles by applying these ratios to the estimated service intensity of conventional vehicles:

$$SIG\_HEV(f,r,y) = LDVSI(f,r,y) * HEVRat(f)$$

$$SIG\_PHEV(f,r,y) = LDVSI(f,r,y) * PHEVRat(f)$$

$$SIE\_PHEV(f,r,y) = LDVSI(f,r,y) * PHEVERat(f)$$

$$SIN\_CNG(f,r,y) = LDVSI(f,r,y) * CNGRat(f)$$

Where, for fuel *f* in region *r* and year *y*,

LDVSI(f,ry,) = service intensity for the stock of conventional vehicles

SIG_HEV(f,r,y) = gasoline service efficiency for HEVs

SIG_PHEV(f,r,y) = gasoline service efficiency for PHEVs

SIE_PHEV(f,r,y) = electricity service efficiency for PHEVs

SIN_CNG(f,r,y) = natural gas service efficiency for CNG

The typical value for the *HEVRat* ratios is 1.5. If the service efficiency were actually measured in miles per gallon (MPG) and the typical conventional vehicle stock had a gasoline MPG of 20 then the gasoline MPG for the HEVs is 30. (Unfortunately, this algorithm is only a rough estimate because ITran is not a stock/flow model. This approach combines the concepts of the MPG for the vehicle stock and the MPG for new vehicles.) Using the same MPG of 20 in the example, the gasoline MPG for PHEVs would be 80, the electric (gasoline equivalent) MPG for PHEVs would be 60, and the natural gas (gasoline equivalent) MPG for CNG would be 20. (The service intensities used in the model are all in terms of Btu, so they can be used interchangeably.)

The consumption projections for each of vehicles type are then calculated as ratios of the service demand and the service efficiency:

$$QtyG\_HEV(f,r,y) = \frac{TotHEV(f,r,y)}{SIG\_HEV(f,r,y)}$$

$$QtyG\_PHEV(f,r,y) = \frac{TotPHEV(f,r,y)}{SIG\_PHEV(f,r,y)}$$

$$QtyE\_PHEV(f,r,y) = \frac{TotPHEV(f,r,y)}{SIE\_PHEV(f,r,y)}$$

$$QtyN\_CNG(f,r,y) = \frac{TotCNG(f,r,y)}{SIN\_CNG(f,r,y)}$$

$$QtyG\_STD(f,r,y) = \frac{TotSTD(f,r,y)}{LDVSI(f,r,y)}$$

Where, for fuel *f* in region *r* and year *y*,

QtyG_HEV(f,r,y) is the consumption of gasoline in HEVs

QtyG_PHEV(f,r,y) is the consumption of gasoline in PHEVs

QtyE_PHEV(f,r,y) is the consumption of electricity in PHEVs

QtyN_CNG(f,r,y) is the consumption of natural gas in CNG

QtyG_STD(f,r,y) is the consumption of gasoline in conventional vehicles

The same estimation process is used for the diesel light duty vehicles. Finally, the amount of gasoline and diesel consumed in the alternative plus conventional vehicles is substituted for the amounts that would otherwise have been consumed for gasoline and diesel in light duty vehicles. The amount of electricity consumed in PHEVs is added to the amount of electricity otherwise consumed, and the amount of natural gas consumed in CNG vehicles is added to the amount of natural gas otherwise consumed.

Appendix A. Model Abstract

Model Name:

Transportation Sector Model of the World Energy Projection System Plus; also International Transportation Model

Model Acronym:

ITran

Model Description:

The Transportation Sector Model (generally referred to as the International Transportation Model or ITran) of the World Energy Projection System Plus (WEPS+) is a computer-based energy demand modeling system of the world transportation sector at a regional level. For the *IEO2011*, the ITran projects the amount of energy that is consumed to provide passenger and freight transportation services. This includes personal household on-road transportation in light duty vehicles, which is counted here rather than in the residential sector. This also includes fuel consumed by natural gas pipelines, and small amounts of lubricants and waxes. The model projects transportation consumption for 13 energy sources in each of the 16 WEPS regions over the projection period to the year 2035. The ITran provides an accounting framework that considers energy service demand (a measure of use) and service intensity (measured as energy efficiency) for the overall stock of vehicles.

Model Purpose:

As a component of the WEPS+ integrated modeling system, the ITran generates long-term projections of transportation sector energy consumption. As part of the system, the model provides consumption inputs for a variety of the other models. The model provides a tool for analysis of international transportation energy within the WEPS+ system and can be run independently as a standalone model.

Most Recent Model Update:

December 2009.

