Institution for Transport Policy Studies International Study of Transport Systems in a Low Carbon Society

Documentation of Fuel and Carbon Intensity Assumptions for the Americas

Final Report

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March 8, 2010

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Acronyms and Abbreviations

BAU	Business As Usual
BEV	Battery-Electric Vehicle
BTL	Biomass to Liquid
CAFE	Corporate Average Fuel Economy (a U.S. regulatory program)
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
DslHEV	Diesel Hybrid Electric Vehicle
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
EU	European Union
FAME	Fatty-Acid Methyl Esters
FC	Fuel Cell or Fuel Consumption (as denoted by context)
FCV	Fuel Cell Vehicle
g	Gram(s)
g/mi	Grams per Mile
GasHEV	Gasoline Hybrid Electric Vehicle
GDP	Gross Domestic Product
GDS	Globally-Driven Scenario
GHG	Greenhouse Gas(es)
GVW	Gross Vehicle Weight (as rated by a vehicle manufacturer)
HDT	Heavy Duty Truck
HDV	Heavy Duty Vehicle
HEV	Hybrid Electric Vehicle
H_2	Hydrogen
H2FC	Hydrogen Fuel Cell
ICCT	International Council on Clean Transportation
ICE	Internal Combustion Engine
IPCC	Intergovernmental Panel on Climate Change
ITPS	Institution for Transport Policy Studies
kg	Kilogram(s)
kg/litge	Kilograms per Liter Gasoline Equivalent
kgCO_2/litge	Kilograms of CO_2 per Liter Gasoline Equivalent
km	Kilometer(s)
LDS	Locally-Driven Scenario
LDV	Light Duty Vehicle
lit	liter(s)

Acronyms and Abbreviations

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lit/100km	Liters per 100 Kilometers
litge/100km	Liters Gasoline Equivalent per 100 Kilometers
LPG	Liquefied Petroleum Gas
MDT	Medium Duty Truck
MDV	Medium Duty Vehicle
mi	Mile(s)
MJ/pass-km	Megajoules per Passenger-Kilometer
MJ/seat-km	Megajoules per Seat-Kilometer
MJ/tonne-km	Megajoules per Tonne-Kilometer
mpg	Miles per U.S. Gallon
RoLA	Rest of Latin America
SMP	WBCSD's Sustainable Mobility Project
SMR	Steam Methane Reforming
ton	Short Ton (Equal to 2,000 Pounds, 907,194.0 Grams, or 0.9072 tonnes)
ton-mile	Ton-Mile
tonne	Metric Ton (Equal to One Million Grams)
tonne-km	Tonne-Kilometer
UCB	University of California at Berkeley
U.S.	United States
WBCSD	World Business Council for Sustainable Development
2WV	Two-Wheeled Vehicle
3WV	Three-Wheeled Vehicle

1. Introduction

The International Council on Clean Transportation (ICCT) was retained by the Institution for Transport Policy Studies (ITPS) to participate in an international study of transport systems in a low carbon society. The ITPS study involves the independent regional analysis of potential policy decisions that might be required to achieve a 50 percent reduction in global carbon dioxide (CO_2) by 2050 (as measured relative to emissions in 2000). By definition, aggressive policy measures will be required to bring about reductions of this magnitude, so none of the estimates presented in this report should be considered to be realistic targets achievable under either business as usual circumstances or through trivial enhancements to current transportation policies.

The ICCT was selected as part of the regional analysis group for North and Latin (South) America, charged with developing fuel and carbon intensity estimates for all transportation modes and supplying those estimates to researchers at the University of California at Berkeley (UCB). UCB researchers, whose work is independently documented, are in turn charged with integrating the ICCT estimates with their own independent estimates of transportation activity, and producing and evaluating a CO_2 production model to compare estimated CO_2 to the ITPS target CO_2 emissions level.

The UCB documentation should be consulted for detailed information on the CO_2 emissions modeling method employed. However, for an appreciation of much of the data presented in this report, it is important to recognize that the model employed for emissions evaluation in the Americas was based on the public domain model developed under the World Business Council for Sustainable Development's (WBCSD's) Sustainable Mobility Project (SMP). [1] The basic format of the ICCT's data, as well as "default" data values that are used in certain specific instances as described further below, are patterned in accordance with SMP model design. The SMP model evaluates CO_2 emissions for eleven specific transport sectors (modes) as follows:

- Light duty passenger vehicles,
- Medium duty trucks,[1]
- Heavy duty trucks,
- Two-wheeled vehicles,
- Three-wheeled vehicles,
- Buses,
- Minibuses,
- Passenger rail,
- Freight rail,
- Aircraft, and
- Marine vessels.

ICCT's fuel and carbon intensity data were thus developed according to this same set of transport modes and were generally provided to UCB in the format employed in the SMP model. In some cases this results in the production of tables that reflect data values that do not change

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[1] The SMP model is ambiguous with regard to the specific definition of medium and heavy duty trucks. [1,29] For purposes of developing the fuel and carbon intensity estimates presented for these modes in this report, the ICCT assumed that medium duty trucks are defined as having a gross vehicle weight rating between 10,000 and 26,000 pounds (4,536 to 11,794 kilograms), while heavy duty trucks are defined as having a gross vehicle weight rating greater than 26,000 pounds (11,794 kilograms).

over time or geography — in effect, tables that might quite adequately be described in narrative format. Nevertheless, such data are presented in this report in the same tabular format utilized in the SMP model so that the specific data employed for modeling purposes is unmistakable and easy to transfer into the model.

With similar intent, this report is also generally structured to reflect the modular format of the SMP model, with individual sections of the report describing the individual transportation modes addressed in each SMP module. In this fashion, readers interested in the modeling approach and inputs for one transportation mode can easily find that information by referring to the specific section for that mode. Thus, there is a one-to-one relationship between individual sections of this report and the eleven transportation modes listed above. There are five additional sections in the report that address overarching issues. This section provides introductory material. Section 2 discusses the policy measures that are envisioned as being necessary to bringing about the reported fuel and carbon intensity data. Since many of these policy measures affect multiple transportation modes, they are addressed in the aggregate. Section 4 discusses minor transportation activity issues which also crosscut individual transportation modes. Section 5 discusses fuel-specific assumptions and estimates, as these similarly affect multiple transportation modes. Section 16 provides an aggregate list of references.

The ICCT/UCB study region was broken down into five specific modeling areas, consisting of Canada, the United States (U.S.), Mexico, Brazil, and the rest of Latin America (RoLA). Generally, the ICCT assumed that individual vehicle and engine technologies could be applied equally across study areas, but that differences in local fleet composition and fleet turnover time could affect the net impact of such technologies in any given modeling area and year.

The ICCT was charged by ITPS to evaluate transportation fuel and carbon intensity impacts through 2050 under two specific scenarios, one representing a future driven by global cooperation and one representing a future driven by local interests. Under the globally-driven scenario (GDS), the ICCT assumed a globally cooperative push to minimize fuel and carbon intensity, combined with a strong linkage between local energy security desires and global carbon reduction efforts. To support such a future, the scenario assumes that appropriate underlying and globally cooperative regulatory, economic, and development policies will be instituted.

Conversely, under the locally-driven scenario (LDS), the ICCT assumes a future that lacks the cooperative global efforts necessary to implement stringent carbon-specific levers. Accordingly, it is assumed that there is no additional incentive to decarbonize fuels (beyond the levels associated with those incentives that are currently in place). Although generally based on localized production (centered in the U.S., EU, and Asia), the transport market is already global in scope and the ICCT sees no reason for this to change. Additionally, the ICCT believes that local (i.e., national) energy security concerns constitute a sufficient lever to push fuel intensity, albeit to levels somewhat less aggressive than assumed for the globally-driven scenario due to the absence of a globally-driven carbon tax (or equivalent) policy. For example, energy security issues will still push fuel cell (and/or battery electric) vehicles into the market, but low carbon hydrogen (and/or electricity) production will not be incentivized.

The specific assumptions employed and data developed for each transport mode are discussed in detail in the following sections. However, before presenting the mode-specific discussions, several summary graphics provide a useful indication of the magnitude of the aggregate fuel and carbon intensity assumptions adopted by the ICCT. It is critical to recognize that in developing the presented metrics, no changes to baseline SMP model activity estimates have been implemented. Such changes are the responsibility of UCB researchers and the ICCT does not want to complicate their work by making independent assumptions in this area. Therefore, the presented data should be taken as indicative of fuel and carbon intensity impacts alone and not as representative of study emission estimates for any given future scenario, as such estimates require the integration of the ICCT data with activity data developed by UCB researchers.

In that context, Figure 1 depicts CO_2 emission estimates, both by modeling area and in the aggregate. Clearly, the U.S. is responsible for the bulk of regional emissions, but notable emission reductions are associated with the alternative fuel and carbon intensity assumptions employed by the ICCT. While "business as usual" (BAU) emissions nearly double between 2000 and 2050, emissions under the alternative futures all decline relative to 2000 emissions (again, without the impact of any assumptions about potential changes in activity).[2] Figure 2 shows the growth in activity between 2000 and 2050 that is inherently included in the 2050 emission estimates.[3] As indicated, growth in several transport modes exceeds 200 percent, which provides an appropriate emphasis on the emission reductions observed between the 2050 BAU and alternative scenarios. Figure 3 shows the breakdown of 2000 and 2050 emissions by transport mode, clearly depicting the rising importance of aircraft emissions and the continuing, but diminished, importance of light duty vehicles and heavy duty trucks.[4] Finally, Figure 4 shows the net change in carbon intensity for each of the transport modes included in the study.[5]

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[2] It should be recognized that the BAU scenario used for the development of the presented metrics is not a robust scenario investigated by the ICCT. Since the target emission reductions for this study are expressed relative to 2000 emissions, the development of a BAU scenario is not formally required. Nevertheless, to get an idea of how future emissions change relative to a "current year" baseline, the ICCT developed a rudimentary BAU scenario by holding fuel and carbon intensity constant after 2015 (except in instances where a currently adopted control program affected forecast years after 2015). Thus, emissions data for the BAU scenario presented in this report should be viewed as reasonable, but rough.

It should also be noted that the scenarios labeled "localization" and "globalization" reflect the alternative locally-driven and globally-driven futures evaluated by the ICCT. The "globalization + 1 lit/100km minicar" scenario is an alternative interpretation of the globally-driven scenario requested by UCB researchers, as described in detail in Section 3 below. There are actually three minicar alternatives that were developed for UCB; that depicted is the most aggressive and is provided for illustrative purposes only. The ICCT does not consider it to be a realistic depiction of a globally-driven future during the time period covered by this study.

[3] It should be understood that the terminology "no changes in activity" does not mean that activity is constant across forecast years, but that the activity estimates of the baseline SMP model (which change over time) have themselves not been altered in any way. Necessary changes to the baseline activity estimates to properly reflect the scenarios investigated in this study will be developed by UCB researchers.

[4] To enhance the readability of Figure 3, emissions from buses and minibuses, two and three wheeled vehicles, and passenger and freight rail have been aggregated and reported as buses, 2/3 wheelers, and rail respectively.

[5] The increase in BAU carbon intensity for buses and minibuses results from an assumption in the baseline SMP model that bus load factors decline over time. Since the ICCT left baseline SMP model activity assumptions unchanged, the net negative impact on carbon intensity is carried through to all future scenarios. However, these and all other activity assumptions are subject to potential revision by UCB researchers.

Figure 1. CO_2 Emissions by Modeling Area (Without Activity Changes)

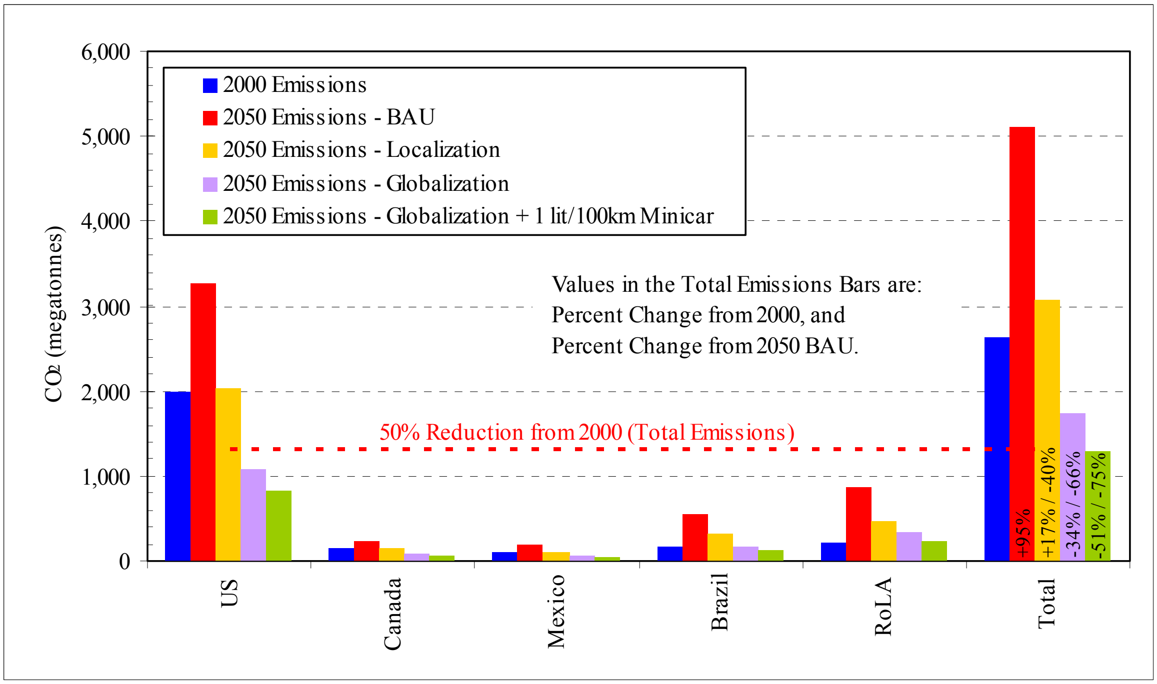


Figure 2. Baseline SMP Model Activity Growth (Without Activity Changes)

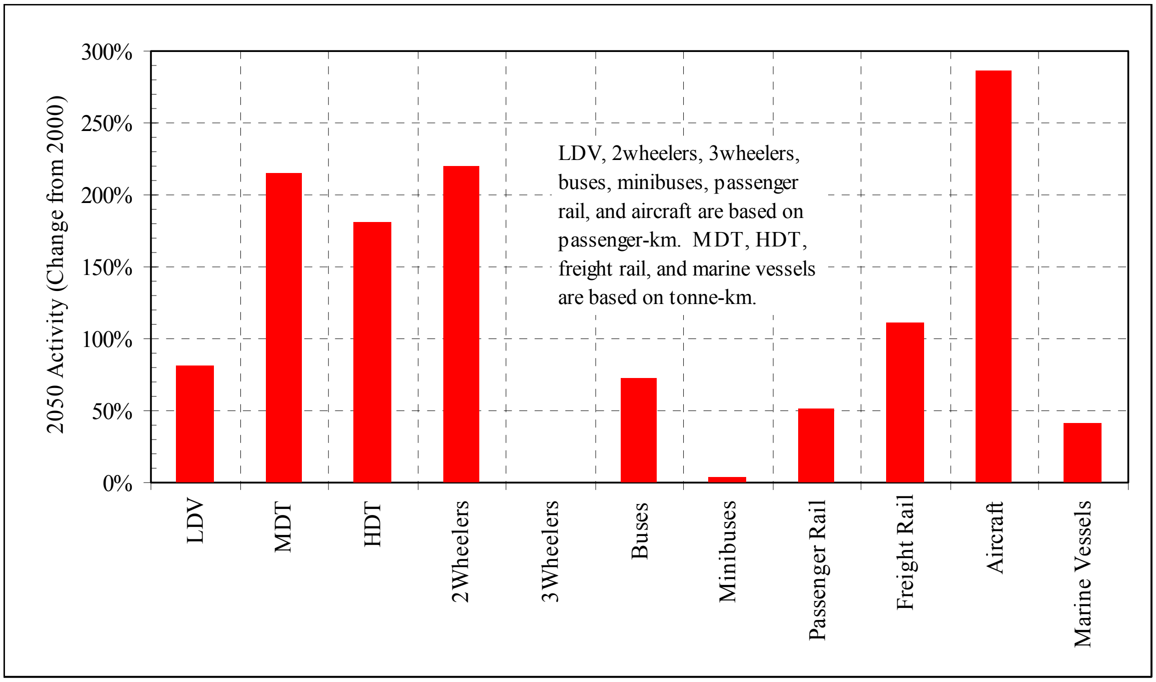


Figure 3. CO_2 Emissions by Transport Mode (Without Activity Changes)

