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TECHNOLOGY UPTAKE, COSTS, AND BENEFITS UNDER A NEXT-PHASE PASSENGER CAR EFFICIENCY PROGRAM IN BRAZIL

Francisco Posada, Joshua Miller, and Cristiano Façanha

THE INTERNATIONAL COUNCIL
ON CLEAN TRANSPORTATION

www.theicct.org

communications@theicct.org

BEIJING | BERLIN | BRUSSELS | SAN FRANCISCO | WASHINGTON

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International Council on Clean Transportation
1225 I Street NW, Suite 900
Washington, DC 20005 USA

communications@theicct.org | www.theicct.org | @TheICCT

EXECUTIVE SUMMARY

Brazil is the sixth largest market for new passenger vehicles worldwide and the largest market in Latin America. As of 2013, passenger vehicles sold in Brazil have adopted fewer fuel-saving technologies than other leading automotive markets, resulting in less efficient cars, especially when compared to markets with similarly sized vehicles, such as Europe or Japan. Moreover, passenger vehicles in Brazil are a substantial contributor to global greenhouse gas (GHG) emissions and energy consumption, emitting an estimated 105 million tonnes of CO_2-equivalent and consuming more than 700,000 barrels of oil equivalent per day in 2015.

In 2012, the Brazilian government announced the Inovar-Auto program aimed at enhancing national competitiveness and incentivizing the auto industry to produce more technologically advanced, safer, and more efficient vehicles (Façanha, 2013). As the program nears completion in 2017, it is important to evaluate whether manufacturers have met these targets in practice (which is pending the availability of detailed 2017 data) as well as consider options for further improving vehicle efficiency. Vehicle efficiency and GHG standards in other markets have been proven to encourage the rate of technology development, and this analysis evaluates the level of technology adoption, costs, and efficiency improvement associated with alignment with the European Union's 2021 target of 95 gCO_2/km (equivalent to 1.27 MJ/km) for new passenger cars in 2023. Such a program would reduce the energy consumption of new cars by 29% from 2017 to 2023, equivalent to 36% below the 2013 baseline level.

This analysis adapted the U.S. Environmental Protection Agency's (EPA's) OMEGA technology optimization model (2012 version) to assess the incremental costs to manufacturers of meeting a target of 1.27 MJ/km in 2023 compared with the Inovar-Auto 2017 target of 1.81 MJ/km (assuming average vehicle weight equal to the 2013 baseline year). Fuel savings to consumers were estimated based on the reduction in energy consumption by vehicle model combined with estimates of annual vehicle travel and projected fuel prices. According to the least-cost-technology pathway identified by OMEGA, the average new car sold in 2023 would save consumers about $4,040 (in 2016 U.S. dollars [USD]) over 15 years—about 2.4 times the cost of additional vehicle technology ($1,660). Since the 2012 EPA technology assessment for its regulations, rapid advances in emerging engine technologies are resulting in the ability to achieve lower fuel consumption levels at lower cost, indicating that these cost estimates are conservative.

In addition to direct benefits to consumers, by 2035, the evaluated targets would achieve a 23% reduction in projected GHG emissions and energy consumption of Brazil's passenger car fleet, preventing the annual release of 35 million tonnes of carbon dioxide equivalent and saving the energy equivalent of 250,000 barrels of oil per day. The evaluated program would also improve the energy efficiency of Brazil's new passenger car fleet at a rate consistent with the regulations adopted in other leading markets, thus leading to increased competitiveness because of more technology adoption (Figure 1). According to OMEGA, the evaluated 2023 target would result in widespread adoption of gasoline direct injection, turbocharging, and advanced transmissions across all segments. Although start-stop and mild-hybrid technologies are estimated to be cost-effective solutions for specific vehicle segments, full hybrid and battery electric vehicle technologies are not needed to meet the 2023 target. These findings indicate that a next-phase program for Brazil to align with the European 95 gCO_2/km target by 2023 could effectively pay for itself and modernize Brazil's new passenger car fleet while reducing GHG emissions and saving energy. Figure 2 illustrates improvements in corporate average energy consumption in major vehicle markets that have proposed or adopted GHG, fuel economy, or fuel consumption standards for passenger vehicles. By adopting the targets evaluated in this analysis, Brazil would align vehicle efficiency with other such markets, thus keeping pace with international technology innovation and industrial competitiveness.