Part of Another Model:

World Energy Projection System Plus (WEPS+).

Model Interfaces:

The Transportation Model receives inputs from the Macroeconomic Model, Refinery Model, World Electricity Model, Natural Gas Model, and Coal Model. It provides outputs to the Refinery Model, World Electricity Model, Petroleum Model, Natural Gas Model, and Coal Model. These inputs and outputs are provided through the common, shared interface file of the WEPS+.

Official Model Representative:

Victoria Zaretskaya
U.S. Energy Information Administration
Transportation Energy Consumption & Efficiency Analysis Team
EI-81/Forrestal Building
United States Department of Energy
1000 Independence Avenue, SW
Washington, D.C. 20585
Telephone: (202) 287-5501
E-mail: Victoria.Zaretskaya@eia.gov

Documentation:

Energy Information Administration, U.S. Department of Energy, *Transportation Model of the World Energy Projection System Plus: Model Documentation 2011*, DOE/EIA-M072(2011) (Washington, DC, August 2011).

Archive Information:

The model is archived as part of the World Energy Projection System Plus archive of the runs used to generate the *International Energy Outlook 2011*.

Energy System Described:

International transportation sector energy consumption

Coverage:

- Geographic: Sixteen WEPS+ regions: U.S., Canada, Mexico, OECD Europe, Japan, Australia/New Zealand, South Korea, Russia, Other Non-OECD Europe and Eurasia, China, India, Other Non-OECD Asia, Middle East, Africa, Brazil, and Other Central and South America.

- Mode: Road, rail, air, water, pipeline.

- Time Unit/Frequency: Annual, 2009 through 2035.

Modeling Features:

The Transportation Model provides an accounting framework that considers energy service demand (a measure of use) and service intensity (measured as an energy efficiency) for the overall stock of vehicles. The model also looks at these measures for both passenger and freight services over a variety of modes and sub-modes, including light duty vehicles, two/three wheel vehicles, bus, heavy truck, other truck, freight rail, passenger rail, air, domestic water, and international water.

DOE Input Sources:

Energy Information Administration, International Energy Statistics Database, web site www.eia.gov/emeu/international (as of April 1, 2011).

Energy Information Administration, *Short Term Energy Outlook* (*STEO*), Washington, D.C., (March 2011 release).

IHS Global Insight,

Non-DOE Input Sources:

International Energy Agency (IEA), *Energy Balances of OECD Countries*, Paris, 2010.

International Energy Agency (IEA), *Energy Balances of Non-OECD Countries*, Paris, 2010.

IHS Global Insight, *World Overview*, *Third Quarter 2010*, Lexington, MA, (November 2010).

Independent Expert Reviews:

None

Computing Environment:

Hardware/Operating System: Basic PC with Windows XP (or other Windows OS).

Language/Software Used: Fortran 90/95 (Currently using Compaq Visual Fortran), not required at runtime.

Run Time/Storage: Standalone model with one iteration runs in about 3-4 seconds, CPU memory is minimal, inputs/executable/outputs require less than 20MB storage.

Special Features: None.

Appendix B. Input Data and Variable Descriptions

The following variables represent data input from the file TranBase.xml.

Classification: Input variable.

BYPetProdShr(f,r):	Product share of total liquids consumption, by region
BYFuelByMode(m,f,r):	Product share of consumption, by transport mode and region
BYFuelModeByServ(s,f,r):	Service share of fuel by mode and region
BYRefServ(s,f):	Reference service intensity of each fuel by service
BYRefServEFM(s,f,r):	Regional reference service efficiency multiplier by fuel
BYRefServLDM(s,f,r):	Regional load factor multiplier for service intensity by fuel
FYRefServEFM(s,f,y):	Reference service intensity index by fuel and projection year
FYRefServLDM(s,f,y):	Reference service load intensity index by fuel and projection year
FYRegServEFM(s,f,r,y):	Regional service intensity index by fuel and projection year
FYRegServLDM(s,f,r,y):	Regional load intensity index by fuel and projection year
FYShrServ(s,f,r,y):	Regional service shares by fuel, region, and year

The following variables represent data input from the file TranBXML.xml.

Classification: Input variable.