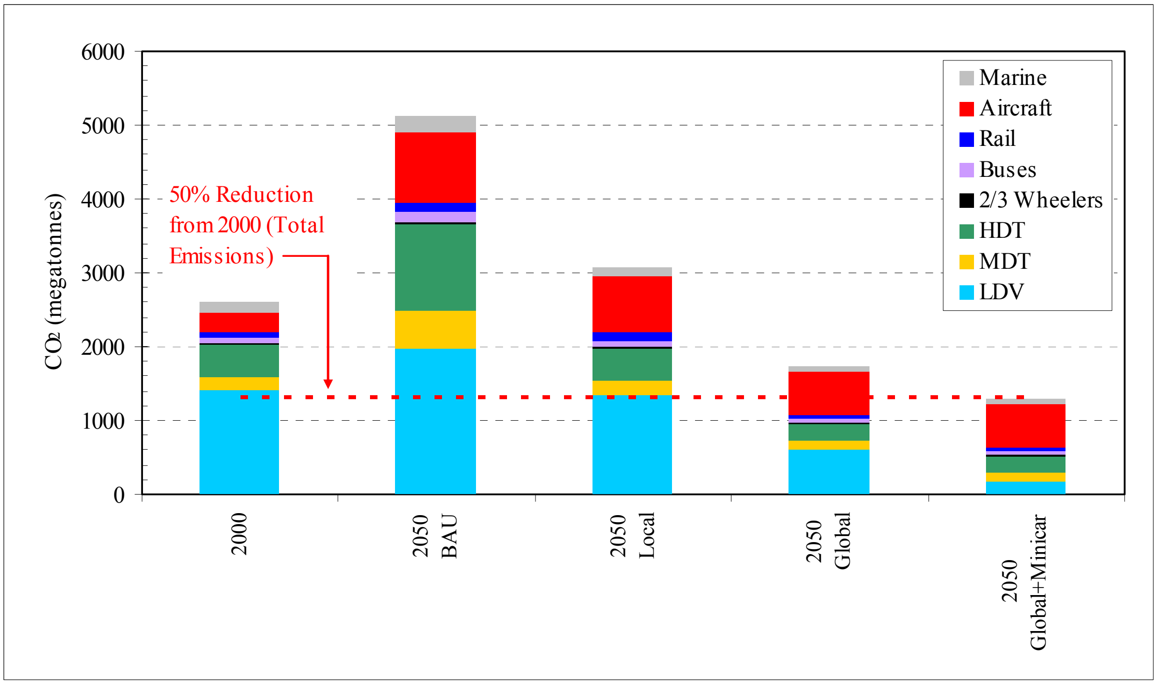
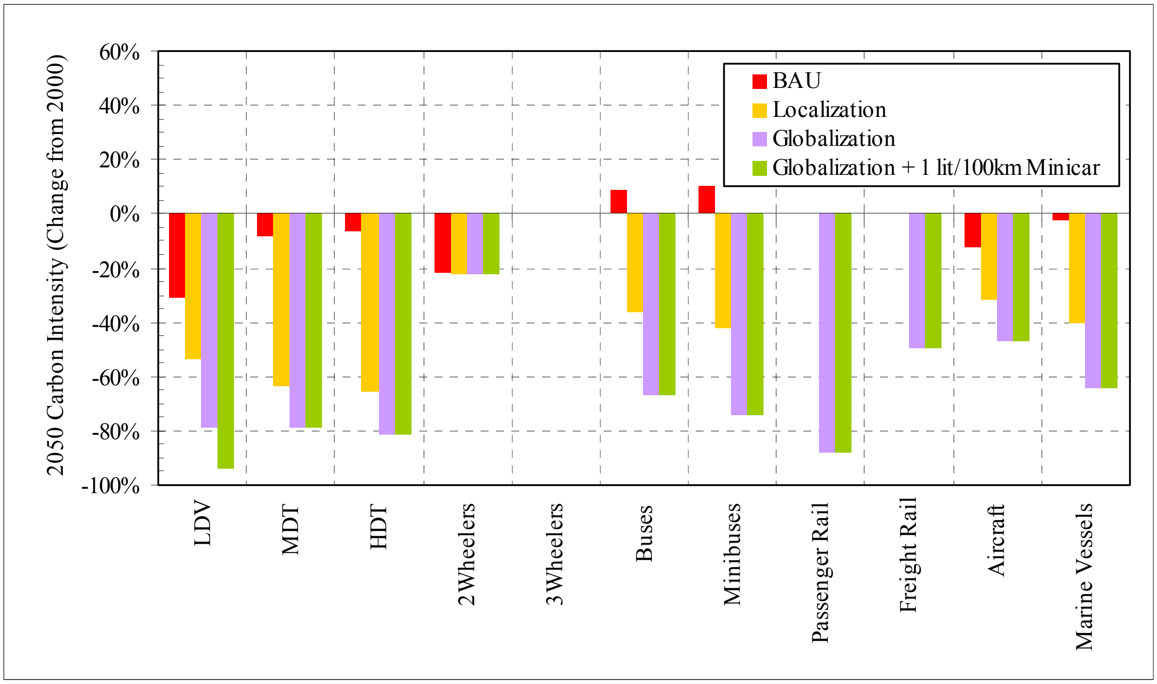


Figure 4. Net Carbon Intensity Change by Mode (Without Activity Changes)



Based on the data presented in Figures 3 and 4, additional carbon intensity reductions in the aircraft sector would be most effective in further reducing 2050 CO_2 (again, pending the impacts of any activity changes implemented by UCB researchers).

2. Required Policy Measures

As described in Section 1, the estimates presented in this report are part of a study of potential policy decisions that might be required to achieve a 50 percent reduction in global CO_2 by 2050 (as measured relative to emissions in 2000). Aggressive policy measures will be required to bring about CO_2 reductions of this magnitude. None of the estimates presented in this report should be considered to be achievable under either business as usual circumstances or through trivial enhancements to current transportation policies. Accordingly, the ICCT believes an aggressive slate of policy measures will be integral component of any future wherein the reported fuel and carbon intensity estimates are attainable.

The ICCT views the imposition of stringent fuel efficiency standards (or alternative comparable programs such as effective feebate structures) *across all transportation modes* as a primary policy measure. For countries that already administer fuel efficiency programs, this means the maintenance of these programs so that cost effective fuel efficiency technology is introduced in the earliest possible timeframe, as well as the expansion of such programs to cover currently unaddressed transportation modes. For countries without existing fuel efficiency programs, this means the implementation and maintenance of such programs with the same goal of promoting the introduction of cost effective fuel efficiency technology. Such programs are critical to overcoming both market externalities and irrationalities. Furthermore, the ICCT believes that, due to energy security concerns, such policies are consistent with both globally-driven and locally-driven futures and therefore assumes fuel efficiency policy existence under both the globally and locally driven futures of this study. In short, the ICCT assumes aggressive fuel efficiency standards are in place in either future.

The ICCT also assumes that additional government intervention will be required between 2010 and 2025 to overcome market barriers to the widespread introduction of non-conventionally fueled vehicles (i.e., vehicles using fuel other than gasoline or diesel). [2,3] This includes both the continued funding of existing programs, such as the U.S. FreedomCAR and Vehicle Technologies Program — since the ICCT's forecasted fuel intensity levels for associated transportation sectors are dependent on the attainment of associated vehicle technology and cost goals — as well as the implementation of new initiatives. Such intervention is required to both reduce technology development and vehicle production costs, as well as establish a competitive refueling infrastructure. For example, assuming fuel cell technology and fuel storage cost targets are met, overall policy support levels have been estimated to be in the $1 to $6 billion annual cost range, with cumulative costs of $10 to $45 billion by 2025. [2,3] These figures are based on U.S.-only investment, but total regional costs are estimated to be similar since the technology is assumed to be "self supporting" once it becomes cost effective (regardless of the initial market in which this cost effectiveness is achieved). Certainly there will be infrastructure costs across the region, but these should be "absorbed" into the market once it is established. For study purposes, it is assumed that fueling infrastructure will develop in a phased manner, with a major metropolitan area focus in the pre-2015 timeframe, followed by an expansion to other large urban areas and urban area interconnections through about 2020, with regional and interregional expansion through 2025. The ICCT assumes all market intervention ceases after 2025.

For the globally-driven future, the ICCT assumes the imposition of a carbon tax (or equivalent). Such a policy can contribute to both fuel switching and alternative fuel production pathways. For example, under a hydrogen light duty vehicle future, fiscal policies related to overcoming market barriers may be sufficient to bring about a hydrogen vehicle market, but they have no influence on the carbon characteristics of hydrogen production in the absence of a carbon tax (or equivalent). Hydrogen can be produced from the same high carbon fuels used to generate electricity. The imposition of a supplemental carbon tax (or equivalent) serves as the lever to promote low-GHG hydrogen production. For transportation modes like rail, the carbon tax (or equivalent) policy is believed to be necessary to promote large scale rail electrification, thereby affecting the net fuel intensity in the sector. Similarly, for modes like marine and aircraft which (due to their inherent international nature) are constrained in the extent that they can be influenced through local policy alone, the carbon tax (or equivalent) policy is assumed to drive efficiency improvements beyond the levels that would occur in the absence of such tax (or equivalent).

Under the globally-driven future, the ICCT specifically assumes a globally cooperative carbon tax beginning between 2010 and 2020 and ramping up to as much as $100 per tonne by 2025. Such a policy is expected to induce the low-GHG production of both electricity and hydrogen for road vehicles, promote electrification (and correspondingly lower fuel intensity) in the rail sector, and promote greater fuel intensity improvements in the marine and aircraft sectors as compared to corresponding estimates for the locally-driven future. The specific fuel and carbon intensity impacts assumed by the ICCT are presented in the detailed sections for each transportation mode that follow.

Under the locally-driven future, the ICCT assumes no global cooperation and no incentive for the imposition of local carbon taxes (or equivalent). It should also be noted that the ICCT has not assumed any carbon "backsliding" under the locally-driven future. Although there is potential for carbon increases due to increases in the processing of higher carbon petroleum sources such as oil sands, the ICCT has assumed that any such increases that might occur will be locally mitigated through low carbon fuel programs (essentially carbon caps) that are already being adopted in many parts of the U.S. In effect, the ICCT assumes that such programs move forward under the locally-driven future and effectively serve to prevent fuel carbon backsliding.

Finally, for heavy duty truck (HDT) sector, the ICCT also assumes that existing restrictions on truck weight and trailer length will be eased to allow for improved economies of scale with regard to the energy intensity of HDT freight movement. For example, the U.S. currently imposes maximum truck weight and trailer length limits of 80,000 pounds (36,288 kilograms) and one standard length (45-48 foot, 13.7-14.6 meter) trailer respectively. There are exceptions in some states where longer (and heavier) trucks were allowed before current federal regulations took effect, but the majority of HDT movement is subject to the federal limits. Similarly, the ICCT also assumes that speed restrictions will be imposed to limit the legal travel speed of HDTs to 60 miles per hour (97 kilometers per hour). Such a restriction would lower the effective aerodynamic drag associated with HDT highway travel and significantly improve the fuel intensity of HDT freight movement. Since these policies are intended to minimize HDT fuel consumption and therefore are consistent with policies adopted in response to local energy security concerns, the ICCT assumes that such policies are in place for both the globally-driven and locally-driven futures of this study.

3. Light Duty Vehicle Fuel and Carbon Intensity Parameters

The SMP model structure for light duty vehicles (LDVs) is substantially more robust than the model structures for other transportation modes. For example, while the model structures for other modes generally require an "offline" (outside the model) accounting of vehicle sales and retirement impacts, the LDV structure includes explicit sales and retirement functions. The LDV structure is also constructed to allow for the independent analysis of conventional gasoline, conventional diesel, gasoline hybrid-electric, diesel hybrid-electric, compressed natural gas (CNG) or liquefied petroleum gas (LPG), and fuel cell (FC) vehicles. Electric-only vehicles (often referred to as battery-electric vehicles, or BEVs) are notably absent from the SMP model structures for road vehicles, but the ICCT does not believe this to be a significant issue for this work due to the fact that the CO_2 emission rates for BEVs are expected to be similar to those for fuel cell vehicles (FCVs).[6] Therefore, although the ICCT uses the SMP model FCV structures as surrogates for both FCVs and BEVs, it is expected that estimated emissions under either the globally or locally driven scenario will be reasonably similar for either a BEV or FCV future.

3.1 LDV Sales by Technology Type

The ICCT has estimated sales by technology type as summarized in Tables 1 through 7. [2,3] As previously described, the vehicle sales forecast is assumed to be independent of whether the future is globally or locally driven. Since the light duty vehicle market is global under current conditions, it is difficult to envision a scenario in which that global market will constrict to consider only local interests. The ICCT views local energy security issues as more than sufficient to drive aggressive light duty vehicle fuel efficiency policies under both globally and locally driven futures. For this reason, light duty vehicle sales shares are unchanged under the two alternative futures. Also, as mentioned above, although the ICCT assumes that policy measures will be implemented to promote the cost effective marketing of fuel cell vehicles during the forecast period, it is further assumed that there will be a lag in the propagation of that technology throughout the Americas. The ICCT assumes no market lag for Canada (relative to the U.S.), but a five year lag in Brazil and Mexico, and a ten year lag throughout the rest of Latin America.

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[6] For example, based on an efficiency and fuel option analysis for BEVs and FCVs, CO_2 emission rates are expected to be within about 17 percent using natural gas (existing technology) as the primary energy source (167 g/mi for a BEV versus 143 g/mi for a FCV) and about 2 percent using coal as the primary energy source (353 g/mi for a BEV versus 346 g/mi for a FCV). As higher efficiency natural gas plants are constructed, the natural gas differential is expected to decline to near zero. Of course, either vehicle emits zero carbon when consuming energy derived from a net zero carbon primary energy source such as solar or wind. While the actual emission rate of either vehicle will vary in accordance with local fueling options, those options are expected to be similar for either vehicle in any given area.

Table 1. Share of Vehicle Sales that are Conventional Gasoline ICEs

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0.997	0.997	0.927	0.638	0.380	0.200	0.110	0.080	0.030	0.020	0.010
Canada	0.997	0.997	0.927	0.638	0.380	0.200	0.110	0.080	0.030	0.020	0.010
Mexico	0.990	0.990	0.990	0.925	0.640	0.380	0.200	0.110	0.080	0.030	0.020
Brazil	0.990	0.990	0.990	0.925	0.640	0.380	0.200	0.110	0.080	0.030	0.020
RoLA	0.990	0.990	0.990	0.995	0.930	0.640	0.380	0.200	0.110	0.080	0.030

Table 2. Share of Vehicle Sales that are Gasoline HEVs

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0.000	0.000	0.070	0.360	0.610	0.760	0.640	0.360	0.200	0.110	0.080
Canada	0.000	0.000	0.070	0.360	0.610	0.760	0.640	0.360	0.200	0.110	0.080
Mexico	0.000	0.000	0.000	0.070	0.360	0.610	0.760	0.640	0.360	0.200	0.110
Brazil	0.000	0.000	0.000	0.070	0.360	0.610	0.760	0.640	0.360	0.200	0.110
RoLA	0.000	0.000	0.000	0.000	0.070	0.360	0.610	0.760	0.640	0.360	0.200

Table 3. Share of Vehicle Sales that are Conventional Diesel ICEs

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Canada	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mexico	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Brazil	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
RoLA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Note: Diesel vehicles are not treated explicitly in the forecast since they do not reflect an evolutionary technology capable of altering the long term carbon footprint of light duty vehicles to the degree required to achieve large scale carbon reductions. While there are diesel vehicles in the respective light duty vehicle fleets, those vehicles are simply treated in combination with gasoline light duty vehicles.

Table 4. Share of Vehicle Sales that are Diesel HEVs

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Canada	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mexico	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Brazil	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
RoLA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Note: Diesel vehicles are not treated explicitly in the forecast since they do not reflect an evolutionary technology capable of altering the long term carbon footprint of light duty vehicles to the degree required to achieve large scale carbon reductions. While there are diesel vehicles in the respective light duty vehicle fleets, those vehicles are simply treated in combination with gasoline light duty vehicles.

Table 5. Share of Vehicle Sales that are CNG/LPG

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0.003	0.003	0.003	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Canada	0.003	0.003	0.003	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mexico	0.010	0.010	0.010	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Brazil	0.010	0.010	0.010	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000
RoLA	0.010	0.010	0.010	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Note: Like diesel vehicles, CNG and LPG vehicles are generally not treated explicitly in the forecast since they do not reflect an evolutionary technology capable of altering the long term carbon footprint of light duty vehicles to the degree required to achieve large scale carbon reductions. Such vehicles are phased out of the light duty vehicle fleet entirely between 2010 and 2020.

Table 6. Share of Vehicle Sales that are Hydrogen Fuel Cell Vehicles

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0.000	0.000	0.000	0.000	0.010	0.040	0.250	0.560	0.770	0.870	0.910
Canada	0.000	0.000	0.000	0.000	0.010	0.040	0.250	0.560	0.770	0.870	0.910
Mexico	0.000	0.000	0.000	0.000	0.000	0.010	0.040	0.250	0.560	0.770	0.870
Brazil	0.000	0.000	0.000	0.000	0.000	0.010	0.040	0.250	0.560	0.770	0.870
RoLA	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.040	0.250	0.560	0.770

Note: Hydrogen fuel cell vehicles are used as a surrogate for both fuel cell and battery electric vehicles. These vehicles represent an evolutionary technology *potentially* capable of altering the long term carbon footprint of light duty vehicles to the degree required to achieve large scale carbon reductions.

Table 7. Share of HEV Sales that are Full Hybrids[7]

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0.750	0.750	0.750	0.813	0.875	0.938	1.000	1.000	1.000	1.000	1.000
Canada	0.750	0.750	0.750	0.813	0.875	0.938	1.000	1.000	1.000	1.000	1.000
Mexico	0.900	0.900	0.900	0.925	0.950	0.975	1.000	1.000	1.000	1.000	1.000
Brazil	0.900	0.900	0.900	0.925	0.950	0.975	1.000	1.000	1.000	1.000	1.000
RoLA	0.900	0.900	0.900	0.925	0.950	0.975	1.000	1.000	1.000	1.000	1.000

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[7] The SMP model is ambiguous with regard to the specific definition of "full hybrid" vehicles (as opposed to mild or moderate hybrid vehicles). For purposes of developing the fuel and carbon intensity estimates presented in this report, the ICCT has assumed that full hybrid vehicles are capable of electric motor only operation (albeit for very short time durations), similar to the current Toyota Hybrid Synergy Drive technology. In contrast, mild or moderate hybrids do not have similar capability, although they still provide significant efficiency benefits through regenerative braking, electric launch assist, and engine off at idle capabilities. However, it is important to note that what is important is not the specific technology employed, but rather that "full hybrids" achieve an assumed greater efficiency level and all hybrids are assumed to achieve this "full hybrid" level of performance by 2030.

For convenience, the ICCT treats the future vehicle fleet as composed of a mix of conventional gasoline, gasoline hybrid-electric, and fuel cell vehicles. Diesel and diesel hybrid-electric vehicles are subsumed into the gasoline and gasoline hybrid-electric vehicle fleets respectively, since sales of such vehicles do not currently represent a significant fraction of the light duty vehicle market in the Americas (and are not forecasted to capture a significant market share in a fuel cell vehicle or battery electric vehicle future). Similarly, CNG and LPG vehicles are phased out of the fleet (from very low current market penetration levels) by 2015.

The ICCT's assumed future can basically be summarized as follows. Sales of gasoline hybrid-electric vehicles grow throughout the 2000-2030 period, overtaking conventional vehicle sales in about 2020. Beginning in about 2020, sales of fuel cell (or battery electric) vehicles begin to become significant, growing throughout the 2020-2050 period. Between 2035 and 2040, fuel cell vehicles become the predominant light duty vehicle architecture and grow to between 75 and 90 percent of light duty vehicle sales (depending on the area being modeled) by 2050.

3.2 Fuel Consumption Ratios of LDV Technology Types

The SMP model estimates the fuel intensity of specific vehicle types through the ratio of fuel consumption for each vehicle type to fuel consumption for a corresponding conventional gasoline vehicle. Table 8 shows the fuel consumption relationships assumed by the ICCT for this study. [3,4] Since these relationships are technology-based, they are assumed to apply without variation in all geographic areas.

Table 8. Fuel Consumption Ratios of LDV Technology Types

Technology	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Gasoline ICE	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
GasHEV - Mild	0.819	0.819	0.819	0.819	0.819	0.819	0.819	0.819	0.819	0.819	0.819
GasHEV - Full	0.690	0.690	0.690	0.690	0.690	0.690	0.690	0.690	0.690	0.690	0.690
Diesel ICE	0.900	0.900	0.900	0.925	0.950	0.950	0.950	0.950	0.950	0.950	0.950
DslHEV - Mild	0.653	0.653	0.653	0.653	0.653	0.653	0.653	0.653	0.653	0.653	0.653
DslHEV - Full	0.550	0.550	0.550	0.550	0.550	0.550	0.550	0.550	0.550	0.550	0.550
CNG/LPG	1.050	1.050	1.050	1.050	1.050	1.050	1.050	1.050	1.050	1.050	1.050
H2 Fuel Cell	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500

3.3 Certification Fuel Consumption Rates for LDV Gasoline ICE Technology

As stated in Section 3.2, the SMP model estimates the fuel intensity of specific vehicle types through the ratio of fuel consumption for each vehicle type to fuel consumption for a corresponding conventional gasoline vehicle. While the ratios for modeled vehicle types are presented above in Table 8, the fleetwide certification fuel consumption for conventional gasoline vehicles (to which the ratios in Table 8 are applied) is presented in Table 9.