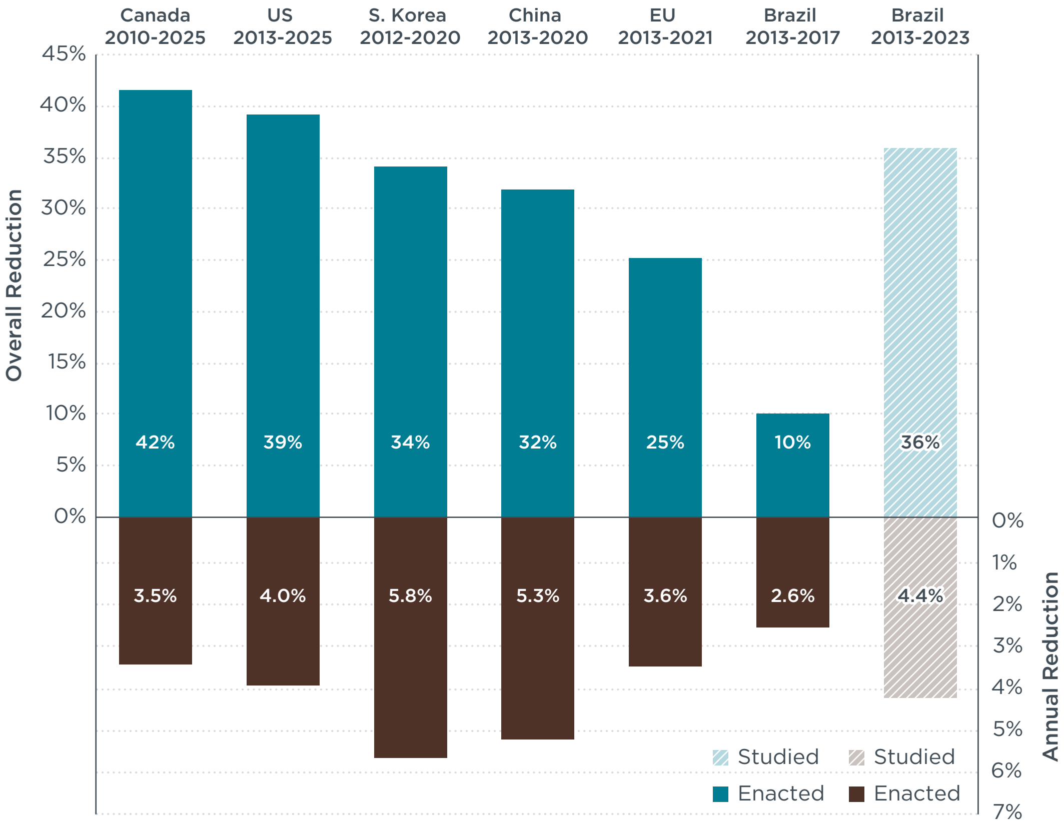

Figure 1. Comparison of adopted regulations for new passenger cars in selected markets. Brazil's fleet would realize a greater efficiency benefit under a program similar to the European Union's 95 gCO_2/km target because the starting level (2013) of technology adoption in Brazil is lower than in the European Union.