TRLab(r):	Regional identifier (USA, CAN, MXC, etc.)
TFLab(f):	Fuel identifier (MGas, Dist, JetF, etc.)
TMLab(m):	Mode identifier (Road, Rail, Water, Air)
TSLab(s):	Service identifier (PDLV, PTTW, PBus, etc.)
MapStoM(s):	Index used to map (associate) a service with a specific mode
MapStoP(s):	Index used to map a service with a purpose (i.e., passenger or freight)
UseSF(s,f):	Index identifying the services used for each fuel (e.g., indicates jet fuel is used only for passenger air and freight air)
TDoReg(r):	Set to 0 if region will not be solved for; 1 if region is solved for
FYEconInd(s,r,y):	Economic indicator used for the economic elasticities for each region, service, and year (GDP, Pop, or GDP_Pop)
FYEconElas(s,r,y):	Elasticity value associated with each economic indicator by region, service, and year
FYPricElas(s,r,y):	Price elasticity associated with each service and year by region

FYMultFac(s,r,y):	Multiplicative trend factors associated with each service and year by region
FYAddFac(s,r,y):	Add factor associated with each service and year by region (currently these are all set to 0)

The following variables represent data input from the file TranMisc.xml.

Classification: Input variable.

GDPElas(f):	U.S. GDP elasticities by liquid fuel product
GDPLag(f):	U.S. GDP lag coefficient by liquid fuel product
PrcElas(f):	U.S. price elasticity by liquid fuel product
PrcLag(f):	U.S. price lag by liquid fuel product
TrendGR(f):	U.S. trend growth coefficient by liquid fuel product
TrnQtyA(11,1,y):	U.S. projection of ethanol consumption in the transportation sector from Annual Energy Outlook 2011 (AEO2011) by year
OLRate(1,r):	Regional rate of growth of ethanol as a percentage of GDP
OLRate(2,r):	Regional rate of growth of biodiesel as a percentage of GDP
OLRate(3,r):	Regional rate of growth of hydrogen fuel as a percentage of GDP
DBSw:	Recalibration indicator. If user wishes to calibrate detailed service demand and recalibrate detailed consumption estimates based upon the calibration the value is set to 1, otherwise it is 0
FFTar(r):	Factor used to adjust the growth path of total liquids consumption by region. Two-thirds of the factor amount is applied to changing service demand; one-third is applied to changing service intensity
FFYr(r):	Factor that informs model the year to begin to adjust the growth path of total liquids consumption
SIGR(s,r):	Service intensity target improvement in 2035 by service and region
RetRate(f):	Retirement rate associated with alternative vehicles (1=motor gasoline fueled; 2=diesel-fueled)
HEVPen(f,y):	Penetration rate of new hybrid electric vehicles by year (1=motor gasoline fueled; 2=diesel-fueled)
PHEVPen(f,y):	Penetration rate of new plug-in hybrid electric vehicles by year (1=motor gasoline fueled; 2=diesel-fueled)

CNGPen(,y):	Penetration rate of new compressed-natural-gas-fueled (CNG-fueled) vehicles by year (1=motor gasoline fueled; 2=diesel-fueled)
HEVRat(f):	Service intensity as a ratio of hybrid electric vehicles relative to conventional vehicles by fuel (1=motor gasoline fueled; 2=diesel-fueled)
PHEVRat(f):	Service intensity as a ratio of plug-in hybrid electric vehicles relative to conventional vehicles by fuel (1=motor gasoline fueled; 2=diesel-fueled)
CNGRat(f):	Service intensity as a ratio of CNG-fueled vehicles relative to conventional vehicles by fuel (1=motor gasoline fueled; 2=diesel-fueled)
PElasMult(s,r):	Price multipliers for the High Oil Price case by service and region

The following variables represent data input from the restart file.

Classification: Input variable from Macroeconomic Model, Refinery Model, and demand models.

GDP_PPP(r,y):	Regional GDP expressed in purchasing power parity by year (note r = 17 is total world GDP)
Pop(r,y)	Regional population by year (note: r = 17 is total world population)
PMGTR(r,y):	Price of motor gasoline for transportation energy use by region and year
PDSTR(r,y):	Price of distillate (diesel) fuel for transportation energy use by region and year
PJFTR(r,y):	Price of jet fuel for transportation energy use by region and year
PRSTR(r,y):	Price of residual fuel for transportation energy use by region and year
PLGTR(r,y):	Price of liquefied petroleum gas for transportation energy use by region and year
PCLTR(r,y):	Price of coal for transportation energy use by region and year
PELTR(r,y):	Price of electricity for transportation energy use by region and year
PNGTR(r,y):	Price of natural gas for transportation energy use by region and year
PETTR(r,y):	Price of ethanol/biofuels for transportation energy use by region and year