Beginning with the year 2025, fleetwide certification fuel consumption for conventional gasoline vehicles in the U.S. is assumed to reach a "minimum" value associated with advanced internal combustion technology and an assumed constant average vehicle size. [3] Corresponding fuel consumption for conventional vehicles in the U.S. for the years 2000, 2005, 2010, and 2015 was developed using either historic data or adopted fuel consumption standards as appropriate. [6] Since reported (and expected 2010 and 2015) data include the fuel consumption effects of both conventional ICE and hybrid-electric vehicles, the pre-2025 baseline U.S. data were adjusted to remove the effect of the hybrid-electric vehicles by altering the model input data for conventional ICE fuel consumption so that the combined conventional and hybrid-electric fuel consumption matched the reported (or expected) fleetwide data. The U.S. baseline data for 2020 was set as the average of estimated 2015 and 2025 data.

Geographic differentials due to variations in either vehicle availability or consumer preference are estimated using 2008 fuel consumption data for the U.S., Mexico, and Brazil. [6,7,8] Canadian conventional gasoline vehicle fuel consumption is set equal to that for the U.S., while conventional gasoline vehicle fuel consumption in the rest of Latin America is set equal to that for Brazil. The fleetwide fuel consumption ratios developed for 2008 are then used without change to estimate geographic area-specific fleetwide conventional gasoline vehicle fuel consumption for all modeling years from that estimated for the U.S. Essentially this assumes no fundamental variation in the *differentials* in vehicle availability and consumer preference across geography over time. Any changes in average vehicle size over time are assumed to occur proportionally across all areas. This also implies that all five geographic areas are either setting stringent standards that take effect in the 2015 to 2020 timeframe, or achieving equivalent impacts due to such adoption in neighboring areas.

As described above, the ICCT views vehicle fuel efficiency technology as independent of whether the future is globally or locally driven, so the values reported in Table 9 are used without change for both alternative futures. Nevertheless, UCB researchers requested several alternative fuel consumption scenarios to evaluate the impact of potential changes in average U.S. vehicle size (and, by extension, average vehicle size in Canada, Mexico, Brazil, and the rest of Latin America). Tables 9a through 9c show the associated certification fuel consumption rates for gasoline ICE technology (with the corresponding rates for alternative technologies based on the presented gasoline ICE rates and the ratios presented above in Table 8).

The alternative fuel consumption scenarios represent a series of very aggressive fleet shifting and technology forcing options (and the presented fuel consumption rates assume a 100 percent penetration rate of "alternative scenario minicars" in the ICE fleet by 2020). The least aggressive option, or minicar option one, is based on the current design ICE minicar that has the highest certification fuel economy, the Smart Fortwo. To convert the current design technology to an advanced technology basis (as is assumed for future ICE fuel consumption), the ratio of the Smart Fortwo unadjusted CAFE fuel economy to 2009 unadjusted fleet average CAFE fuel economy was used to scale the fleetwide advanced gasoline ICE fuel consumption to an advanced minicar equivalent.[8] [6,9,10]

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[8] In other words, the assumed advanced technology minicar fuel economy is equal to the ratio of the Smart Fortwo fuel economy to the 2009 fleet average fuel economy times the assumed fuel economy for an advanced technology internal combustion engine fleet (composed of a full line of vehicles, as presented in Table 9).

Table 9. Fuel Consumption Rates for Gasoline ICE Technology (lit/100km)

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	9.484	9.260	8.168	7.575	7.497	7.420	7.420	7.420	7.420	7.420	7.420
Canada	9.484	9.260	8.168	7.575	7.497	7.420	7.420	7.420	7.420	7.420	7.420
Mexico	9.212	8.994	7.933	7.357	7.282	7.206	7.206	7.206	7.206	7.206	7.206
Brazil	8.369	8.171	7.207	6.683	6.615	6.547	6.547	6.547	6.547	6.547	6.547
RoLA	8.369	8.171	7.207	6.683	6.615	6.547	6.547	6.547	6.547	6.547	6.547

Table 9a. Minicar Option 1: Current Design/Materials (lit/100km)

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	9.484	9.260	8.168	7.575	5.903	4.230	4.230	4.230	4.230	4.230	4.230
Canada	9.484	9.260	8.168	7.575	5.903	4.230	4.230	4.230	4.230	4.230	4.230
Mexico	9.212	8.994	7.933	7.357	5.733	4.109	4.109	4.109	4.109	4.109	4.109
Brazil	8.369	8.171	7.207	6.683	5.208	3.733	3.733	3.733	3.733	3.733	3.733
RoLA	8.369	8.171	7.207	6.683	5.208	3.733	3.733	3.733	3.733	3.733	3.733

Table 9b. Minicar Option 2: Advanced Design/Materials (lit/100km)

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	9.484	9.260	8.168	7.575	5.142	2.710	2.710	2.710	2.710	2.710	2.710
Canada	9.484	9.260	8.168	7.575	5.142	2.710	2.710	2.710	2.710	2.710	2.710
Mexico	9.212	8.994	7.933	7.357	4.994	2.632	2.632	2.632	2.632	2.632	2.632
Brazil	8.369	8.171	7.207	6.683	4.537	2.391	2.391	2.391	2.391	2.391	2.391
RoLA	8.369	8.171	7.207	6.683	4.537	2.391	2.391	2.391	2.391	2.391	2.391

Table 9c. Minicar Option 3: GasICE Version of 1 lit/100km DslHEV (lit/100km)

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	9.484	9.260	8.168	7.575	4.696	1.818	1.818	1.818	1.818	1.818	1.818
Canada	9.484	9.260	8.168	7.575	4.696	1.818	1.818	1.818	1.818	1.818	1.818
Mexico	9.212	8.994	7.933	7.357	4.561	1.765	1.765	1.765	1.765	1.765	1.765
Brazil	8.369	8.171	7.207	6.683	4.144	1.604	1.604	1.604	1.604	1.604	1.604
RoLA	8.369	8.171	7.207	6.683	4.144	1.604	1.604	1.604	1.604	1.604	1.604

Minicar option two is intended to represent the level of fuel consumption that might be attained with an advanced design minicar. Base fuel consumption data for an advanced design Volkswagen diesel HEV concept car (1.49 liters per hundred kilometers) was adjusted to an equivalent fuel consumption for an otherwise equivalent gasoline ICE using the diesel HEV to gasoline ICE fuel consumption ratio presented above in Table 8. [11] The resulting fuel consumption value is taken as the estimated fuel consumption for an advanced design and materials ICE gasoline minicar.

Finally, minicar option three assumes that the same VW diesel HEV concept car actually meets its stated fuel consumption design goal of one liter per hundred kilometers (lit/100km). A base fuel consumption of one lit/100km was adjusted to an equivalent fuel consumption for a gasoline ICE using the diesel HEV to gasoline ICE fuel consumption ratio presented above in Table 8. The resulting fuel consumption value is taken as the estimated fuel consumption for an advanced design and materials ICE gasoline minicar, assuming a technology base where a diesel HEV version of the minicar achieves 1 lit/100km.

3.4 In-Use Fuel Consumption Rates for LDV Technology

The SMP model uses an in-use to certification fuel consumption ratio (denoted as a “gap factor”) to estimate in-use fuel consumption from the certification fuel consumption data presented above. The ICCT estimates for the in-use to certification fuel consumption ratio are based on data developed by the U.S. Environmental Protection Agency (EPA) in support of a 2008 rulemaking related to fuel economy labeling.

For ICE vehicles and HEVs, the in-use fuel economy relations are as follows (where FC indicates fuel consumption) [5]:

$$\text{City FC} = 0.003259 + (1.1805\times\text{Certification City FC})$$

$$\text{Highway FC} = 0.001376 + (1.3466\times\text{Certification Highway FC})$$

Based on an analysis of EPA certification data, the ICCT estimates that certification city and certification highway fuel consumption are about 19.0% higher and 23.1% lower respectively (on average) than composite certification fuel consumption. Additionally, the composite in-use fuel consumption adjustment factor assumes 57% highway and 43% city operation. [5] For fuel cell vehicles, the ICCT assumes an 11.1% increase in in-use fuel consumption. [5]

It is important to recognize that the ICCT assumed these same relations across all study regions and all forecast years. It is entirely possible that the gap factor may vary, but in the absence of alternative data, the U.S. relations were applied without change. The net effect of any error associated with this assumption is expected to be minor as the magnitude of potential variation is correspondingly minor and is likely to result from shifts in driving patterns rather than fundamental physical variability. Moreover, such an assumption is consistent with the approach employed in the baseline SMP model.

4. <u>Activity Disaggregation</u>

As described above, the ICCT was charged with defining fuel and carbon intensity data for five specific modeling areas. Although this charge does not entail the explicit development of assumptions regarding the transportation activity impacts of any given future, the baseline SMP model used for analysis purposes treated the five areas modeled in this study as two larger composite areas (namely North and Latin America). As a result, to evaluate ICCT fuel and carbon intensity data using the study model for internal quality control purposes, it was necessary to disaggregate the composite area activity data into the more resolved five area geography. To accomplish this, the ICCT simply disaggregated all activity on the basis of gross domestic product (GDP) relations for the five areas.

2003 GDP estimates were obtained for each of the five modeling areas, as well as for North and Latin America in the aggregate. [12] Total North American activity for each transportation mode in the baseline SMP model was disaggregated to the U.S., Canada, and Mexico (which comprise the North American region in the SMP model) on the basis of the ratio of their individual GDP values to total North American GDP. The resulting activity shares were estimated to be 88.4 percent for the U.S., 6.5 percent for Canada, and 5.1 percent for Mexico. Similarly, total Latin American activity for each transportation mode in the baseline SMP model was disaggregated to Brazil and the rest of Latin America on the basis of the ratio of their individual GDP values to total Latin American GDP. The resulting activity shares were estimated to be 44.5 percent for Brazil and 55.5 percent for the rest of Latin America.

In cases where activity assignment rather than disaggregation was appropriate (e.g., load factors), Canada and the U.S. were simply assigned baseline SMP model data for North America and Brazil and the rest of Latin America were simply assigned baseline SMP model data for Latin America. Mexico was assigned either the baseline SMP model data for North America or the baseline SMP model data for Latin America depending of the context of the specific data parameter. If the particular parameter was more closely related to trade or influence from North America, then North American data were assigned. If the particular parameter was more closely related to trade or influence from Latin America, then Latin American data were assigned.

It is emphasized that these disaggregations and assignments were merely undertaken to allow the development of a quality control tool for internal ICCT purposes. All of these data are merely placekeepers subject to replacement by more robust activity data developed by UCB researchers in accordance with their study responsibilities. Clearly, some activity data (e.g., mass transit ridership) might be more appropriately related to GDP in an inverse fashion rather than the direct fashion employed by the ICCT. However, the goal was not accuracy per se, but rather an expansion of “test” data from the two areas included in the baseline SMP model to the five areas modeled in this study. ICCT activity estimates should not be assigned any inherent validity.

5. Fuel Assumptions

The SMP model defines the carbon intensity of transportation modes in terms of both fuel intensity and the carbon characteristics of the particular fuel mix utilized. The model relies on a number of production pathway parameters to define the overall transportation fuel mix, including the share of:

- Gasoline energy supplied by ethanol,
- Ethanol energy derived from grain,
- Ethanol energy derived from sugar cane via low-GHG processes,
- Ethanol energy derived from cellulosic sources via low-GHG processes,
- Diesel energy supplied by biodiesel,
- Biodiesel energy derived from fatty-acid methyl esters (FAME),
- Biodiesel energy derived from low-GHG processes,

- Hydrogen energy derived from steam methane reforming (SMR),
- Hydrogen energy derived from low-GHG processes,
- Electricity energy derived from conventional production processes, and
- Electricity energy derived from low-GHG processes,

It is perhaps worth noting that the ICCT added the latter two pathways to the SMP model to properly account for a future with low-GHG electricity production.

Table 10 shows the share of the gasoline energy pool that is assumed to be derived from ethanol. The share of U.S. gasoline energy supplied by ethanol for 2006-2030 is calculated from data reported by the U.S. Energy Information Administration (EIA). [13,14] Data for 2031-2050 were estimated through regression analysis of the 2006-2030 data. The share of Brazilian gasoline energy supplied by ethanol for 2000-2050 was calculated from data on the forecasted distribution of Brazilian light duty vehicle fuel. [8] The share of Canadian gasoline energy supplied by ethanol was set equal to that for the U.S., while the share of gasoline energy supplied by ethanol was set to zero throughout the forecast period for Mexico and the rest of Latin America.

Tables 11 through 13 show the percentage of ethanol energy that is derived from grain, low-GHG sugar cane, and low-GHG cellulosic (or other) processes respectively.[9] Data for 2006-2030 for the U.S. is derived from U.S. EIA data, while regression analysis of the 2006-2030 data was used to estimate data for 2031-2050. [14] The energy distribution of Brazilian ethanol for 2000-2050 was calculated from data on the forecasted distribution of Brazilian light duty vehicle fuel. [8] The energy distribution of Canadian ethanol was set equal to that for the U.S., while the ethanol energy distributions for Mexico and the rest of Latin America were set equal to that for Brazil (although for practical purposes the distributions in Mexico and the rest of Latin America are irrelevant since neither is assumed to distribute ethanol throughout the forecast period).

Table 14 shows the share of the diesel energy pool that is assumed to be derived from biodiesel. The share of U.S. diesel energy supplied by biodiesel for 2006-2030 is calculated from data reported by the U.S. EIA. [13,14] Data for 2031-2050 were estimated through regression analysis of the 2006-2030 data. The share of Brazilian diesel energy supplied by biodiesel for 2000-2050 was calculated from data on the forecasted distribution of Brazilian light duty vehicle fuel. [8] The share of Canadian diesel energy supplied by biodiesel was set equal to that for the U.S., while the share of diesel energy supplied by biodiesel was set to zero throughout the forecast period for Mexico and the rest of Latin America.

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[9] It is certainly possible to envision differing ethanol production pathways and volumes under the locally and globally driven futures. The tabulated data essentially represent the assumptions for a locally driven future as they are based on locally derived forecasts that reflect existing responses to local energy security concerns. While increased ethanol volumes and shifts toward lower GHG production pathways might be expected under a globally driven future, the ICCT believes that such a transition would be far overshadowed by the much larger benefits to be derived through an alternative transition to electric or fuel cell vehicles. Thus, it is assumed that ethanol production is unaffected and global efforts are targeted at electric and/or fuel cell vehicles.

Table 10. Share of “Gasoline” Energy that is Ethanol

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	1.4%	3.5%	6.4%	7.3%	9.7%	11.3%	13.4%	15.7%	17.7%	19.8%	21.8%
Canada	1.4%	3.5%	6.4%	7.3%	9.7%	11.3%	13.4%	15.7%	17.7%	19.8%	21.8%
Mexico	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Brazil	30.9%	34.5%	47.2%	62.0%	67.9%	69.4%	69.6%	69.6%	69.6%	69.7%	69.7%
RoLA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 11. Share of Ethanol Energy Derived from Grain Processing

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	100.0%	100.0%	99.8%	98.6%	87.8%	75.9%	72.2%	70.5%	67.6%	64.6%	61.6%
Canada	100.0%	100.0%	99.8%	98.6%	87.8%	75.9%	72.2%	70.5%	67.6%	64.6%	61.6%
Mexico	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Brazil	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RoLA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 12. Share of Ethanol Energy Derived from Low-GHG Sugar Cane Processing

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Canada	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mexico	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Brazil	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
RoLA	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 13 Share of Ethanol Energy Derived from Low-GHG Cellulosic Processing

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0.0%	0.0%	0.2%	1.4%	12.2%	24.1%	27.8%	29.5%	32.4%	35.4%	38.4%
Canada	0.0%	0.0%	0.2%	1.4%	12.2%	24.1%	27.8%	29.5%	32.4%	35.4%	38.4%
Mexico	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Brazil	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RoLA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 14. Share of “Diesel” Energy that is Biodiesel

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0.0%	0.0%	1.7%	4.2%	5.8%	9.6%	11.1%	13.7%	16.0%	18.4%	20.7%
Canada	0.0%	0.0%	1.7%	4.2%	5.8%	9.6%	11.1%	13.7%	16.0%	18.4%	20.7%
Mexico	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Brazil	0.0%	0.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
RoLA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Tables 15 and 16 show the percentage of biodiesel energy that is derived from FAME and low-GHG processes respectively. Data for 2006-2030 for the U.S. is derived from U.S. EIA data, while regression analysis of the 2006-2030 data was used to estimate data for 2031-2050. [14] The energy distribution of Brazilian biodiesel for 2000-2050 was calculated from data on the forecasted distribution of Brazilian light duty vehicle fuel. [8] The energy distribution of Canadian biodiesel was set equal to that for the U.S., while the biodiesel energy distributions for Mexico and the rest of Latin America were set equal to that for Brazil (although for practical purposes the distributions in Mexico and the rest of Latin America are irrelevant since neither is assumed to distribute biodiesel throughout the forecast period).

Table 17 shows the share of hydrogen fuel energy that is derived from low-GHG processes for a globally-driven future, the remainder of which is assumed to be derived from natural gas reforming. [3] These data assume the imposition of an effective carbon tax (or equivalent). Table 18 shows the corresponding share of low-GHG process hydrogen energy for a locally-driven future. [3] These data assume that no effective carbon tax (or equivalent) is in place. Data for all other modeling areas are set equal to the U.S. under the assumption that a hydrogen vehicle market will go global if viable (analogous to the current gasoline/diesel vehicle market).

Based on the same assumptions with regard to an effective carbon tax (or equivalent) for a globally-driven future and no effective carbon tax (or equivalent) for a locally-driven future, Tables 19 and 20 show the share of electrical energy that is derived from low-GHG processes in the globally-driven and locally-driven futures respectively. The share of transportation electricity from low-GHG sources is set equal to the low-GHG hydrogen energy share due to similar production economics. The balance of electrical energy is assumed to be derived from processes equivalent to current average electrical power generation conditions. Finally, Table 21 shows the assumed CO_2 emission rate for current average electrical power generation conditions (based on the U.S. national average for 2009). [15,16,17] As with hydrogen, data for all other modeling areas are set equal to the U.S. average emission rate of 6.129 kilograms of CO_2 per liter gasoline equivalent (kg/litge) under the assumption that an electric vehicle market will go global if viable (analogous to the current gasoline/diesel vehicle market). Although CO_2 emission rates for electrical production currently vary across the five modeling areas, it is assumed that any marginal generating capacity required to satisfy an emergent transportation sector demand will be similar to marginal generation in the U.S., so that the average U.S. emission rate is applied without variation across the five modeling areas.[10] It is also important to note that the ICCT did not alter the fuel-specific CO_2 emission rates for any other fuels from the values included in the baseline SMP model.

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[10] This is not dissimilar to the assumption in the baseline SMP model that the average CO_2 emission rate for electrical generation in all regions covered by the model is equal to the average emission rate for the European Union. The ICCT effectively switched the EU emission rate to that for the U.S. For comparative purposes, the emission rate in the baseline SMP model was 4.495 kgCO_2/litge versus an ICCT-estimated emission rate of 6.129 kgCO_2/litge based on U.S. average data.