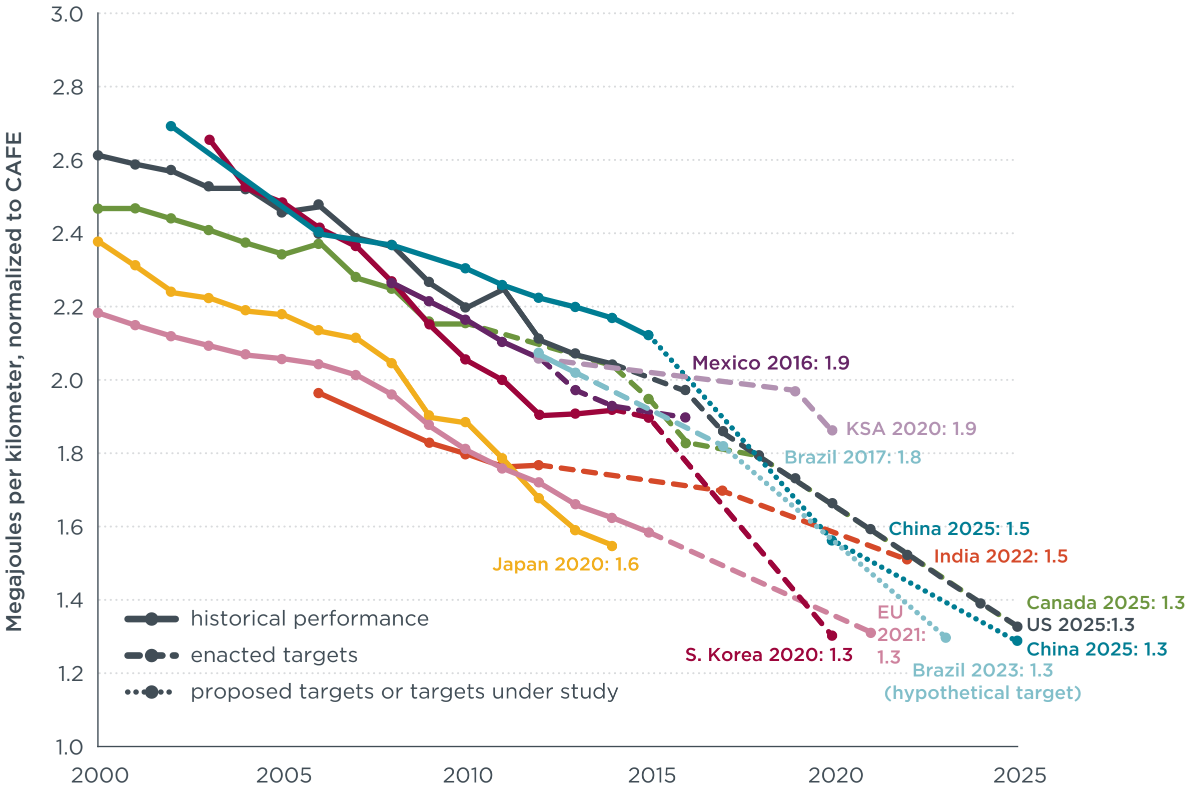

Figure 2. Passenger car energy consumption normalized to two-cycle CAFE test equivalent values. Data labels are rounded to two significant figures. Brazil's targets for 2023 correspond to the values discussed in this analysis and should not be interpreted as regulated values, nor as values endorsed by Brazilian authorities in charge of developing national regulations on vehicle energy consumption. Japan has already exceeded its 2020 target as of 2013. KSA = Kingdom of Saudi Arabia.

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INTRODUCTION

Brazil is the sixth largest market for new passenger vehicles worldwide and the largest market in Latin America. Passenger vehicles in Brazil are a substantial contributor to greenhouse gas (GHG) emissions and energy use, emitting an estimated 105 million tonnes of CO_2-equivalent and consuming more than 700,000 barrels of oil equivalent per day in 2015. According to previous research (Façanha, 2013), new cars sold in Brazil have a lower rate of adoption of fuel-saving technologies, resulting in less efficient cars than in comparable markets (Figure 3). In 2012, Brazil's Ministry of Industry, Trade and Services (MDIC) announced the Inovar-Auto program aimed at enhancing competitiveness by giving the auto industry incentives to produce more efficient vehicles (Façanha, 2013). As the program nears completion in 2017, it is important to consider options for further improving vehicle efficiency beyond the 2017 targets established by Inovar-Auto.