AMGTR(r,y):	Carbon price increment to transportation sector motor gasoline price associated with the carbon allowance price by region and year (dollars per million Btu)
ADSTR(r,y):	Carbon price increment to transportation sector distillate (diesel) fuel price associated with the carbon allowance price by region and year (dollars per million Btu)
AJFTR(r,y):	Carbon price increment to transportation sector jet fuel price associated with the carbon allowance price by region and year (dollars per million Btu)
ARSTR(r,y):	Carbon price increment to transportation sector residual fuel price associated with the carbon allowance price by region and year (dollars per million Btu)
ALGTR(r,y):	Carbon price increment to transportation sector liquefied petroleum gas price associated with the carbon allowance price by region and year (dollars per million Btu)
ACLTR(r,y):	Carbon price increment to transportation sector coal price associated with the carbon allowance price by region and year (dollars per million Btu)
AELTR(r,y):	Carbon price increment to transportation sector electricity price associated with the carbon allowance price by region and year (dollars per million Btu)
ANGTR(r,y):	Carbon price increment to transportation sector natural gas price associated with the carbon allowance price by region and year (dollars per million Btu)
AETTR(r,y):	Carbon price increment to transportation sector ethanol/biofuels price associated with the carbon allowance price by region and year (dollars per million Btu)
QHMGTR(r,y):	Historical motor gasoline consumption in the transportation sector by region and year (years 2005 through 2008)
QHDSTR(r,y):	Historical distillate (diesel) fuel consumption in the transportation sector by region and year (years 2005 through 2008)
QHRSTR(r,y):	Historical residual fuel consumption in the transportation sector by region and year (years 2005 through 2008)
QHLGTR(r,y):	Historical liquefied petroleum gas consumption in the transportation sector by region and year (years 2005 through 2008)
QHJFTR(r,y):	Historical jet fuel consumption in the transportation sector by region and year (years 2005 through 2008)

QHSPTR(r,y):	Historical sequestered petroleum fuel consumption in the transportation sector by region and year (years 2005 through 2008)
QHOPTR(r,y):	Historical other petroleum consumption in the transportation sector by region and year (years 2005 through 2008)
QHNGTR(r,y):	Historical natural gas consumption in the transportation sector by region and year (years 2005 through 2008)
QHCLTR(r,y):	Historical coal consumption in the transportation sector by region and year (years 2005 through 2008)
QHELTR(r,y):	Historical electricity consumption in the transportation sector by region and year (years 2005 through 2008)
QHETTR(r,y):	Historical ethanol (E85) consumption in the transportation sector by region and year (years 2005 through 2008)
QHOBTR(r,y):	Historical biofuels (excluding ethanol) consumption in the transportation sector by region and year (years 2005 through 2008)
QHHYTR(r,y):	Historical hydrogen fuel consumption in the transportation sector by region and year (years 2005 through 2008)
QNGPPTR(r,y):	Historical transportation natural gas pipeline consumption by region and year (years 2005 through 2008)
STEOPTTR(r,y):	Projections of liquids for the transportation sector based upon EIA's Short-Term Energy Outlook by region and year (years 2008 through 2011)

The following variables represent data calculated in the subroutine Tran.

Classification: Computed variable.

OPr2(f,r,y):	By-fuel regional price adjusted according to carbon price
TrnQty(s,f,r,y):	Transportation energy consumed by service, fuel, and region
TrnSI(s,f,r,y):	Transportation energy service intensity by fuel and region
TrnSD(s,f,r,y):	Transportation service demand by fuel and region
QtyG_HEV(f,r,y):	Consumption by hybrid electric vehicles by fuel (gasoline and diesel) and region
QtyG_PHEV(f,r,y):	Consumption by plug-in hybrid electric vehicles by fuel (gasoline and diesel) and region
QtyG_STD(f,r,y):	Consumption by standard, conventional vehicles by fuel (gasoline and diesel) and region