Table 15. Share of Biodiesel Energy Derived from FAME Processing

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	100.0%	100.0%	98.3%	78.5%	54.3%	33.0%	27.1%	23.2%	19.5%	15.8%	12.1%
Canada	100.0%	100.0%	98.3%	78.5%	54.3%	33.0%	27.1%	23.2%	19.5%	15.8%	12.1%
Mexico	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Brazil	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
RoLA	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 16. Share of Biodiesel Energy Derived from Low-GHG Processing

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0.0%	0.0%	1.7%	21.5%	45.7%	67.0%	72.9%	76.8%	80.5%	84.2%	87.9%
Canada	0.0%	0.0%	1.7%	21.5%	45.7%	67.0%	72.9%	76.8%	80.5%	84.2%	87.9%
Mexico	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Brazil	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RoLA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 17. Share of H_2 Energy Derived from Low-GHG Processing -- Global Future

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	41.7%	53.8%	73.3%	82.3%	88.2%
Canada	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	41.7%	53.8%	73.3%	82.3%	88.2%
Mexico	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	41.7%	53.8%	73.3%	82.3%	88.2%
Brazil	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	41.7%	53.8%	73.3%	82.3%	88.2%
RoLA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	41.7%	53.8%	73.3%	82.3%	88.2%

Table 18. Share of H_2 Energy Derived from Low-GHG Processing -- Local Future

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Canada	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mexico	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Brazil	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RoLA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 19. Share of Electrical Energy from Low-GHG Processing -- Global Future

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	41.7%	53.8%	73.3%	82.3%	88.2%
Canada	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	41.7%	53.8%	73.3%	82.3%	88.2%
Mexico	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	41.7%	53.8%	73.3%	82.3%	88.2%
Brazil	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	41.7%	53.8%	73.3%	82.3%	88.2%
RoLA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	41.7%	53.8%	73.3%	82.3%	88.2%

Table 20. Share of Electrical Energy from Low-GHG Processing -- Local Future

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Canada	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mexico	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Brazil	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RoLA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 21. Electrical Generation CO_2 Under Current Conditions (kg/litge consumed)

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	6.129	6.129	6.129	6.129	6.129	6.129	6.129	6.129	6.129	6.129	6.129
Canada	6.129	6.129	6.129	6.129	6.129	6.129	6.129	6.129	6.129	6.129	6.129
Mexico	6.129	6.129	6.129	6.129	6.129	6.129	6.129	6.129	6.129	6.129	6.129
Brazil	6.129	6.129	6.129	6.129	6.129	6.129	6.129	6.129	6.129	6.129	6.129
RoLA	6.129	6.129	6.129	6.129	6.129	6.129	6.129	6.129	6.129	6.129	6.129

6. Medium Duty Truck Fuel and Carbon Intensity Parameters

The SMP model structure for medium duty trucks (MDTs) is less robust than the model structure for light duty vehicles. Unlike the light duty vehicle structure, the MDT structure includes no algorithms to address vehicle sales or retirement. As a result, the impact of sales and retirement on the rate at which new or alternative vehicle technologies penetrate the overall MDT market must be estimated “offline” (outside the model). The MDT structure allocates overall MDT activity (expressed in tonne-kilometers) into conventional gasoline, conventional diesel, gasoline hybrid-electric, diesel hybrid-electric and fuel cell (FC) vehicle components. Electric-only vehicles are notably absent from the SMP model structures for road vehicles, but the ICCT does not believe this to be a significant issue for this work due to the fact that, as described in Section 3 above, the CO_2 emission rates for BEVs are expected to be similar to those for fuel cell vehicles (FCVs). Therefore, although the ICCT uses the SMP model FCV structures as surrogates for both FCVs and BEVs, it is expected that estimated emissions under either the globally or locally driven scenario will be reasonably similar for either a BEV or FCV future.

6.1 Fuel Consumption Ratios of MDT Technology Types

The SMP model estimates the fuel intensity of specific MDT types through the ratio of fuel consumption for each MDT type to fuel consumption for a corresponding conventional diesel MDT. As described above, the model’s MDT structure specifically treats five MDT types: conventional gasoline, conventional diesel, gasoline HEV, diesel HEV, and fuel cell MDTs. For this study, diesel HEVs and gasoline HEVs are treated in combination with conventional diesel and conventional gasoline vehicles respectively, so that the fuel consumption impacts of HEV technology penetration are simply reflected through an inherent impact on “conventional” vehicle fuel intensity. Table 22 shows the fuel consumption relationships assumed by the ICCT for this study. [3,4,19,20,21] Since these relationships are technology-based, they are assumed to apply without variation in all geographic areas.

Two specific issues should be noted with regard to the presented data. First, the SMP model fuel intensity structure for MDTs is based on energy consumption rates rather than fuel consumption per se. The model relies on input fuel consumption in units of energy (megajoules) per tonne-kilometer of travel. Thus, while gasoline fuel consumption per se (i.e., fuel volume per unit travel) is generally on the order of 20 percent higher than diesel (and, in fact, the gasoline fuel consumption ratio for MDTs in the baseline SMP model is 1.2), unit *energy* consumption is actually only about 10 percent higher since diesel fuel contains about 10 percent more energy per unit volume than gasoline. [1,21] Thus, the ICCT has modified the baseline SMP model fuel consumption ratio for gasoline MDTs as indicated in Table 22. The ICCT has also modified the baseline SMP model fuel consumption ratio for fuel cell MDTs (from 0.6 to 0.5). As discussed above in Section 3.2, the ICCT assumed a 50 percent fuel consumption reduction for fuel cell light duty vehicles. Available literature on heavy duty fuel cell trucks indicates a similar fuel consumption reduction. [19,20] Since MDTs fall between these two vehicle classes, the ICCT has assumed a similar 50 percent fuel consumption benefit for fuel cell MDTs.

Table 22. Fuel Consumption Ratios of MDT Technology Types

Technology	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Gasoline	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100
Diesel	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
H2 Fuel Cell	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500

6.2 MDT Fuel Intensity

The SMP model estimates the fuel intensity of specific MDT types through the ratio of fuel consumption for each MDT type to fuel consumption for a corresponding conventional diesel MDT. While the ratios for modeled vehicle types are presented above in Table 22, the fleetwide fuel consumption for conventional diesel vehicles (to which the ratios in Table 22 are applied) is presented in Table 23. As discussed above, the model's MDT structure specifically treats five MDT types: conventional gasoline, conventional diesel, gasoline HEV, diesel HEV, and fuel cell MDTs. However, for this study, diesel HEVs and gasoline HEVs are treated in combination with conventional diesel and conventional gasoline vehicles respectively, so that an increasing penetration of HEV technology is simply reflected through its impact on "conventional" vehicle fuel intensity. In effect, "conventional" vehicles reflect both conventional and HEV technology and the HEV-specific components of the model's MDT structure are ignored, effectively "simplifying" the MDT modeling structure to three technology types: diesel, gasoline, and fuel cell MDTs.[11] It is also important to recognize that, as described in Section 6.1 above, the model

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[11] To conform to this modeling standard, activity shares for hybrid-electric vehicles, as discussed in Section 6.3 below, are set to zero throughout the modeling period.

Table 23. Fuel Consumption for Diesel (Including HEV) MDTs (MJ/tonne-km)

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	5.167	5.167	5.167	3.545	3.003	2.760	2.756	2.756	2.756	2.756	2.756
Canada	5.167	5.167	5.167	3.545	3.003	2.760	2.756	2.756	2.756	2.756	2.756
Mexico	5.167	5.167	5.167	3.545	3.003	2.760	2.756	2.756	2.756	2.756	2.756
Brazil	5.421	5.421	5.421	3.719	3.150	2.895	2.891	2.891	2.891	2.891	2.891
RoLA	5.421	5.421	5.421	3.719	3.150	2.895	2.891	2.891	2.891	2.891	2.891

treats MDT fuel consumption in terms of energy (as opposed to fuel volume) consumed per unit tonne-kilometer traveled.

Baseline (year 2000, 2005, and 2010) MDT fuel intensity for the U.S. was set at reported historic values. [22] For Brazil, reported baseline fuel intensity data (14.9 lit/100km, 15.8 mpg) were considered but rejected as unreasonable, so that baseline data for Brazil were set to the values reported in the baseline SMP model for Latin America in the year 2000 (23.8 lit/100km, 9.9 mpg). [1,8] Canada and Mexico are assumed to have U.S.-equivalent baseline fuel intensity, while the rest of Latin America is assumed to have Brazil-equivalent baseline fuel intensity.

Future fuel intensity for conventional MDTs (including HEV technology as described above) was estimated through a two-step process. In step one, base fuel consumption reduction *potential* was set at levels expected by the U.S. Department of Energy through 2050; 31.0 percent for diesel MDT and 30.6 percent for gasoline MDT. [18] Step two consisted of an expansion of the step one fuel consumption improvement potentials for consistency with detailed simulation modeling on advanced HDT technology. [23] The U.S. Department of Energy reference materials used to set the step one fuel consumption improvement potential for MDTs, also included a corresponding fuel consumption improvement potential estimate of 35.5 percent for combination (tractor and trailer) HDTs. For this same vehicle configuration, the simulation modeling results predicted a 50.1 percent improvement potential.[12] The ICCT used the resulting ratio, (1-0.501)/(1-0.355) or 0.774, to adjust the step one improvement potentials for MDTs to 46.6 percent and 46.3 percent for conventional diesel and conventional gasoline MDTs respectively.[13] The aggregate MDT fuel consumption improvement potential for conventional vehicles (including HEV technology) was estimated by weighting the diesel and gasoline improvement potentials by their corresponding fuel use fractions (73 percent diesel, 27 percent gasoline). [18]

Additionally, the detailed simulation model used to adjust the baseline Department of Energy fuel consumption improvement estimates indicates that such improvements are achievable in the

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[12] The simulation modeling fuel consumption improvement potential for a combination HDT was taken as the average of reported "package 14" impacts. [23]

[13] The specific adjustment for diesel is (1-0.310)×0.774=0.534, for a net improvement of 0.534-1, or 46.6 percent. Similarly, the adjustment for gasoline is (1-0.306)×0.774=0.537, for a net improvement of 0.537-1, or 46.3 percent. Actual calculations are performed to a greater level of precision, so minor round off errors may exist between the values presented in this report and the actual values used in modeling calculations.

2012-2017 timeframe. As a result, the improvement estimates are applied to all post-2010 MDT sales. Of course, this assumes the near term imposition of stringent fuel efficiency standards for MDTs to drive this improvement. While delays in the imposition of such standards might delay the introduction of such vehicles by several years, it is likely to have little impact on emissions after 2030 (although the tabulated efficiency estimates for 2015 through 2030 are less certain and more dependent on the timely near term imposition of standards).

Unfortunately, the SMP model does not include a fleet turnover algorithm for MDTs, so the effect of new vehicle fuel consumption improvement on the overall MDT fleet in any given year was estimated “offline” (i.e., outside the model). To perform the necessary analysis, the median *mileage weighted* age for Class 3 through 6 trucks was calculated (4.8 years) and a crude estimate of MDT turnover per year was calculated as one over twice the median age (which, for MDTs, evaluates to 1/[2×4.78], or 10.5 percent turnover per year). [21] As indicated above, the ICCT estimate of fleetwide MDT impacts is based on the fraction of the MDT fleet that is pre-2010 achieving 2000 era (i.e., baseline) fuel intensity levels and the fraction of the fleet that is post-2010 achieving improved fuel intensity levels. Weighting these two fleet fractions together produces the fleetwide fuel intensity estimates presented in Table 23. As with the baseline fuel intensity estimates, Canada and Mexico are assumed to have U.S.-equivalent future fuel intensities, while the rest of Latin America is assumed to have Brazil-equivalent future fuel intensities. As was the case for light duty vehicles, no technology lag is assumed for what are essentially “conventional” vehicle technologies, and this implies that all five geographic areas are either setting stringent standards that take effect in the 2010 to 2015 timeframe, or achieving equivalent impacts due to such adoption in neighboring areas

Finally, it is important to note that in performing the fuel intensity calculations, estimated volumetric fuel consumption estimates per unit travel were converted to equivalent energy per unit tonne-kilometer metrics, as required by the SMP model structure for MDTs, using MDT activity (both tonne-kilometers and kilometers traveled) estimates for North America and Latin America, as well as diesel fuel energy content taken from the baseline SMP model. [1]

6.3 MDT Tonne-Kilometer Shares by Technology Type

The ICCT estimates for the share of MDT tonne-kilometers by technology type are presented in Tables 24 through 26. The forecast is assumed to be independent of whether the future is globally or locally driven. Since the vehicle production market is global under current conditions, it is difficult to envision a scenario in which that global market will constrict to consider only local interests. The ICCT views local energy security issues as more than sufficient to continue driving vehicle fuel efficiency demands under both globally or locally driven futures. For this reason, vehicle technology shares are unchanged under the two alternative futures. It is critical to recognize, however, that this does not mean that CO_2 emissions are unchanged since, as described in Section 5 above, fuel production pathways (and associated carbon emissions) vary considerably under the two alternative futures.

The ICCT estimated the fuel cell MDT activity share using the same technology penetration rates used to estimate light duty vehicle fuel cell sales, as described in Section 3 above. [2,3] While the penetration rates were developed for the light duty vehicle market, they essentially reflect the

Table 24. Share of MDT Activity Accumulated by Diesel ICEs (Including HEVs)

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	72.0%	72.0%	72.0%	72.0%	71.9%	71.1%	66.1%	54.9%	40.9%	28.6%	19.6%
Canada	72.0%	72.0%	72.0%	72.0%	71.9%	71.1%	66.1%	54.9%	40.9%	28.6%	19.6%
Mexico	72.0%	72.0%	72.0%	72.0%	72.0%	71.9%	71.1%	66.1%	54.9%	40.9%	28.6%
Brazil	73.0%	73.0%	73.0%	73.0%	73.0%	72.9%	72.0%	67.0%	55.6%	41.5%	29.0%
RoLA	73.0%	73.0%	73.0%	73.0%	73.0%	73.0%	72.9%	72.0%	67.0%	55.6%	41.5%

Table 25. Share of MDT Activity Accumulated by Gasoline ICEs (Including HEVs)

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	28.0%	28.0%	28.0%	28.0%	28.0%	27.6%	25.7%	21.3%	15.9%	11.1%	7.6%
Canada	28.0%	28.0%	28.0%	28.0%	28.0%	27.6%	25.7%	21.3%	15.9%	11.1%	7.6%
Mexico	28.0%	28.0%	28.0%	28.0%	28.0%	28.0%	27.6%	25.7%	21.3%	15.9%	11.1%
Brazil	27.0%	27.0%	27.0%	27.0%	27.0%	27.0%	26.6%	24.8%	20.6%	15.3%	10.7%
RoLA	27.0%	27.0%	27.0%	27.0%	27.0%	27.0%	27.0%	26.6%	24.8%	20.6%	15.3%

Table 26. Share of MDT Activity Accumulated by Hydrogen Fuel Cell Vehicles

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0.0%	0.0%	0.0%	0.0%	0.1%	1.3%	8.2%	23.8%	43.2%	60.3%	72.7%
Canada	0.0%	0.0%	0.0%	0.0%	0.1%	1.3%	8.2%	23.8%	43.2%	60.3%	72.7%
Mexico	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	1.3%	8.2%	23.8%	43.2%	60.3%
Brazil	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	1.3%	8.2%	23.8%	43.2%	60.3%
RoLA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	1.3%	8.2%	23.8%	43.2%

market penetration that would be expected once fuel cell vehicles become cost effective and the barriers to market introduction are removed (assuming that fuel cell vehicles can provide equivalent performance). Since it is expected that fuel cell vehicles can perform as well (or better) from a power and torque perspective than conventional gasoline and diesel engines, and since the policy measures necessary to overcome market barriers and promote technology cost effectiveness are assumed to be in place under both the globally and locally driven futures, it is also assumed that the market penetration curves *for new vehicles* will be similar across vehicle classes for which such assumptions are reasonable.

Since the assumed policy measures are expected to result in the market introduction of fuel cell vehicles beginning in the 2020 timeframe, the ICCT undertook the same approach described in Section 6.2 above to convert new fuel cell vehicle sales shares into an estimate of the fraction of the overall MDT fleet that would be displaced by fuel cell vehicles in each forecast year. Essentially this involves an estimate of the median MDT age, an associated MDT turnover rate, and tracking the increasing sales of fuel cell MDT's over time through the end of the forecast period in 2050. As with other vehicle technologies, the ICCT assumes a global vehicle market regardless of whether the future is globally or locally driven. However, the ICCT does assume a technology lag time for fuel cell MDT's in Mexico, Brazil, and the rest of Latin America (no lag is assumed for Canada). For Mexico and Brazil, the ICCT assumes a five year market lag, while the lag for the rest of Latin America is assumed to be ten years. The resulting estimates of fleetwide fuel cell vehicle shares are shown in Table 26.

The fraction of the fleet that is not utilizing fuel cell technology is split between diesel and gasoline technology (including diesel and gasoline HEV technology), based on baseline diesel and gasoline activity shares. Shares in the U.S., Canada, and Mexico are assumed to be consistent with MDT mileage shares reported by the U.S. Department of Energy (72 percent diesel, 28 percent gasoline). [18] Shares in Brazil and the rest of Latin America are based on the activity shares reported in the baseline SMP model for Latin America (73 percent diesel, 27 percent gasoline). [1] The resulting diesel and gasoline MDT activity shares are shown in Tables 24 and 25 respectively.

7. Heavy Duty Truck Fuel and Carbon Intensity Parameters

The SMP model structure for heavy duty trucks (HDTs) is less robust than the model structure for light duty vehicles. Unlike the light duty vehicle structure, the HDT structure includes no algorithms to address vehicle sales or retirement. As a result, the impact of sales and retirement on the rate at which new or alternative vehicle technologies penetrate the overall HDT market must be estimated "offline" (outside the model). The HDT structure allocates overall HDT activity (expressed in tonne-kilometers) into conventional gasoline, conventional diesel, gasoline hybrid-electric, diesel hybrid-electric and fuel cell (FC) vehicle components. Electric-only vehicles are notably absent from the SMP model structures for road vehicles, but the ICCT does not believe this to be a significant issue for this work due to the fact that, as described in Section 3 above, the CO_2 emission rates for BEVs are expected to be similar to those for fuel cell vehicles (FCVs). Therefore, although the ICCT uses the SMP model FCV structures as surrogates for both FCVs and BEVs, it is expected that estimated emissions under either the globally or locally driven scenario will be reasonably similar for either a BEV or FCV future.

7.1 Fuel Consumption Ratios of HDT Technology Types

The SMP model estimates the fuel intensity of specific HDT types through the ratio of fuel consumption for each HDT type to fuel consumption for a corresponding conventional diesel HDT. As described above, the model's HDT structure specifically treats five HDT types: conventional gasoline, conventional diesel, gasoline HEV, diesel HEV, and fuel cell HDTs. For this study, diesel HEVs and gasoline HEVs are treated in combination with conventional diesel and conventional gasoline vehicles respectively, so that the fuel consumption impacts of HEV technology penetration are simply reflected through an inherent impact on "conventional" vehicle fuel intensity. Table 27 shows the fuel consumption relationships assumed by the ICCT for this study. [3,4,19,20,21] Since these relationships are technology-based, they are assumed to apply without variation in all geographic areas.