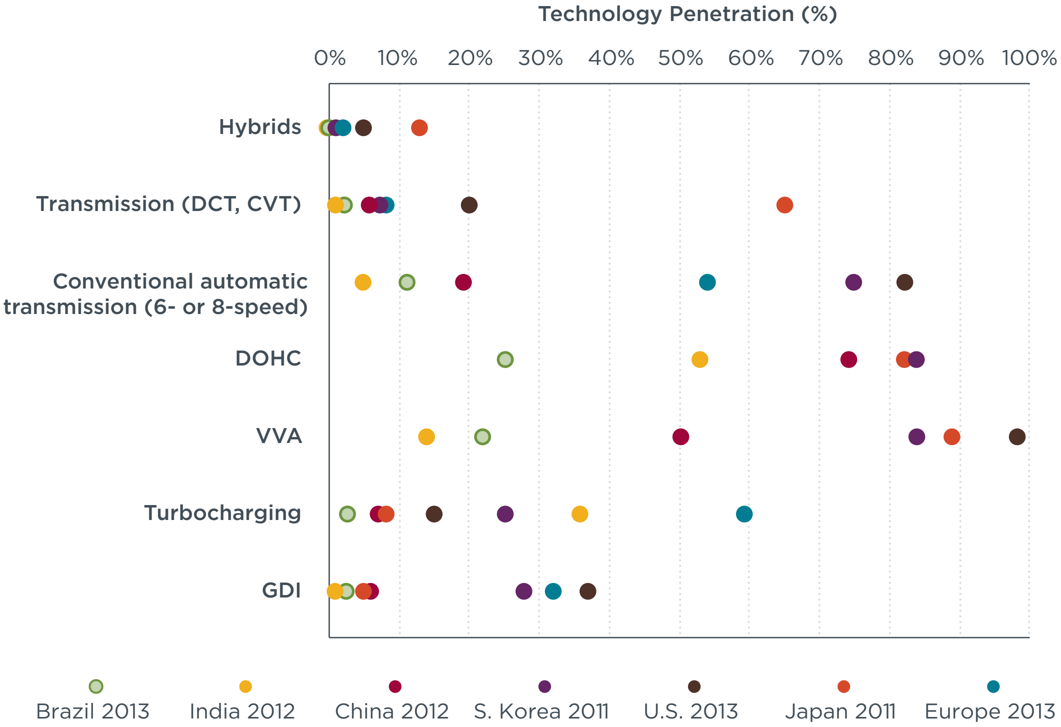

Figure 3. International comparison of technology penetration in passenger vehicles. Country labels indicate the dataset year. Source: Posada and Façanha (2015). VVA, variable valve actuation; other terms are defined below.

Because Inovar-Auto's most stringent target for 2017 (Equation 3 of the current policy) is roughly equivalent to the European Union's target of 130 gCO_2/km in 2015, this analysis assumes a vehicle energy consumption target in 2023 that is consistent with the European Union's 2021 target of 95 gCO_2/km. The focus of this report is twofold: to estimate the expected level of technology deployment in Brazil's passenger car fleet in 2017 under the current Inovar-Auto program relative to a 2013 baseline, and to evaluate the costs, benefits, and level of technology adoption to meet a 2023 target versus the 2017 target. The analysis builds on ICCT's 2013 database of passenger vehicle sales in Brazil, which includes efficiency and technology data by vehicle model, manufacturer, and segment (Posada & Façanha, 2015).

This analysis relies on EPA technology modeling to assess the costs and benefits of passenger vehicle efficiency regulations. The Optimization Model for Reducing Emissions of Greenhouse Gases from Automobiles (OMEGA) evaluates the relative costs and effectiveness (CO_2/energy consumption reduction) of vehicle technologies and applies them to a defined vehicle fleet in order to meet a specified CO_2 (or energy consumption) target. OMEGA estimates of technology effectiveness and cost were developed with substantial effort by technical experts, and the results of that work are well documented and available to the public. The technology inputs are based on automaker and supplier input, state-of-the-art teardown cost assessment, and rigorous physics-based vehicle simulation modeling. No other regulatory agency in the world has released equivalent technical and cost analyses supporting the decision process to adopt fuel economy or GHG regulations for new vehicles. We adapted EPA's OMEGA for Brazil to evaluate the cost of technology needed to meet the standards, using the characteristics of Brazil's existing new light-duty vehicle fleet as a baseline. The OMEGA analysis presented here for a next-phase Inovar-Auto program used the technology packages and costs developed by EPA in 2012 for analysis of the "2017 and Later Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards" regulation in the United States.

The EPA has subsequently released new estimates of technology effectiveness and costs as part of the midterm evaluation of the 2022–2025 light-duty greenhouse gas standards. These estimates, released in July 2016 in the Draft Technical Assessment Report (U.S. EPA/NHTSA/CARB, 2016) and in November 2016 in the Proposed Determination (U.S. EPA, 2016), suggest that technology innovation is advancing at a faster pace than anticipated and that costs are lower than initially estimated in 2012. Since the U.S. 2012 regulatory assessment, advances in such technologies as cylinder deactivation, direct injection, cooled exhaust gas recirculation, lightweighting, and electric vehicle batteries are resulting in the ability to achieve lower CO_2 emissions at lower cost (ICCT, 2016b). For these reasons, the cost results presented here are conservatively high. Future analysis that applies the OMEGA version released in EPA's Proposed Determination and incorporates additional refinements to technology effectiveness and costs can be expected to result in substantially lower costs than estimated here. Finally, these technology costs do not capture the potential for even lower production costs in Brazil, given that the costs to research and develop many of these technologies have already been incurred in the United States, Europe, or Japan and have been popularized in those countries over the past decade.