QtyE_PHEV(f,r,y):	Consumption of electricity by plug-in hybrid electric vehicles by fuel vehicle type (gasoline and diesel) and region
QtyN_CNG(f,r,y):	Consumption of natural gas by compressed natural gas vehicles by fuel vehicle type (gasoline and diesel) and region
ShrRS(r):	Residual fuel share of the total consumption of residual fuel, sequestered petroleum, and other petroleum in 2005 by region
ShrSP(r):	Sequestered petroleum share of the total consumption of residual fuel, sequestered petroleum, and other petroleum in 2005 by region
ShrOP(r):	Other petroleum share of the total consumption of residual fuel, sequestered petroleum, and other petroleum in 2005 by region
ShrET(r):	Ethanol share of the total consumption of ethanol and other biofuels in 2005 by region
ShrOB(r):	Other biofuels share of the total consumption of ethanol and other biofuels in 2005 by region
QMGTR(r,y):	Motor gasoline consumption in the transportation sector by region and year
QDSTR(r,y):	Distillate fuel consumption in the transportation sector by region and year
QRSTR(r,y):	Residual fuel consumption in the transportation sector by region and year
QLGTR(r,y):	Liquefied petroleum gas consumption in the transportation sector by region and year
QJFTR(r,y):	Jet fuel consumption in the transportation sector by region and year
QSPTR(r,y):	Sequestered petroleum fuel consumption in the transportation sector by region and year
QOPTR(r,y):	Other petroleum consumption in the transportation sector by region and year
QNGTR(r,y):	Natural gas consumption in the transportation sector by region and year
QCLTR(r,y):	Coal consumption in the transportation sector by region and year
QELTR(r,y):	Electricity consumption in the transportation sector by region and year
QETTR(r,y):	Ethanol (E85) consumption in the transportation sector by region and year
QOBTR(r,y):	Biofuels (excluding ethanol) consumption in the transportation sector by region and year

QHYTR(r,y):	Hydrogen fuel consumption in the transportation sector by region and year

Appendix C. References

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2. Franklin J. Stermole and John M. Stermole, *Economic Evaluation and Investment Decision Methods: Eleventh Edition* (Investment Evaluations Corporation, Lockwood, CO, 2006).

3. C. Dahl, *International Energy Markets: Understanding Pricing, Policies, and Profits* (PennWell Books, March 2004).

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5. Wayne L. Winston, *Operations Research: Applications and Algorithms* (Brooks/Cole—Thomson Learning, Belmont, CA, 2004).

6. U.S. Environmental Protection Agency, Office of Mobile Sources, "Announcement/Update: EPA Releases Tier 2 Report to Congress" (press release, August 7, 1998), web site www.epa.gov/orcdizux/ regs/ld-hwy/tier-2/f98028.htm.

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8. International Energy Agency, *Energy Statistics and Balances of OECD Countries*, web site www.iea.org (subscription site).

9. International Energy Agency, *Transport, Energy and CO2: Moving Toward Sustainability* (Paris, France, 2009).

10. International Energy Agency, *Energy Technology Perspectives: Strategies and Scenarios to 2050*, (Paris, France 2008).

11. International Energy Agency, *World Energy Outlook 2010 Edition* (Paris, France, November 2010).

Appendix D. Data Quality

Introduction

The WEPS+ International Transportation Model develops projections of world transportation energy use by service (light duty vehicles, two- and three-wheel vehicles, buses, heavy duty truck, other truck, passenger rail, freight rail, domestic water, international water, and air) and fuel (motor gasoline, distillate fuel, residual fuel, liquefied petroleum gas, jet fuel, other petroleum, ethanol, other biofuels, hydrogen fuel, sequestered petroleum, natural gas, coal, and electricity) for 16 regions of the world. These projections are based on the data elements described in Appendix B of this report. In Chapter 4: Model Structure, the documentation details transformations, estimation methodologies, and inputs required to implement the model algorithms. The quality of the principal sources of input data is discussed in Appendix D. Information regarding the quality of parameter estimates and user inputs is provided where available.

Source and Quality of Input Data

Sources of Input Data

- *Short-Term Energy Outlook (STEO)* – Short-term liquid fuel consumption from 2005 to 2012 is provided by region from EIA's *STEO.* The *IEO2011* results are benchmarked to the *STEO* results from the March 2011 edition of the report.

- *International Statistics Database* – The Energy Information Administration provides historical data on international energy consumption by fuel type from 1980 through 2008. These data are used as the historical basis for all regional projections that appear in the *IEO2011*. While the numbers are continually updated, WEPS+ used a "snap shot" of the database as it existed on April 1, 2011 as the source of its international data.

- *International Energy Agency* – The by-end-use-sector, by-product historical data are available from the OECD and non-OECD balances and statistics database by country on the subscription site www.iea.org. These data are benchmarked to the historical aggregate energy consumption data provided in the Energy Information Administration's international statistical data base.

- *NEMS* – Many of the assumptions about price and economic elasticities are based in large part on those included in the National Energy Modeling System for the United States. In WEPS+, expert judgment on regional economic conditions has been used to modify the NEMS-based assumptions for some specific regions.

Data Quality Verification

As a part of the input and editing procedure, an extensive program of edits and verifications was used, including:

- Checks on world and U.S. consumption of liquid fuel, prices, and elasticities, based on previous values, responses, and regional and technical knowledge

- Consistency checks

- Technical edits to detect and correct errors, extreme variability