Two specific issues should be noted with regard to the presented data. First, the SMP model fuel intensity structure for HDTs is based on energy consumption rates rather than fuel consumption per se. The model relies on input fuel consumption in units of energy (megajoules) per

Table 27. Fuel Consumption Ratios of HDT Technology Types

Technology	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Gasoline	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600
Diesel	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
H2 Fuel Cell	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500

tonne-kilometer of travel. Thus, while gasoline fuel consumption per se (i.e., fuel volume per unit travel) is generally on the order of 20 percent higher than diesel (and, in fact, the gasoline fuel consumption ratio for HDTs in the baseline SMP model is 1.2), unit *energy* consumption is actually only about 10 percent higher since diesel fuel contains about 10 percent more energy per unit volume than gasoline. [1,21] However, unlike the medium duty truck sector, which is populated with gasoline and diesel vehicles of similar size and weight, the few gasoline vehicles that populate the heavy duty truck sector tend to be much smaller than their diesel counterparts. Due to the economies of scale associated with freight movement (tonne-kilometers) in larger HDTs, the actual energy use of gasoline trucks per unit freight movement in the HDT sector tends to be nearly 60 percent higher than diesel HDT freight movement. [21] Thus, the ICCT has modified the baseline SMP model fuel consumption ratio for gasoline HDTs as indicated in Table 27.[14] The ICCT has also modified the baseline SMP model fuel consumption ratio for fuel cell HDTs (from 0.6 to 0.5), as available literature on heavy duty fuel cell trucks indicates an approximate 50 percent reduction in fuel consumption relative to a conventional HDT. [19,20]

7.2 HDT Fuel Intensity

The SMP model estimates the fuel intensity of specific HDT types through the ratio of fuel consumption for each HDT type to fuel consumption for a corresponding conventional diesel HDT. While the ratios for modeled vehicle types are presented above in Table 27, the fleetwide fuel consumption for conventional diesel vehicles (to which the ratios in Table 27 are applied) is presented in Table 28. As discussed above, the model's HDT structure specifically treats five HDT types: conventional gasoline, conventional diesel, gasoline HEV, diesel HEV, and fuel cell HDTs. However, for this study, diesel HEVs and gasoline HEVs are treated in combination with conventional diesel and conventional gasoline vehicles respectively, so that an increasing penetration of HEV technology is simply reflected through an impact on "conventional" vehicle fuel intensity. In effect, "conventional" vehicles reflect both conventional and HEV technology and the HEV-specific components of the model's HDT structure are ignored, effectively "simplifying" the HDT modeling structure to three technology types: diesel, gasoline, and fuel cell HDTs.[15] It is also important to recognize that, as described in Section 7.1 above, the model treats HDT fuel consumption in terms of energy (as opposed to fuel volume) consumed per unit tonne-kilometer traveled.

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[14] In reality, this adjustment for gasoline HDTs is entirely academic since gasoline HDTs are responsible for less than one percent of tonne-kilometers of travel in the sector. In fact, gasoline HDT activity shares are set to zero in this study based on fuel use data for both the U.S. and Brazil. [8,18]

[15] To conform to this modeling standard, activity shares for hybrid-electric vehicles, as discussed in Section 7.3 below, are set to zero throughout the modeling period.

Table 28. Fuel Consumption for Diesel (Including HEV) HDTs (MJ/tonne-km)

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	1.568	1.568	1.568	1.018	0.850	0.786	0.786	0.786	0.786	0.786	0.786
Canada	1.568	1.568	1.568	1.018	0.850	0.786	0.786	0.786	0.786	0.786	0.786
Mexico	1.568	1.568	1.568	1.018	0.850	0.786	0.786	0.786	0.786	0.786	0.786
Brazil	2.135	2.135	2.135	1.386	1.158	1.070	1.070	1.070	1.070	1.070	1.070
RoLA	2.135	2.135	2.135	1.386	1.158	1.070	1.070	1.070	1.070	1.070	1.070

Baseline (year 2000, 2005, and 2010) HDT fuel intensity for the U.S. and Brazil was set at reported historic values. [8,22] Canada and Mexico are assumed to have U.S.-equivalent baseline fuel intensity, while the rest of Latin America is assumed to have Brazil-equivalent baseline fuel intensity.

Future fuel intensity for conventional HDTs (including HEV technology as described above) was estimated through a two-step process. In step one, base fuel consumption reduction *potential* was set at levels expected by the U.S. Department of Energy through 2050; 35.5 percent for diesel combination (tractor and trailer) HDT and 33.3 percent for diesel single unit HDT. [18] Step two consisted of an expansion of the step one fuel consumption improvement potentials for consistency with detailed simulation modeling on advanced HDT technology. [23] For combination (tractor and trailer) HDTs, the simulation modeling results predicted a 50.1 percent improvement potential.[16] The ICCT used the resulting ratio, (1-0.501)/(1-0.355) or 0.774, to adjust the step one improvement potentials for HDTs to 50.1 percent and 48.4 percent for combination and single unit HDTs respectively.[17] The aggregate HDT fuel consumption improvement potential for conventional vehicles (including HEV technology) was estimated by weighting the combination and single unit improvement potentials by their corresponding fuel use fractions (84.7 percent combination unit, 15.3 percent single unit). [18]

Additionally, the detailed simulation model used to adjust the baseline Department of Energy fuel consumption improvement estimates indicates that such improvements are achievable in the 2012-2017 timeframe. As a result, the improvement estimates are applied to all post-2010 HDT sales. Of course, this assumes the near term imposition of stringent fuel efficiency standards for HDTs to drive this improvement. While delays in the imposition of such standards might delay the introduction of such vehicles by several years, it is likely to have little impact on emissions after 2030 (although the tabulated efficiency estimates for 2015 through 2030 are less certain and more dependent on the timely near term imposition of standards).

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[16] The simulation modeling fuel consumption improvement potential for a combination HDT was taken as the average of reported “package 14” impacts. [23]

[17] The specific adjustment for combination HDTs is (1-0.355)×0.774=0.499, for a net improvement of 0.499-1, or 50.1 percent. Similarly, the adjustment for single unit HDTs is (1-0.333)×0.774=0.516, for a net improvement of 0.516-1, or 48.4 percent. Actual calculations are performed to a greater level of precision, so minor round off errors may exist between the values presented in this report and the actual values used in modeling calculations.

Unfortunately, the SMP model does not include a fleet turnover algorithm for HDTs, so the effect of new vehicle fuel consumption improvement on the overall HDT fleet in any given year was estimated "offline" (i.e., outside the model). To perform the necessary analysis, the median *mileage weighted* age for Class 7 and 8 trucks was calculated (4.6 years) and a crude estimate of HDT turnover per year was calculated as one over twice the median age (which, for HDTs, evaluates to 1/[2×4.6], or 10.9 percent turnover per year). [21] As indicated above, the ICCT estimate of fleetwide HDT impacts is based on the fraction of the HDT fleet that is pre-2010 achieving 2000 era (i.e., baseline) fuel intensity levels and the fraction of the fleet that is post-2010 achieving improved fuel intensity levels. Weighting these two fleet fractions together produces the fleetwide fuel intensity estimates presented in Table 28. As with the baseline fuel intensity estimates, Canada and Mexico are assumed to have U.S.-equivalent future fuel intensities, while the rest of Latin America is assumed to have Brazil-equivalent future fuel intensities. As was the case for light and medium duty vehicles, no technology lag is assumed for what are essentially "conventional" vehicle technologies, and this implies that all five geographic areas are either setting stringent standards that take effect in the 2010 to 2015 timeframe, or achieving equivalent impacts due to such adoption in neighboring areas

Finally, it is important to note that in performing the fuel intensity calculations, estimated volumetric fuel consumption estimates per unit travel were converted to equivalent energy per unit tonne-kilometer metrics, as required by the SMP model structure for HDTs, using HDT activity (both tonne-kilometers and kilometers traveled) estimates for North America and Latin America, as well as diesel fuel energy content taken from the baseline SMP model. [1]

7.3 HDT Tonne-Kilometer Shares by Technology Type

The ICCT estimates for the share of HDT tonne-kilometers by technology type are summarized in Tables 29 through 31. The forecast is assumed to be independent of whether the future is globally or locally driven. Since the vehicle production market is global under current conditions, it is difficult to envision a scenario in which that global market will constrict to consider only local interests. The ICCT views local energy security issues as more than sufficient to continue driving vehicle fuel efficiency demands under both globally or locally driven futures. For this reason, vehicle technology shares are unchanged under the two alternative futures. It is critical to recognize, however, that this does not mean that CO_2 emissions are unchanged since, as described in Section 5 above, fuel production pathways (and associated carbon emissions) vary considerably under the two alternative futures.

The ICCT estimated the fuel cell HDT activity share using the same technology penetration rates used to estimate light duty vehicle fuel cell sales, as described in Section 3 above. [2,3] While the penetration rates were developed for the light duty vehicle market, they essentially reflect the market penetration that would be expected once fuel cell vehicles become cost effective and the barriers to market introduction are removed (assuming that fuel cell vehicles can provide equivalent performance). Since it is expected that fuel cell vehicles can perform as well (or better) from a power and torque perspective than conventional gasoline and diesel engines, and since the policy measures necessary to overcome market barriers and promote technology cost effectiveness are assumed to be in place under both the globally and locally driven futures, it is

Table 29. Share of HDT Activity Accumulated by Diesel ICEs (Including HEVs)

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	100.0%	100.0%	100.0%	100.0%	99.9%	98.7%	91.6%	75.6%	55.8%	38.7%	26.3%
Canada	100.0%	100.0%	100.0%	100.0%	99.9%	98.7%	91.6%	75.6%	55.8%	38.7%	26.3%
Mexico	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	98.7%	91.6%	75.6%	55.8%	38.7%
Brazil	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	98.7%	91.6%	75.6%	55.8%	38.7%
RoLA	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	98.7%	91.6%	75.6%	55.8%

Table 30. Share of HDT Activity Accumulated by Gasoline ICEs (Including HEVs)

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Canada	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mexico	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Brazil	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RoLA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 31. Share of HDT Activity Accumulated by Hydrogen Fuel Cell Vehicles

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0.0%	0.0%	0.0%	0.0%	0.1%	1.3%	8.4%	24.4%	44.2%	61.3%	73.7%
Canada	0.0%	0.0%	0.0%	0.0%	0.1%	1.3%	8.4%	24.4%	44.2%	61.3%	73.7%
Mexico	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	1.3%	8.4%	24.4%	44.2%	61.3%
Brazil	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	1.3%	8.4%	24.4%	44.2%	61.3%
RoLA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	1.3%	8.4%	24.4%	44.2%

assumed that the market penetration curves *for new vehicles* will be similar across vehicle classes for which such assumptions are reasonable.

Since the assumed policy measures are expected to result in the market introduction of fuel cell vehicles beginning in the 2020 timeframe, the ICCT undertook the same approach described in Section 7.2 above to convert new fuel cell vehicle sales shares into an estimate of the fraction of the overall HDT fleet that would be displaced by fuel cell vehicles in each forecast year. Essentially this involves an estimate of the median HDT age, an associated HDT turnover rate, and tracking the increasing sales of fuel cell HDTs over time through the end of the forecast period in 2050. As with other vehicle technologies, the ICCT assumes a global vehicle market regardless of whether the future is globally or locally driven. However, the ICCT does assume a technology lag time for fuel cell HDTs in Mexico, Brazil, and the rest of Latin America (no lag is assumed for Canada). For Mexico and Brazil, the ICCT assumes a five year market lag, while the lag for the rest of Latin America is assumed to be ten years. The resulting estimates of fleetwide fuel cell vehicle shares are shown in Table 31.

The fraction of the fleet that is not utilizing fuel cell technology is split between diesel and gasoline technology (including diesel and gasoline HEV technology) based on baseline diesel and gasoline activity shares. Shares in the U.S., Canada, and Mexico are assumed to be consistent with HDT mileage shares reported by the U.S. Department of Energy (100 percent diesel, zero percent gasoline). [18] Shares in Brazil are based on reported HDT technology shares (100 percent diesel, zero percent gasoline). [8] Shares for the rest of Latin America are assumed to equal those of Brazil. The resulting diesel and gasoline HDT activity shares are shown in Tables 29 and 30 respectively.

8. Bus Fuel and Carbon Intensity Parameters

The SMP model structure for buses is less robust than the model structure for light duty vehicles. Unlike the light duty vehicle structure, the bus structure includes no algorithms to address vehicle sales or retirement. As a result, the impact of sales and retirement on the rate at which new or alternative vehicle technologies penetrate the overall bus market must be estimated "offline" (outside the model). The bus structure allocates overall energy use into gasoline, diesel, and fuel cell (FC) vehicle components. Electric-only vehicles are notably absent from the SMP model structures for road vehicles, but the ICCT does not believe this to be a significant issue for this work due to the fact that, as described in Section 3 above, the CO_2 emission rates for BEVs are expected to be similar to those for fuel cell vehicles (FCVs). Therefore, although the ICCT uses the SMP model FCV structures as surrogates for both FCVs and BEVs, it is expected that estimated emissions under either the globally or locally driven scenario will be reasonably similar for either a BEV or FCV future.

It is also important to note that the SMP model has a separate modeling structure for minibuses.[18] As a result, minibuses are not included in the bus modeling and are treated separately as discussed in Section 9 below.

8.1 Bus Fuel Intensity

The SMP model structure for buses is somewhat different than that for light, medium, and heavy duty vehicles wherein the model assigns a "base" fuel intensity to one specific vehicle type (e.g., conventional diesel vehicles in the case of heavy duty trucks) and then estimates the fuel intensity for other vehicle types using defined fuel consumption ratios. In contrast, the bus structure of the model is based on a single "net" fuel intensity that reflects the combined fuel intensities of all component bus technologies. In effect, the fuel intensity of diesel buses is combined (on the basis of overall energy usage fractions) with that of gasoline and fuel cell buses. Total bus-related energy consumption is then calculated from the net fuel intensity and subsequently disaggregated to specific bus technologies in accordance with their overall energy shares. The logic is a bit circular since calculating the net fuel intensity requires the very energy shares that are then subsequently used to disaggregate bus energy, but that is the way the

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[18] Minibuses are generally small buses designed to carry between 8 and 30 passengers. Although used for private services on a global scale, minibuses largely comprise the range of large passenger vans and small buses used throughout the developing world for informal paratransit services. For modeling purposes, minibuses are meant to reflect the distinction between these smaller transit-like services and the larger buses that are more typically operated by transit systems.

structure is designed. The bottom line is that many of the energy calculations that are performed directly by the model algorithms for other transport modes must be performed “offline” (outside the model) for buses. These same offline calculations must also address new bus technology penetration rates and old technology retirement rates as described above.

The ICCT estimates for the fleetwide fuel consumption rates for buses are presented in Table 32. These estimates are derived by adjusting base year fuel intensity estimates for forecasted changes in the penetration of advanced bus technologies and the effect that increased penetration has on net fleetwide fuel consumption. The specific methodology employed is discussed in the remainder of this section.

Table 32. Bus Fuel Consumption (litge/100km)

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	41.5	41.5	41.5	41.5	35.8	32.0	29.0	26.2	24.1	22.7	21.6
Canada	41.5	41.5	41.5	41.5	35.8	32.0	29.0	26.2	24.1	22.7	21.6
Mexico	41.5	41.5	41.5	41.5	41.5	35.8	32.0	29.0	26.2	24.1	22.7
Brazil	37.9	37.9	37.9	37.9	37.9	32.7	29.2	26.5	24.0	22.1	20.8
RoLA	37.9	37.9	37.9	37.9	37.9	37.9	32.7	29.2	26.5	24.0	22.1

Baseline (year 2000) bus fuel intensity for the U.S. and Brazil was set at reported historic values, converted to gasoline volume equivalents for consistency with SMP model input data assumptions.[19] [8,24] Canada and Mexico are assumed to have U.S.-equivalent baseline fuel intensity, while the rest of Latin America is assumed to have Brazil-equivalent baseline fuel intensity.

The potential fuel intensity impact of alternative bus technology was estimated for two specific technology levels. The first “advanced technology” level assumes the implementation of electric hybridization technology, while the second “fuel cell technology” level assumes the replacement of conventional engine systems with fuel cell-based electric propulsion. The ICCT assumes that advanced technology could be implemented on a widespread basis in the U.S. beginning in the 2015 timeframe, while fuel cell technology introduction in the U.S. could *begin* in the 2020 timeframe (with significant penetrations not occurring until 2030 and later). As with the other onroad vehicle types, the ICCT relies on the same fuel cell market penetration curve employed for light duty vehicles to estimate the fraction of new bus sales that could employ fuel cell technology. [3] The ICCT assumes a technology lag time for buses in Mexico, Brazil, and the rest of Latin America (no lag is assumed for Canada). For Mexico and Brazil, the ICCT assumes a five year market lag, while the lag for the rest of Latin America is assumed to be ten years.

Buses with advanced technology are assumed to have 34.0 percent lower fuel consumption than current generation buses, while buses with fuel cell technology are assumed to have 55.3 percent

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[19] Baseline bus fuel consumption rates for the U.S. are taken as the average of 2000-2006 data. [24] All volumetric energy conversions utilize the gasoline and diesel fuel energy contents assumed in the baseline SMP model. [1]

lower fuel consumption than current generation buses. Both estimates are based on published fuel consumption data for bus test programs being conducted in Canada. [25] The forecasted intensity changes are generally consistent with advanced and fuel cell technology impacts assumed in other transportation road vehicle sectors.

Unfortunately, the SMP model does not include a fleet turnover algorithm for buses, so the effect of new vehicle fuel consumption improvement on the overall bus fleet in any given year was estimated "offline" (i.e., outside the model). To perform the necessary analysis, the average age for buses was calculated (6.2 years) and a crude estimate of bus turnover per year was calculated as one over twice the average age (which evaluates to 1/[2×6.2], or 8.1 percent turnover per year). [26] As stated above, the ICCT assumes advanced technology buses are "market ready" beginning in 2015 in the U.S. and fuel cell technology buses are "market ready" beginning in 2020 in the U.S. (at very low penetration rates). "Market ready" dates in other modeling areas are affected by the assumed technology lag times discussed above (no lag in Canada, a five year lag in Mexico and Brazil, and a ten year lag in the rest of Latin America). Therefore, the ICCT estimate of fleetwide bus impacts is based on the fraction of the bus fleet that is pre-2015 (pre-2020 in Mexico and Brazil, pre-2025 in the rest of Latin America) achieving 2000 era (i.e., baseline) fuel intensity levels, the fraction of the fleet that is post-2015 (post-2020 in Mexico and Brazil, post-2025 in the rest of Latin America) achieving advanced technology fuel intensity levels, and the fraction of the fleet that is fuel cell technology achieving fuel cell fuel intensity levels. Weighting these three fleet fractions together produces the fleetwide fuel intensity estimates presented in Table 32.

8.2 Bus Energy Shares by Technology Type

The ICCT has estimated the share of bus energy consumption by technology type as summarized in Tables 33 through 35. The forecast is assumed to be independent of whether the future is globally or locally driven. Since the vehicle production market is global under current conditions, it is difficult to envision a scenario in which that global market will constrict to consider only local interests. The ICCT views local energy security issues as more than sufficient to continue driving vehicle fuel efficiency demands under both globally or locally driven futures. For this reason, vehicle technology (and associated energy) shares are unchanged under the two alternative futures. It is critical to recognize, however, that this does not mean that CO_2 emissions are unchanged since, as described in Section 5 above, fuel production pathways (and associated carbon emissions) vary considerably under the two alternative futures.

The energy shares for fuel cell technology buses are estimated as described in Section 8.1 above, wherein the associated energy shares were required to estimate the impact of fuel cell technology on the net fleetwide fuel intensity of buses. The calculated energy shares are simply carried over without change. The diesel (plus biodiesel) energy fraction of the non-fuel cell portion of the bus fleet is taken as 96 percent in the U.S. and 100 percent in Brazil. [27,8] The diesel (plus biodiesel) energy fractions in Canada and Mexico are assumed to be consistent with those of the U.S., while diesel (plus biodiesel) energy shares for the rest of Latin America are assumed to equal those of Brazil. The remainder of bus energy is assumed to be gasoline (including ethanol blends).

Table 33. Share of Bus Energy Supplied by Gasoline and Gasoline/Ethanol Blends

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	3.7%	3.2%	2.5%	1.9%	1.4%
Canada	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	3.7%	3.2%	2.5%	1.9%	1.4%
Mexico	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	3.7%	3.2%	2.5%	1.9%
Brazil	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RoLA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 34. Share of Bus Energy Supplied by Diesel and Diesel/Biodiesel Blends

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	96.0%	96.0%	96.0%	96.0%	95.9%	95.0%	89.6%	77.1%	60.8%	45.4%	33.3%
Canada	96.0%	96.0%	96.0%	96.0%	95.9%	95.0%	89.6%	77.1%	60.8%	45.4%	33.3%
Mexico	96.0%	96.0%	96.0%	96.0%	96.0%	95.9%	95.0%	89.6%	77.1%	60.8%	45.4%
Brazil	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	99.0%	93.4%	80.3%	63.3%	47.3%
RoLA	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	99.0%	93.4%	80.3%	63.3%

Table 35. Share of Bus Energy Supplied by Hydrogen

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0.0%	0.0%	0.0%	0.0%	0.1%	1.0%	6.6%	19.7%	36.7%	52.7%	65.4%
Canada	0.0%	0.0%	0.0%	0.0%	0.1%	1.0%	6.6%	19.7%	36.7%	52.7%	65.4%
Mexico	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	1.0%	6.6%	19.7%	36.7%	52.7%
Brazil	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	1.0%	6.6%	19.7%	36.7%	52.7%
RoLA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	1.0%	6.6%	19.7%	36.7%

9. <u>Minibus Fuel and Carbon Intensity Parameters</u>

The SMP model structure for minibuses is less robust than the model structure for light duty vehicles.[20] Unlike the light duty vehicle structure, the minibus structure includes no algorithms to address vehicle sales or retirement. As a result, the impact of sales and retirement on the rate at which new or alternative vehicle technologies penetrate the overall minibus market must be estimated "offline" (outside the model). The minibus structure allocates overall energy use into gasoline, diesel, and fuel cell (FC) vehicle components. Electric-only vehicles are notably absent from the SMP model structures for road vehicles, but the ICCT does not believe this to be a significant issue for this work due to the fact that, as described in Section 3 above, the CO_2 emission rates for BEVs are expected to be similar to those for fuel cell vehicles (FCVs).

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[20] Minibuses are generally small buses designed to carry between 8 and 30 passengers. Although used for private services on a global scale, minibuses largely comprise the range of large passenger vans and small buses used throughout the developing world for informal paratransit services. For modeling purposes, minibuses are meant to reflect the distinction between these smaller transit-like services and the larger buses that are more typically operated by transit systems.

Therefore, although the ICCT uses the SMP model FCV structures as surrogates for both FCVs and BEVs, it is expected that estimated emissions under either the globally or locally driven scenario will be reasonably similar for either a BEV or FCV future.

9.1 Minibus Fuel Intensity

The SMP model structure for minibuses is somewhat different than that for light, medium, and heavy duty vehicles wherein the model assigns a "base" fuel intensity to one specific vehicle type (e.g., conventional diesel vehicles in the case of heavy duty trucks) and then estimates the fuel intensity for other vehicle types using defined fuel consumption ratios. In contrast, the minibus structure of the model is based on a single "net" fuel intensity that reflects the combined fuel intensities of all component minibus technologies. In effect, the fuel intensity of diesel minibuses is combined (on the basis of overall energy usage fractions) with that of gasoline and fuel cell minibuses. Total minibus-related energy consumption is then calculated from the net fuel intensity and subsequently disaggregated to specific minibus technologies in accordance with their overall energy shares. The logic is a bit circular since calculating the net fuel intensity requires the very energy shares that are then subsequently used to disaggregate minibus energy, but that is the way the structure is designed. The bottom line is that many of the energy calculations that are performed directly by the model algorithms for other transport modes must be performed "offline" (outside the model) for minibuses. These same offline calculations must also address new minibus technology penetration rates and old technology retirement rates as described above.

The ICCT estimates for the fleetwide fuel consumption rates for minibuses are presented in Table 36. These estimates are derived by adjusting base year fuel intensity estimates for forecasted changes in the penetration of advanced minibus technologies and the effect that increased penetration has on net fleetwide fuel consumption. The specific methodology employed is discussed in the remainder of this section.

Baseline (year 2000) minibus fuel intensity for the U.S. was set at the average of reported historic values for Class 2 and 3 trucks, converted to gasoline volume equivalents for consistency with SMP model input data assumptions.[21] [22] In the absence of alternative data, all other modeling areas are assumed to have U.S.-equivalent baseline fuel intensity.

The potential fuel intensity impact of alternative minibus technology was estimated for two specific technology levels. The first "advanced technology" level assumes the implementation of the same conventional technology (including hybridization) improvements assumed for medium duty trucks (the class of vehicles to which minibuses belong), which are described in Section 6.2 above. The only difference is that the expected diesel and gasoline improvements are weighted equally to better reflect the fueling distribution of minibuses. This reweighting actually makes little difference since the expected improvements for diesel and gasoline MDTs is

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[21] Class 2 trucks range from 6,001 to 10,000 pounds (2,722 to 4,536 kg) Gross Vehicle Weight (GVW), while Class 3 trucks range from 10,001 to 14,000 pounds (4,536 to 6,350 kg) GVW. Minibuses up to about 17 passengers fall within Class 2, while larger minibuses fall within Class 3. In the absence of specific minibus population distribution data, the ICCT uses a simple arithmetic average of Class 2 and 3 fuel consumption data as representative of the overall minibus fleet.

Table 36. Minibus Fuel Consumption (litge/100km)

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	19.4	19.4	19.4	19.4	14.2	11.3	10.1	9.5	8.9	8.3	7.9
Canada	19.4	19.4	19.4	19.4	14.2	11.3	10.1	9.5	8.9	8.3	7.9
Mexico	19.4	19.4	19.4	19.4	19.4	14.2	11.3	10.1	9.5	8.9	8.3
Brazil	19.4	19.4	19.4	19.4	19.4	14.2	11.3	10.1	9.5	8.9	8.3
RoLA	19.4	19.4	19.4	19.4	19.4	19.4	14.2	11.3	10.1	9.5	8.9

quite similar at 46.6 and 46.3 percent respectively, resulting in a weighted average improvement of 46.5 percent for minibuses. The second "fuel cell technology" level assumes the replacement of conventional engine systems with fuel cell-based electric propulsion. Based on the fuel cell data for full size buses, as described in Section 8.1 above, the ICCT assumes a similar 32.3 percent additional fuel consumption improvement for fuel cell minibuses (relative to advanced conventional hybridized minibuses). [25]

The ICCT assumes that advanced technology could be implemented on a widespread basis in the U.S. beginning in the 2015 timeframe, while fuel cell technology introduction in the U.S. could *begin* in the 2020 timeframe (with significant penetrations not occurring until 2030 and later). As with the other onroad vehicle types, the ICCT relies on the same fuel cell market penetration curve employed for light duty vehicles to estimate the fraction of new minibus sales that could employ fuel cell technology. [3] The ICCT assumes a technology lag time for minibuses in Mexico, Brazil, and the rest of Latin America (no lag is assumed for Canada). For Mexico and Brazil, the ICCT assumes a five year market lag, while the lag for the rest of Latin America is assumed to be ten years.

Unfortunately, the SMP model does not include a fleet turnover algorithm for minibuses, so the effect of new vehicle fuel consumption improvement on the overall minibus fleet in any given year was estimated "offline" (i.e., outside the model). To perform the necessary analysis, the average age for minibuses was calculated (4.3 years) and a crude estimate of minibus turnover per year was calculated as one over twice the average age (which evaluates to 1/[2×4.3], or 11.6 percent turnover per year). [26] As stated above, the ICCT assumes advanced technology minibuses are "market ready" beginning in 2015 in the U.S. and fuel cell technology minibuses are "market ready" beginning in 2020 in the U.S. (at very low penetration rates). "Market ready" dates in other modeling areas are affected by the assumed technology lag times discussed above (no lag in Canada, a five year lag in Mexico and Brazil, and a ten year lag in the rest of Latin America). Therefore, the ICCT estimate of fleetwide minibus impacts is based on the fraction of the minibus fleet that is pre-2015 (pre-2020 in Mexico and Brazil, pre-2025 in the rest of Latin America) achieving 2000 era (i.e., baseline) fuel intensity levels, the fraction of the fleet that is post-2015 (post-2020 in Mexico and Brazil, post-2025 in the rest of Latin America) achieving advanced technology fuel intensity levels, and the fraction of the fleet that is fuel cell technology achieving fuel cell fuel intensity levels. Weighting these three fleet fractions together produces the fleetwide fuel intensity estimates presented in Table 36.

9.2 Minibus Energy Shares by Technology Type

The ICCT has estimated the share of minibus energy consumption by technology type as summarized in Tables 37 through 39. The forecast is assumed to be independent of whether the future is globally or locally driven. Since the vehicle production market is global under current conditions, it is difficult to envision a scenario in which that global market will constrict to consider only local interests. The ICCT views local energy security issues as more than sufficient to continue driving vehicle fuel efficiency demands under both globally or locally driven futures. For this reason, vehicle technology (and associated energy) shares are unchanged under the two alternative futures. It is critical to recognize, however, that this does not mean that CO_2 emissions are unchanged since, as described in Section 5 above, fuel production pathways (and associated carbon emissions) vary considerably under the two alternative futures.

The energy shares for fuel cell technology minibuses are estimated as described in Section 9.1 above, wherein the associated energy shares were required to estimate the impact of fuel cell technology on the net fleetwide fuel intensity of minibuses. The calculated energy shares are simply carried over without change. In the absence of alternative data, the diesel (plus biodiesel) energy fraction of the non-fuel cell portion of the minibus fleet is retained at the levels assumed in the baseline SMP model. [1] For North America (Canada, Mexico, and the U.S.) the diesel (plus biodiesel) fraction is 50 percent, while that for Latin America (Brazil and the rest of Latin America) is 20 percent. The remainder of minibus energy is assumed to be gasoline (including ethanol blends).

Table 37. Share of Minibus Energy Supplied by Gasoline and Ethanol Blends

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	50.0%	50.0%	50.0%	50.0%	49.9%	49.3%	45.6%	37.2%	27.1%	18.4%	12.3%
Canada	50.0%	50.0%	50.0%	50.0%	49.9%	49.3%	45.6%	37.2%	27.1%	18.4%	12.3%
Mexico	50.0%	50.0%	50.0%	50.0%	50.0%	49.9%	49.3%	45.6%	37.2%	27.1%	18.4%
Brazil	80.0%	80.0%	80.0%	80.0%	80.0%	79.9%	78.9%	72.9%	59.5%	43.3%	29.4%
RoLA	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%	79.9%	78.9%	72.9%	59.5%	43.3%

Table 38. Share of Minibus Energy Supplied by Diesel and Diesel/Biodiesel Blends

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	50.0%	50.0%	50.0%	50.0%	49.9%	49.3%	45.6%	37.2%	27.1%	18.4%	12.3%
Canada	50.0%	50.0%	50.0%	50.0%	49.9%	49.3%	45.6%	37.2%	27.1%	18.4%	12.3%
Mexico	50.0%	50.0%	50.0%	50.0%	50.0%	49.9%	49.3%	45.6%	37.2%	27.1%	18.4%
Brazil	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	19.7%	18.2%	14.9%	10.8%	7.4%
RoLA	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	19.7%	18.2%	14.9%	10.8%

Table 39. Share of Minibus Energy Supplied by Hydrogen

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0.0%	0.0%	0.0%	0.0%	0.1%	1.4%	8.9%	25.6%	45.9%	63.2%	75.4%
Canada	0.0%	0.0%	0.0%	0.0%	0.1%	1.4%	8.9%	25.6%	45.9%	63.2%	75.4%
Mexico	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	1.4%	8.9%	25.6%	45.9%	63.2%
Brazil	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	1.4%	8.9%	25.6%	45.9%	63.2%
RoLA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	1.4%	8.9%	25.6%	45.9%

10. Two-Wheeled Vehicle Fuel and Carbon Intensity Parameters

The SMP model structure for two-wheeled vehicles (2WVs) is less robust than the model structure for light duty vehicles. Unlike the light duty vehicle structure, the 2WV structure includes no algorithms to address vehicle sales or retirement. As a result, the impact of sales and retirement on the rate at which new or alternative vehicle technologies penetrate the overall 2WV market must be estimated “offline” (outside the model). Additionally, the model structure allocates all 2WV energy use to gasoline (and gasoline/ethanol blends), and this is generally consistent with historic data. While it is possible that alternative technologies such as electric-only or alternative fueled 2WVs could penetrate the market in the future, the general insignificance of 2WV emissions in the Americas (relative to emissions from other transport modes) led to a decision not to update the SMP model 2WV structure for this study. While a more robust treatment of 2WVs might be important should sales of such vehicles actually increase at a greater rate than expected, current expectations of a tripling of 2WV activity between now and 2050 still leave 2WVs responsible for less than one percent of CO_2 in the Americas (under either alternative future) despite substantially greater per-vehicle emission reductions in other transport sectors.[22]

10.1 Two-Wheeled Vehicle Fuel Intensity

Table 40 shows the fuel consumption rates for two-wheeled vehicles, expressed as an aggregate of all component technologies in energy equivalent liters of gasoline per hundred kilometers. Baseline 2WV fuel intensity for the U.S. is taken as 50 miles per gallon (4.70 litge/100km), while that for Brazil is taken as 110 miles per gallon (2.14 litge/100km), both based on reported historic data. [28,8] The substantial difference between the Brazilian and U.S. data is assumed to result from the significant difference in average 2WV engine displacement observed between the two areas. The baseline SMP fuel intensity forecast for 2WVs in North and Latin America assumes both shifts in the size distribution of two-wheelers and improved efficiency for two-wheelers of all sizes. [1,29] Unfortunately, there is no way to disentangle these two influences and there is little alternative data available to develop an independent forecast that is any more reliable than the SMP baseline forecast. As a result, SMP baseline forecast data are simply scaled according to the differences between the SMP and observed baseline data for the

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[22] Currently, 2WVs are responsible for only 0.2 percent of CO_2 emissions in the Americas, so that even through future responsibility rises by nearly a factor of five the resulting contribution remains minor throughout the forecast period.

Table 40. Two-Wheeled Vehicle Fuel Consumption (litge/100km)

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	4.7	4.4	4.1	3.8	3.5	3.3	3.1	3.1	3.1	3.1	3.1
Canada	4.7	4.4	4.1	3.8	3.5	3.3	3.1	3.1	3.1	3.1	3.1
Mexico	2.1	2.2	2.4	2.5	2.6	2.6	2.6	2.6	2.6	2.6	2.6
Brazil	2.1	2.2	2.4	2.5	2.6	2.6	2.6	2.6	2.6	2.6	2.6
RoLA	2.1	2.2	2.4	2.5	2.6	2.6	2.6	2.6	2.6	2.6	2.6

U.S. and Brazil. Mexico and the rest of Latin America are assumed to be equivalent to Brazil due to the inordinately large displacement two-wheelers predominant in the U.S, while Canada is assumed to be equivalent to the U.S.

10.2 Two-Wheeled Vehicle Energy Shares by Technology Type

As described above, the SMP model structure allocates all 2WV energy use to gasoline (and gasoline/ethanol blends), and the ICCT opted not to update the structure for this study due to the general insignificance of 2WV CO_2 emissions. Thus, the carbon intensity of 2WVs is directly related to the fuel production pathways associated with gasoline and gasoline/ethanol blends as described in Section 5 above.

11. Three-Wheeled Vehicle Fuel and Carbon Intensity Parameters

The SMP model structure for three-wheeled vehicles (3WVs) is less robust than the model structure for light duty vehicles. Unlike the light duty vehicle structure, the 3WV structure includes no algorithms to address vehicle sales or retirement. As a result, the impact of sales and retirement on the rate at which new or alternative vehicle technologies penetrate the overall 3WV market must be estimated "offline" (outside the model). Additionally, the model structure allocates all 3WV energy use to gasoline (and gasoline/ethanol blends). However, since there are no 3WV in general operation in the Americas, neither the lack of robustness nor the energy distribution is of any consequence.

While it is certainly possible that a market could develop for 3WVs in the Americas in the future and that alternative technologies such as electric-only or alternative fueled 3WVs could penetrate that market, neither is expected. Thus, while a more robust treatment of 3WVs might be important should such a market develop, current expectations that such development will not occur led to a decision not to update the SMP model 3WV structure for this study.

11.1 Three-Wheeled Vehicle Fuel Intensity

Table 41 shows the fuel consumption rates for three-wheeled vehicles, expressed as an aggregate of all component technologies in energy equivalent liters of gasoline per hundred kilometers. Due to the lack of a 3WV market in the Americas, the baseline SMP model forecast for three-wheelers was not altered for this study in any way. Fuel intensities in Mexico, Brazil, and the rest of Latin America are set equal to the baseline SMP model values for Latin America,

Table 41. Three-Wheeled Vehicle Fuel Consumption (litge/100km)

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Canada	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Mexico	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Brazil	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
RoLA	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0

while fuel intensities in the U.S. and Canada are set equal to the baseline SMP model values for North America. [1]

11.2 Three-Wheeled Vehicle Energy Shares by Technology Type

As described above, the SMP model structure allocates all 3WV energy use to gasoline (and gasoline/ethanol blends), and the ICCT opted not to update the structure for this study due to the lack of a 3WV market in the Americas. Thus, the carbon intensity of 3WVs is directly related to the fuel production pathways associated with gasoline and gasoline/ethanol blends as described in Section 5 above.

12. Passenger Rail Fuel and Carbon Intensity Parameters

The SMP model structure for passenger rail is fairly robust, but like the structures for most other transport modes, the passenger rail structure includes no algorithms to address vehicle (i.e., locomotive) sales or retirement. As a result, the impact of sales and retirement on the rate at which new or alternative locomotive technologies penetrate the overall passenger rail market must be estimated "offline" (outside the model). The passenger rail structure allocates overall energy use into diesel-powered and electricity-powered components. In fact, the rail portions of the SMP model (both passenger rail and freight rail as discussed in Section 13 below) are the only model structures that explicitly treat electric-powered vehicles.

However, there are two major shortcomings in the rail portions of the model (both for passenger rail and freight rail as discussed in Section 13 below) that have been addressed by the ICCT. The first shortcoming is that the baseline SMP model structure treats energy intensity in terms of passenger-kilometers (or tonne-kilometers in the case of freight rail) *without any consideration of a load factor*. In effect, two rail systems hauling 100 passengers over a 100 kilometer route are treated identically whether they move the 100 passengers using one train or ten. To properly account for this potential difference, the ICCT modified the SMP model structure for passenger rail to *calculate* energy intensity in terms of passenger-kilometers using an added alternative structure based on input energy intensity in terms of seat-kilometers and an associated input load factor (i.e., passengers per seat). While this modified structure is not as precise as it could be since it does not adjust seat-kilometer intensity for the mass effects of changing load factors, the ICCT believes that the mass effect is minor for any reasonably expected load factor changes and that the seat-kilometer approach is far superior to the baseline model approach.

The second shortcoming is that the baseline SMP model structures for rail (both passenger and freight as discussed in Section 13 below) do not properly distinguish the differing *onboard* efficiencies of electric and "onboard combustion" (diesel-electric) locomotives, instead treating efficiency and fuel as independent parameters (providing, for example, *onboard* electric efficiency to diesel combustion). As is the case throughout the transportation sector, *onboard* efficiency for electric locomotives is much higher than for combustion locomotives (this is balanced to a greater or lesser extent, depending on electricity production processes, by *offboard* electricity generation inefficiencies) and therefore aggregate locomotive efficiency must be tied directly to the type of fuel consumed to avoid miscalculating overall rail energy use. The ICCT has modified the SMP model to properly account for this important distinction. This is a bigger issue for passenger rail due to its inherent ability to be more readily electrified (as a large portion of passenger rail service occurs within well defined urban areas and corridors), but both passenger and freight rail can be significantly affected due to impacts on both baseline and alternative future efficiencies.

12.1 Passenger Rail Energy Shares by Technology Type

The ICCT has estimated the share of passenger rail energy consumption by technology type as summarized in Tables 42 through 45. Unlike road vehicles (for which vehicle technology is assumed to be independent of whether the future is globally or locally driven), the ICCT assumes that the degree rail electrification is dependent on whether the future is globally or locally driven (in accordance with the assumed carbon tax policy in place under the globally-driven future, or the lack thereof under the locally-driven future). Tables 42 and 43 show the estimated energy shares for a *globally-driven future*, while Tables 44 and 45 show the corresponding shares for a *locally-driven future*. As is the case for all transportation sectors, the share of electrical energy that is derived from low-GHG processes is defined using the electrical energy fractions presented in Section 5 above.

The baseline energy share of electric passenger rail in the U.S. (48 percent) is taken from data reported by the U.S. Department of Energy. [27] The same rate is applied without change to all five modeling areas for two primary reasons. First, no alternative references are readily available. For example, even though Brazil reported a substantial quantity of transport data, rail energy is not among the reported parameters. [8] Second, the electrification energy shares for North America and Latin America in the baseline SMP model are 80 and 75 percent respectively, similar to each other, but only modestly lower than the 90 percent electric rail energy share for the European Union. The ICCT believes that rail electrification is much more widespread in Europe than in the Americas (as supported by the reported U.S. data) and, as a result, the reported U.S. baseline data have been applied without change to each modeled area.

Although there are case studies indicating that rail electrification is economically viable, even in the absence of additional fiscal policies, there is little evidence of widespread conversion of existing diesel rail lines. [30] Therefore, it is assumed that no additional electrification will take place in a locally-driven future wherein there is no assumed carbon tax (or equivalent), and the baseline electrification rate (48 percent) is unchanged throughout the forecast period. For the globally-driven future, it is assumed that electrification is promoted via the CO_2 tax (or

Table 42. Share of Passenger Rail Energy Supplied by Diesel -- Global Future

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	52%	52%	52%	52%	52%	45%	38%	31%	24%	17%	10%
Canada	52%	52%	52%	52%	52%	45%	38%	31%	24%	17%	10%
Mexico	52%	52%	52%	52%	52%	45%	38%	31%	24%	17%	10%
Brazil	52%	52%	52%	52%	52%	45%	38%	31%	24%	17%	10%
RoLA	52%	52%	52%	52%	52%	45%	38%	31%	24%	17%	10%

Table 43. Share of Passenger Rail Energy Supplied by Electricity -- Global Future

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	48%	48%	48%	48%	48%	55%	62%	69%	76%	83%	90%
Canada	48%	48%	48%	48%	48%	55%	62%	69%	76%	83%	90%
Mexico	48%	48%	48%	48%	48%	55%	62%	69%	76%	83%	90%
Brazil	48%	48%	48%	48%	48%	55%	62%	69%	76%	83%	90%
RoLA	48%	48%	48%	48%	48%	55%	62%	69%	76%	83%	90%

Table 44. Share of Passenger Rail Energy Supplied by Diesel -- Local Future

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	52%	52%	52%	52%	52%	52%	52%	52%	52%	52%	52%
Canada	52%	52%	52%	52%	52%	52%	52%	52%	52%	52%	52%
Mexico	52%	52%	52%	52%	52%	52%	52%	52%	52%	52%	52%
Brazil	52%	52%	52%	52%	52%	52%	52%	52%	52%	52%	52%
RoLA	52%	52%	52%	52%	52%	52%	52%	52%	52%	52%	52%

Table 45. Share of Passenger Rail Energy Supplied by Electricity -- Local Future

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	48%	48%	48%	48%	48%	48%	48%	48%	48%	48%	48%
Canada	48%	48%	48%	48%	48%	48%	48%	48%	48%	48%	48%
Mexico	48%	48%	48%	48%	48%	48%	48%	48%	48%	48%	48%
Brazil	48%	48%	48%	48%	48%	48%	48%	48%	48%	48%	48%
RoLA	48%	48%	48%	48%	48%	48%	48%	48%	48%	48%	48%

equivalent) policy so that between 2020 and 2050 electrification reaches the same (i.e., 90 percent) level assumed in the baseline SMP model for Europe.

All non-electric rail energy is assumed to be diesel, consistent with both baseline SMP model assumptions and reported data.

12.2 Passenger Rail Fuel Intensity

Tables 46 and 47 show the assumed fuel consumption rates, expressed as megajoules per seat-kilometer, for passenger rail under the globally and locally driven futures respectively. It is important to note that the primary influence on the presented rates is the degree of rail electrification. Since the primary inefficiencies of electrical energy generation occur offboard the rail locomotive (i.e., at the location of the generation of the electricity), the *onboard* efficiency of electric propulsion is considerably greater than that of diesel-electric propulsion (since the inefficiencies associated with the conversion of diesel fuel to electrical energy occur onboard the locomotive). Thus, the *onboard* locomotive efficiency is quite dependent on the source of energy. Since the SMP model is structured to account for energy consumption on an onboard basis, it is critical that this distinction be reflected in the assumed fuel intensity data. Of course, offboard (upstream) CO_2 for offboard electricity generation can be much higher than offboard (upstream) CO_2 for diesel production and this is accounted for in the analysis using the electricity generation CO_2 emission rates presented in Section 5 above.

To properly account for differing onboard efficiencies, passenger locomotive energy intensity was estimated separately for electric and diesel locomotives. The associated calculations are based on total electricity and diesel use reported by Amtrak, the major U.S. intercity passenger rail carrier. [31] Diesel use was converted to traction energy using an assumed tank-to-wheels efficiency of 30 percent.[23] Total (electricity plus diesel) traction energy was then divided by passenger-miles, as reported by Amtrak, to derive an estimated traction energy intensity value. [33] This traction energy intensity is also taken to be equivalent to an electric locomotive energy intensity (assuming no onboard losses). The estimated intensity is 0.52 megajoules per passenger-kilometer (MJ/pass-km).

This estimate inherently includes an associated load factor (i.e., passengers per seat). To properly account for this inherent dependency, the ICCT, as described above, adjusted the SMP model structure for passenger rail to a more general megajoules per seat-kilometer (MJ/seat-km) basis. To convert the estimated MJ/pass-km intensity into the more general MJ/seat-km metric, the MJ/pass-km intensity was multiplied the reported Amtrak load factor (0.48 passengers per seat, or 48 percent) to derive an estimated electric locomotive (onboard) energy intensity of 0.25 MJ/seat-km. [34] The estimated diesel locomotive efficiency is then simply equal to the traction intensity divided by the assumed tank-to-wheels efficiency (30 percent), or 0.83 MJ/seat-km. The net energy intensity in any given forecast year is the fuel weighted average of the derived

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[23] To ensure reasonability, the assumed 30 percent tank-to-wheels efficiency was validated against published fuel consumption data for a typical line haul diesel locomotive evaluated over the standard U.S. Environmental Protection Agency line haul locomotive cycle. [32] Reported fuel consumption of 0.43 pounds per horsepower-hour was converted to an equivalent efficiency using a typical diesel fuel density and energy content of 7 pounds per gallon and 128,400 Btu per gallon (lower heating value) respectively. The resulting calculation indicates a net cycle efficiency of 32 percent, evaluated as follows:

$$\left(\frac{1\,\text{hphr}}{0.43\,\text{lb dsl}}\right)\times\left(\frac{7\,\text{lb dsl}}{1\,\text{gal dsl}}\right)\times\left(\frac{2545\,\text{Btu}}{1\,\text{hphr}}\right)\times\left(\frac{1\,\text{gal dsl}}{128400\,\text{Btu}}\right)=0.32$$

Based on this similarity, the ICCT believes that the assumed tank-to-wheels efficiency of 30 percent is reasonable.

Table 46. Passenger Rail Fuel Consumption (MJ/seat-km) -- Global Future

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0.55	0.55	0.55	0.55	0.55	0.51	0.47	0.43	0.39	0.35	0.31
Canada	0.55	0.55	0.55	0.55	0.55	0.51	0.47	0.43	0.39	0.35	0.31
Mexico	0.55	0.55	0.55	0.55	0.55	0.51	0.47	0.43	0.39	0.35	0.31
Brazil	0.55	0.55	0.55	0.55	0.55	0.51	0.47	0.43	0.39	0.35	0.31
RoLA	0.55	0.55	0.55	0.55	0.55	0.51	0.47	0.43	0.39	0.35	0.31

Table 47. Passenger Rail Fuel Consumption (MJ/seat-km) -- Local Future

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
Canada	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
Mexico	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
Brazil	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
RoLA	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55

electric and diesel intensities. It is assumed that any improvements in the onboard efficiency of electric or diesel locomotives will be minor given the maturity of both technologies (as compared to the change in energy intensity associated with shifting from diesel to electric rail), so that the derived energy intensity estimates are used without change throughout the forecast period.[24] Additionally, in recognition of the global nature of the locomotive industry, the same energy intensity data are assumed for all five modeling areas.

Finally, it should also be noted that the ICCT properly expanded the SMP model structure for passenger rail to include the load factor (passengers per seat) required to convert generalized input fuel intensity into corresponding passenger kilometer-specific energy consumption. For initialization purposes only, the ICCT encoded a load factor value of 48 percent (derived as described above) for all modeling areas and all forecast years, with the expectation that UCB researchers would update the initialization values as appropriate as an integral part of their independent transportation activity estimation. Although of no importance to the ICCT analysis, the corresponding placekeeper value for SMP model areas outside the Americas was set to 83 percent as that value is generally required to achieve the default energy intensity values included in the baseline SMP model for those areas.

13. <u>Freight Rail Fuel and Carbon Intensity Parameters</u>

The SMP model structure for freight rail is fairly robust, but like the structures for most other transport modes, the freight rail structure includes no algorithms to address vehicle (i.e., locomotive) sales or retirement. As a result, the impact of sales and retirement on the rate at which new or alternative locomotive technologies penetrate the overall freight rail market must

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[24] Net passenger rail energy intensity does, of course, change over time with the degree of assumed electrification.

be estimated “offline” (outside the model). The freight rail structure allocates overall energy use into diesel-powered and electricity-powered components. In fact, the rail portions of the SMP model (both freight rail and passenger rail as discussed in Section 12 above) are the only model structures that explicitly treat electric-powered vehicles.

However, as described in Section 12, there are two major shortcomings in the rail portions of the model that have been addressed by the ICCT. The first shortcoming is that the baseline SMP model structure treats energy intensity in terms of tonne-kilometers (or passenger-kilometers in the case of passenger rail) *without any consideration of a load factor*. In effect, two rail systems hauling 100 tonnes of freight over a 100 kilometer route are treated identically whether they move the 100 tonnes using one train or ten. To properly account for this potential difference, the ICCT modified the SMP model structure for freight rail to *calculate* energy intensity in terms of tonne-kilometers using an added alternative structure based on input energy intensity in terms of capacity tonne-kilometers and an associated input load factor (i.e., tonnes per tonne capacity). Since the term capacity for freight trains is somewhat of a misnomer as train cars are simply added or removed to accommodate a given freight load (so that freight capacity utilization is always high), the term load factor in this context can best be viewed as an indicator of freight hauled to maximum potential freight hauled. Moreover, the term can be treated in a relative sense (and is treated as such under the ICCT approach) with current load factors being set to unity and added or removed freight per locomotive being treated as deviations from unity. For example, the added model load factor term should be set to 1.1 to reflect a scenario in which freight train per-locomotive loads are increased by 10 percent relative to current conditions. While this modified structure is not as precise as it could be since it does not adjust tonne-kilometer intensity for the mass effects of changing load factors, the ICCT believes that the mass effect is minor for any reasonably expected load factor changes and that the capacity tonne-kilometer approach is far superior to the baseline model approach.

The second shortcoming is that the baseline SMP model structures for rail (both freight and passenger as discussed in Section 12 above) do not properly distinguish the differing *onboard* efficiencies of electric and “onboard combustion” locomotives, instead treating efficiency and fuel as independent parameters (providing, for example, *onboard* electric efficiency to diesel combustion). As is the case throughout the transportation sector, *onboard* efficiency for electric locomotives is much higher than for combustion locomotives (this is balanced to a greater or lesser extent, depending on electricity production processes, by *offboard* electricity generation inefficiencies) and therefore aggregate locomotive efficiency must be tied directly to the type of fuel consumed to avoid miscalculating overall rail energy use. The ICCT has modified the SMP model to properly account for this important distinction. This is a bigger issue for passenger rail due to its inherent ability to be more readily electrified (as a large portion of passenger rail service occurs within well defined urban areas and corridors), but both passenger and freight rail can be significantly affected due to impacts on both baseline and alternative future efficiencies.

13.1 Freight Rail Energy Shares by Technology Type

The ICCT has estimated the share of freight rail energy consumption by technology type as summarized in Tables 48 through 51. Unlike road vehicles (for which vehicle technology is assumed to be independent of whether the future is globally or locally driven), the ICCT assumes

Table 48. Share of Freight Rail Energy Supplied by Diesel -- Global Future

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	100%	100%	100%	100%	100%	93%	87%	80%	73%	67%	60%
Canada	100%	100%	100%	100%	100%	93%.	87%	80%	73%	67%	60%
Mexico	100%	100%	100%	100%	100%	93%	87%	80%	73%	67%	60%
Brazil	100%	100%	100%	100%	100%	93%	87%	80%	73%	67%	60%
RoLA	100%	100%	100%	100%	100%	93%	87%	80%	73%	67%	60%

Table 49. Share of Freight Rail Energy Supplied by Electricity -- Global Future

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0%	0%	0%	0%	0%	7%	13%	20%	27%	33%	40%
Canada	0%	0%	0%	0%	0%	7%	13%	20%	27%	33%	40%
Mexico	0%	0%	0%	0%	0%	7%	13%	20%	27%	33%	40%
Brazil	0%	0%	0%	0%	0%	7%	13%	20%	27%	33%	40%
RoLA	0%	0%	0%	0%	0%	7%	13%	20%	27%	33%	40%

Table 50. Share of Freight Rail Energy Supplied by Diesel -- Local Future

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Canada	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Mexico	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Brazil	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
RoLA	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 51. Share of Freight Rail Energy Supplied by Electricity -- Local Future

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Canada	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mexico	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Brazil	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
RoLA	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

that the degree rail electrification is dependent on whether the future is globally or locally driven (in accordance with the assumed carbon tax policy in place under the globally-driven future, or the lack thereof under the locally-driven future). Tables 48 and 49 show the estimated energy shares for a *globally-driven future*, while Tables 50 and 51 show the corresponding shares for a *locally-driven future*. As is the case for all transportation sectors, the share of electrical energy that is derived from low-GHG processes is defined using the electrical energy fractions presented in Section 5 above.

The baseline energy share of electric freight rail in the U.S. (zero percent) is taken from data reported by the U.S. Department of Energy. [27] The same rate is applied without change to all five modeling areas for two primary reasons. First, no alternative references are readily available. For example, even though Brazil reported a substantial quantity of transport data, rail energy is not among the reported parameters. [8] Second, the electrification energy shares for North America and Latin America in the baseline SMP model are 1.6 and 15 percent respectively, sufficiently similar to each other and the reported U.S. rate. As a result, the reported U.S. baseline data have been applied without change to each modeled area.

Although there are case studies indicating that rail electrification is economically viable, even in the absence of additional fiscal policies, there is little evidence of widespread conversion of existing diesel rail lines. [30] Therefore, it is assumed that no additional electrification will take place in a locally-driven future wherein there is no assumed carbon tax (or equivalent), and the baseline electrification rate (zero percent) is unchanged throughout the forecast period. For the globally-driven future, it is assumed that electrification is promoted via the CO_2 tax (or equivalent) policy so that between 2020 and 2050 electrification reaches the 40 percent level, which equates to an expansion rate equal to that assumed for passenger rail and is similar to the 50 percent electrification rate assumed in the baseline SMP model for Europe.

All non-electric rail energy is assumed to be diesel, consistent with both baseline SMP model assumptions and reported data.

13.2 Freight Rail Fuel Intensity

Tables 52 and 53 show the assumed fuel consumption rates, expressed as megajoules per capacity tonne-kilometer, for freight rail under the globally and locally driven futures respectively. It is important to note that the primary influence on the presented rates is the degree of rail electrification. Since the primary inefficiencies of electrical energy generation occur offboard the rail locomotive (i.e., at the location of the generation of the electricity), the *onboard* efficiency of electric propulsion is considerably greater than that of diesel-electric propulsion (since the inefficiencies associated with the conversion of diesel fuel to electrical energy occur onboard the locomotive). Thus, the *onboard* locomotive efficiency is quite dependent on the source of energy. Since the SMP model is structured to account for energy consumption on an onboard basis, it is critical that this distinction be reflected in the assumed fuel intensity data. Of course, offboard (upstream) CO_2 for offboard electricity generation can be much higher than offboard (upstream) CO_2 for diesel production and this is accounted for in the analysis using the electricity generation CO_2 emission rates presented in Section 5 above.

To properly account for differing onboard efficiencies, freight locomotive energy intensity was estimated separately for electric and diesel locomotives. Freight rail diesel fuel use was taken from data reported by the U.S. Department of Energy. [27] Diesel use was converted to traction energy using the same tank-to-wheels efficiency assumed for diesel passenger locomotives (30 percent), as described in Section 12.2 above. Total traction energy (which equals diesel traction energy since there is currently no freight rail electrification in the U.S.) was then divided by freight rail ton-miles, as reported by the U.S. Department of Energy, to derive an estimated traction energy intensity value. [35] This traction energy intensity is also taken to be equivalent

Table 52. Freight Rail Fuel Consumption (MJ/tonne-km) -- Global Future

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0.25	0.25	0.25	0.25	0.25	0.24	0.23	0.21	0.20	0.19	0.18
Canada	0.25	0.25	0.25	0.25	0.25	0.24	0.23	0.21	0.20	0.19	0.18
Mexico	0.25	0.25	0.25	0.25	0.25	0.24	0.23	0.21	0.20	0.19	0.18
Brazil	0.25	0.25	0.25	0.25	0.25	0.24	0.23	0.21	0.20	0.19	0.18
RoLA	0.25	0.25	0.25	0.25	0.25	0.24	0.23	0.21	0.20	0.19	0.18

Table 53. Freight Rail Fuel Consumption (MJ/tonne-km) -- Local Future

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Canada	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Mexico	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Brazil	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
RoLA	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25

to an electric locomotive energy intensity (assuming no onboard losses). The estimated intensity is 0.074 megajoules per tonne-kilometer (MJ/tonne-km).

This estimate inherently includes an associated load factor (i.e., tonnes per tonne capacity). To properly account for this inherent dependency, the ICCT, as described above, adjusted the SMP model structure for freight rail to a more general megajoules per capacity tonne-kilometer (MJ/capacity tonne-km) basis. However, since the load factor associated with the reported freight rail intensity is unknown and since freight rail load may be more appropriately thought of as a capacity utilization factor anyway, the ICCT elected to treat the factor on a relative basis so that changes in load factor are reflected relative to the current (unknown) load factor. On this basis, the current capacity utilization factor is defined as one and all changes are reflected as percentage deviations. Thus, to convert the estimated MJ/tonne-km intensity into the more general MJ/capacity tonne-km metric, the MJ/tonne-km intensity was simply multiplied by one to derive an estimated electric locomotive (onboard) energy intensity of 0.074 MJ/tonne-km *at current capacity utilization rates*. The corresponding diesel locomotive efficiency is then simply equal to this traction intensity divided by the assumed tank-to-wheels efficiency (30 percent), or 0.25 MJ/tonne-km. The net energy intensity in any given forecast year is the fuel weighted average of the derived electric and diesel intensities. It is assumed that any improvements in the onboard efficiency of electric or diesel locomotives will be minor given the maturity of both technologies (as compared to the change in energy intensity associated with shifting from diesel to electric rail), so that the derived energy intensity estimates are used without change throughout the forecast period.[25] Additionally, in recognition of the global nature of the locomotive industry, the same energy intensity data are assumed for all five modeling areas.

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[25] Net freight rail energy intensity does, of course, change over time with the degree of assumed electrification.

Finally, it should also be noted that the ICCT properly expanded the SMP model structure for freight rail to include the load factor (capacity utilization factor) required to convert generalized input fuel intensity into corresponding tonne kilometer-specific energy consumption. For initialization purposes only, the ICCT encoded a load factor value of one (derived as described above) for all modeling areas and all forecast years, with the expectation that UCB researchers would update the initialization values as appropriate as an integral part of their independent transportation activity estimation. As indicated above, the load factor is treated as a relative metric so that researchers wishing to investigate the impacts of alternative freight rail load factors should input the alternative factors in terms of percent change from current conditions (e.g., a 25 percent increase in load factor would be modeled through a load factor input of 1.25).

14. Marine Vessel Fuel and Carbon Intensity Parameters

The SMP model structure for marine vessels is the least robust of all transport modes. The entire structure essentially consists of an estimate of residual and distillate fuel use and the conversion of these estimates into CO_2 emissions using carbon profiles for those fuels. Not only does the marine structure (like the structures for most other transport modes) include no algorithms to address the impacts of marine engine sales or retirement on either fuel or carbon intensity, but it also does not include even a basic fleetwide intensity estimate or a lever to adjust marine CO_2 for changes in activity (other than by directly altering fuel use estimates).

While the ICCT believes that residual and diesel fuel use will continue to dominate the marine market throughout the forecast period, it is not realistic for ICCT researchers to adjust fuel consumption for expected changes in efficiency and then expect UCB researchers to independently readjust those already adjusted fuel consumption estimates for the independent effects of changes in marine activity. Therefore, the ICCT modified the SMP model structure for marine vessels to allow for these independent influences on overall fuel consumption to be input independent of not only each other, but baseline fuel use as well. To accomplish this, the ICCT added a fuel intensity module to the SMP model marine structure, allowing the input of fleetwide marine energy consumption rates. Although the impacts of new technologies on the fleetwide energy consumption rates must still be developed offline (as is the case with all transport modes except light duty vehicles), the impacts of changes in fleetwide consumption rates can be modeled without manually adjusting marine fuel consumption directly. This allows for both multiple scenarios to be evaluated and other independent researchers to view and understand the basic fuel intensity assumptions underlying each scenario. Similarly, the ICCT also added an activity module to the SMP model marine structure, allowing researchers to input alternative marine activity assumptions that lead to the automatic adjustment of overall marine fuel consumption so that alternative activity scenarios can be easily modeled and tracked.

Both added modules function as relative adjustment algorithms, so that the user is free to input data in any actual units, as long as they are input consistently throughout the forecast period. In effect, the modules function as follows:

$$\text{Fuel Consumption} = \text{Baseline Fuel Consumption} \times \left(\frac{\text{Scenario Fuel Consumption Rate}}{\text{Baseline Fuel Consumption Rate}} \right) \times \left(\frac{\text{Scenario Activity}}{\text{Baseline Activity}} \right)$$

While the ICCT inputs fuel intensity data in MJ/tonne-km, it could just as easily be input in terms of dimensionless relative fuel consumption. In fact, because activity estimates are the responsibility of UCB researchers, the ICCT initialized the values of the activity parameter in just such a relative sense, setting all parameter values to one across all forecast years and all modeling areas (with the expectation that UCB researchers would update the initialization values as appropriate as an integral part of their independent transportation activity estimation).

14.1 Marine Vessel Energy Shares by Technology Type

The ICCT has estimated the share of marine vessel energy consumption by technology type as summarized in Tables 54 and 55. It is expected that marine vessel fuel will continue to comprise distillate and residual fuel exclusively over the forecast period. Moreover, given the global nature of the marine shipping industry, the ICCT does not expect the marine fuel distribution to be affected in any significant way whether the future is globally or locally driven.

The baseline SMP model estimates marine fuel use in terms of “national distillate use,” “national residual use,” and “international residual use.” Although the aggregate total of these three fuel use categories appears reasonable, both the national/international and distillate/residual splits are significantly different than implied by available data for the Americas. To correct for this apparent discrepancy while simultaneously retaining the overall global distribution of marine vessel fuel use as established in the baseline SMP model, the baseline total fuel use numbers were used as the baseline fuel use estimates for this study, but the national/international distinction was eliminated and the distillate/residual split was re-estimated. Thus, total fuel use under the ICCT approach is divided into two components only, distillate and residual. Although the distillate/residual split is assumed to change over time, no significant penetration of other fuel types are expected in the marine market throughout the forecast period.

Table 54. Share of Marine Energy Supplied by Distillate Fuel

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	29.0%	29.0%	30.2%	38.5%	37.4%	94.1%	100.0%	100.0%	100.0%	100.0%	100.0%
Canada	29.0%	29.0%	30.2%	38.5%	37.4%	94.1%	100.0%	100.0%	100.0%	100.0%	100.0%
Mexico	29.0%	29.0%	30.2%	38.5%	37.4%	94.1%	100.0%	100.0%	100.0%	100.0%	100.0%
Brazil	29.0%	29.0%	30.2%	38.5%	37.4%	94.1%	100.0%	100.0%	100.0%	100.0%	100.0%
RoLA	29.0%	29.0%	30.2%	38.5%	37.4%	94.1%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 55. Share of Marine Energy Supplied by Residual Fuel

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	71.0%	71.0%	69.8%	61.5%	62.6%	5.9%	0.0%	0.0%	0.0%	0.0%	0.0%
Canada	71.0%	71.0%	69.8%	61.5%	62.6%	5.9%	0.0%	0.0%	0.0%	0.0%	0.0%
Mexico	71.0%	71.0%	69.8%	61.5%	62.6%	5.9%	0.0%	0.0%	0.0%	0.0%	0.0%
Brazil	71.0%	71.0%	69.8%	61.5%	62.6%	5.9%	0.0%	0.0%	0.0%	0.0%	0.0%
RoLA	71.0%	71.0%	69.8%	61.5%	62.6%	5.9%	0.0%	0.0%	0.0%	0.0%	0.0%

Distillate and residual fuel shares through 2025 are taken from a recent market forecast of marine vessel fuel use. [36] This forecast predicts a drop in marine vessel residual fuel demand from 67 percent (by mass) to 6 percent (by mass) between 2020 and 2025 due to expected sulfur controls and associated air pollutant regulations. Given this dramatic drop, it is assumed that the residual fuel share drops to zero by 2030. Furthermore, because such controls and regulations are expected regardless of whether the future is locally or globally driven, the same fuel splits are used for both alternative futures in this study. To properly convert the mass-based fuel share data to the energy-based shares used in the SMP model, the tonnage-based shares were converted to corresponding energy equivalents using appropriate fuel density and energy content data. [37] Given the global nature of the marine industry, the same fuel share data are assumed for all five modeling areas.

14.2 Marine Vessel Fuel Intensity

Tables 56 and 57 show the assumed fuel consumption rates for marine vessels under the globally and locally driven futures respectively. While the ICCT forecasts significant efficiency improvement regardless of whether the future is globally or locally driven, the stringent carbon tax (or equivalent) policy assumed to be in place under the globally-driven future leads to substantially greater improvements than assumed for the locally-driven future.

Marine fuel intensity data were developed from a recent study of marine vessel greenhouse gas reduction potential. [38] This reference study treats marine vessels in a somewhat disaggregated fashion, but it is possible to estimate aggregate sector impacts from various reported data. Using reported tonne-mile indices for 2020 and 2050 for three vessel types, and a fleetwide marine average, the fraction of total tonne-miles associated with each of the three ship types in each of the two forecast years was calculated. Reported "low," "baseline," and "high" efficiency improvement estimates for 2020 and 2050 for the same three ship types were then aggregated, using the calculated tonne-mile fractions, to derive corresponding fleetwide efficiency improvements. The "baseline" estimate was assumed to be reflective of a locally-driven (i.e., a CO_2 tax or equivalent is not in place) future, while the "best" estimate was assumed to be reflective of a globally-driven (i.e., a CO_2 tax or equivalent is in place) future.

Although not specifically required since, as described above, the fuel intensity data for marine vessels are used in a relative sense only (and thus the improvement estimates can be used directly), a baseline marine fuel intensity estimate was developed using marine energy consumption data and marine ton-mile data reported by the U.S. Department of Energy. [27,35] Forecast year marine vessel fuel intensities were developed from the baseline fuel intensity and the forecasted intensity improvements. Given the global nature of the marine industry, the same fuel intensity data are assumed for all five modeling areas, as presented in Tables 56 and 57.

15. Aircraft Fuel and Carbon Intensity Parameters

The SMP model structure for aircraft is fairly robust, but like the structures for most other transport modes, the aircraft structure includes no algorithms to address aircraft sales or retirement. As a result, the impact of sales and retirement on the rate at which new or alternative aircraft technologies penetrate the overall market must be estimated "offline" (outside the model).

Table 56. Marine Vessel Fuel Consumption (MJ/tonne-km) -- Global Future

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0.366	0.366	0.366	0.319	0.271	0.249	0.226	0.204	0.181	0.158	0.136
Canada	0.366	0.366	0.366	0.319	0.271	0.249	0.226	0.204	0.181	0.158	0.136
Mexico	0.366	0.366	0.366	0.319	0.271	0.249	0.226	0.204	0.181	0.158	0.136
Brazil	0.366	0.366	0.366	0.319	0.271	0.249	0.226	0.204	0.181	0.158	0.136
RoLA	0.366	0.366	0.366	0.319	0.271	0.249	0.226	0.204	0.181	0.158	0.136

Table 57. Marine Vessel Fuel Consumption (MJ/tonne-km) -- Local Future

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	0.366	0.366	0.366	0.341	0.315	0.300	0.285	0.270	0.256	0.241	0.226
Canada	0.366	0.366	0.366	0.341	0.315	0.300	0.285	0.270	0.256	0.241	0.226
Mexico	0.366	0.366	0.366	0.341	0.315	0.300	0.285	0.270	0.256	0.241	0.226
Brazil	0.366	0.366	0.366	0.341	0.315	0.300	0.285	0.270	0.256	0.241	0.226
RoLA	0.366	0.366	0.366	0.341	0.315	0.300	0.285	0.270	0.256	0.241	0.226

The aircraft structure assumes all energy use is jet fuel, so that aircraft CO_2 emission estimates are based solely on aircraft energy intensity and the carbon profile of that fuel. Given available research, the ICCT believes that the jet fuel only assumption is reasonable for the forecast period associated with this study and has, therefore, not modified the fuel allocation portion of the SMP model structure for aircraft in any way.

However, similar to the issue described in Sections 12 and 13 above for rail, the baseline SMP model structure treats aircraft energy intensity in terms of passenger-kilometers *without any consideration of a load factor*. In effect, two airlines transporting 100 passengers over a 100 kilometer route are treated identically whether they move the 100 passengers using one aircraft or ten. To properly account for this potential difference, the ICCT modified the SMP model structure for aircraft to include a load factor module, and include consideration of the load factor data in the calculation of aircraft energy use. The ICCT correspondingly redesigned the aircraft energy intensity module in terms of seat-kilometers (rather than passenger-kilometers). In effect, energy intensity in passenger-kilometers is defined by input energy intensity in seat-kilometers divided by the input load factor (i.e., passengers per seat). While this modified structure is not as precise as it could be since it does not adjust seat-kilometer intensity for the mass effects of changing load factors, the ICCT believes that the mass effect is minor for any reasonably expected load factor changes and that the seat-kilometer approach is far superior to the baseline model approach.

15.1 Aircraft Energy Shares by Technology Type

As discussed above, the SMP model structure for aircraft assumes that all energy consumed in the sector is jet fuel. While it may become economical at some point to produce jet fuel from alternative energy sources, the ICCT believes that the primary drivers of aircraft efficiency improvement over the forecast period will be engine and airframe design improvements. Thus, for this study, the ICCT has elected to retain the petroleum-based jet fuel-only focus of the SMP model structure for aircraft. Accordingly, 100 percent of aircraft energy is assumed to be supplied by petroleum-based jet fuel throughout the forecast period under both the globally and locally driven future scenarios.

15.2 Aircraft Fuel Intensity

Tables 58 and 59 show the assumed fuel consumption rates for aircraft under the globally and locally driven futures respectively. While the ICCT forecasts significant efficiency improvement regardless of whether the future is globally or locally driven, the stringent carbon tax (or equivalent) policy assumed to be in place under the globally-driven future leads to substantially greater improvements than assumed for the locally-driven future.

Table 58. Aircraft Fuel Consumption (MJ/seat-km) -- Global Future

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	1.87	1.75	1.64	1.56	1.49	1.13	1.10	1.07	1.05	1.02	1.00
Canada	1.87	1.75	1.64	1.56	1.49	1.13	1.10	1.07	1.05	1.02	1.00
Mexico	1.87	1.75	1.64	1.56	1.49	1.13	1.10	1.07	1.05	1.02	1.00
Brazil	1.87	1.75	1.64	1.56	1.49	1.13	1.10	1.07	1.05	1.02	1.00
RoLA	1.87	1.75	1.64	1.56	1.49	1.13	1.10	1.07	1.05	1.02	1.00

Table 59. Aircraft Fuel Consumption (MJ/seat-km) -- Local Future

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
US	1.87	1.75	1.64	1.56	1.49	1.45	1.42	1.38	1.35	1.31	1.28
Canada	1.87	1.75	1.64	1.56	1.49	1.45	1.42	1.38	1.35	1.31	1.28
Mexico	1.87	1.75	1.64	1.56	1.49	1.45	1.42	1.38	1.35	1.31	1.28
Brazil	1.87	1.75	1.64	1.56	1.49	1.45	1.42	1.38	1.35	1.31	1.28
RoLA	1.87	1.75	1.64	1.56	1.49	1.45	1.42	1.38	1.35	1.31	1.28

The baseline 2010 energy intensity for the U.S. is derived from data reported by the U.S. Department of Energy. [27,35] Data on the expected changes in aircraft energy intensity are taken from research complied by the Intergovernmental Panel on Climate Change (IPCC). [39] Data produced in a United Kingdom Department of Trade and Industry forecast (as compiled by the IPCC), indicates the expected change in aircraft energy intensity to be 1.3 percent per year between 2000 and 2010, 1.0 percent per year between 2011 and 2020, and 0.5 percent per year from 2021 through 2050. These data predict a 31.5 percent reduction in fuel consumption per seat-km between 2000 and 2050, and are generally consistent with the 17 or so other data sources compiled by the IPCC, so that the ICCT believes they represent a reasonable reference for this study. As a result, they have been applied to the reported U.S. baseline energy intensity data to derive expected future aircraft energy intensity throughout the forecast period. It should be noted that 2000 and 2005 energy intensity data are also calculated using these same data and backcasting from the reported 2010 baseline. Since these efficiency forecasts are based on a future that does not include a carbon tax (or equivalent), they are assumed to reflect aircraft energy intensity potential under a locally-driven future.

For a globally-driven future, an additional efficiency improvement is assumed to result from the imposition of a \$100 per tonne CO_2 tax (or equivalent) beginning in the 2020-2025 timeframe. The United Kingdom Department of Trade and Industry commissioned a study to determine the impacts of just such a tax on their forecasted aircraft energy intensities, and that study predicted an additional 22.2 percent reduction in fuel consumption relative to the improvements estimated for the locally-driven future. [40] Accordingly, the ICCT has applied this additional improvement to the 2025 through 2050 aircraft fuel intensity estimates for the locally-driven future to derive corresponding estimates for the globally-driven future. Given the global nature of aircraft production, the same fuel intensity data are assumed for all five modeling areas, as presented in Tables 58 and 59.

Finally, as discussed above, the ICCT properly expanded the SMP model structure for aircraft to include the load factor (passengers per seat) required to convert generalized input energy intensity into corresponding passenger-kilometer specific energy consumption. For initialization purposes only, the ICCT encoded a load factor value of 70 percent based on fleetwide average data reported by the IPCC. [39] This value was applied to all modeling areas and all forecast years, with the expectation that UCB researchers would update the initialization values as appropriate as an integral part of their independent transportation activity estimation.

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