The report is structured as follows: The first section summarizes the methodologies for adapting the OMEGA model to Brazil's fleet and calculating the costs, benefits, and payback of next-phase standards; the second section presents the results of the OMEGA modeling and payback analysis; and the final section interprets the implications of this analysis for the next phase of Brazil's passenger car energy efficiency program.

METHODS

The objective of applying OMEGA to the Brazilian market was to gain a precise understanding of the vehicle technologies that would be required to meet the next phase of vehicle energy consumption standards and the cost implications of different regulatory scenarios. The OMEGA model was developed by the U.S. EPA as a tool to evaluate the impact of the U.S. 2012–2016 GHG regulations for the light-duty vehicle fleet and was updated, improved, and used again in the development and assessment of the 2017–2025 standards.

Broadly, OMEGA requires a detailed baseline fleet, including manufacturer, sales, base CO_2 emissions, footprint (shadow area defined by the tires' contact with the ground), and the extent to which emission control technologies are already in use. The Brazilian fleet analyzed encompasses 331 vehicle models and total sales of approximately 2.3 million vehicles. The analysis is intended to capture the important differences in vehicle and engine design of future vehicle sales in the 2017–2023 time frame. The model includes a list of technologies that are applicable to various types of vehicles, along with the technologies' cost and effectiveness, and the percentage of vehicle sales that can receive each technology. The model uses this information to project how various manufacturers would apply the available technology in order to meet increasingly stringent CO_2 (or energy consumption) targets. The result is a description of the technologies that would need to be added to each vehicle platform, along with the resulting costs, to reach the CO_2 targets for various scenarios.

OMEGA is designed to apply technology in a manner similar to the way that a vehicle manufacturer might make such decisions. In general, the model considers two factors important to the manufacturer: the cost of the technology, and the degree to which the technology moves the manufacturer toward achieving its fleetwide CO_2 emission target. OMEGA solves a minimization problem trying to find the lowest cost for each manufacturer while meeting the standard; this allows for some specific vehicle models being overcompliant and others exceeding the target. OMEGA applies technology (subject to phase-in constraints such as hybrid and electric vehicle penetration rates) to vehicles until the sales-weighted emission average complies with the specified standard or until all the available technologies have been applied.

The standards applied to OMEGA are structured following the Inovar-Auto standards for passenger vehicles (Equation 1 of the current policy), and the final target follows the mass-based standard designed in Europe and adapted here to comply with the metric used under the Brazilian program, megajoules per kilometer (MJ/km). Whereas the OMEGA model uses default units of grams of CO_2 per mile (gCO_2/mi), all results in this paper are presented in units of MJ/km assuming an average blend of 27% ethanol and 73% gasoline by volume (E27, where E100 is pure ethanol). Ethanol and gasoline are assumed to have energy intensities of 21.27 and 31.66 MJ/liter, respectively. Manufacturer flexibilities that help compliance with the standard were also included. This covers off-cycle credits for start-stop systems, active grill shutters, gear shift indicators, tire pressure monitoring systems, and use of ethanol fuel.[1,2]

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[1] Some of the technologies listed as manufacturer flexibilities (e.g., gear shift indicators) in Innovar-Auto program do not provide any real world efficiency benefit (Façanha, 2015)

[2] An additional correction factor established in MDIC Ordinance No. 117 of 04/15/2016 affects only sports cars (sales 7600 units), off-road vehicles (sales 500 units), and light commercial vehicles (LCVs) up to a maximum of 2000 units. The first two categories represent less than 0.3% of sales, and LCVs are not considered in this analysis. Considering the cap of 2000 units, this credit is not explicitly modeled in this analysis.

We modified the structure of the inputs from Brazilian vehicles in order to run the EPA-designed model. Given that the OMEGA model was originally designed to investigate compliance with CO_2 targets that are based on vehicle footprint, we had to modify the inputs from the Brazilian regulatory framework, which set targets in MJ/km based on vehicle mass. This modification is explained at the end of this section.

OMEGA MODEL STRUCTURE

The overall structure of the OMEGA model is described in Figure 4. OMEGA includes several components, including a number of preprocessors that assist the user in preparing a baseline vehicle database, creating and ranking technology packages, and calculating the degree to which technology is present on baseline vehicles. The OMEGA core model collates this information and produces estimates of changes in vehicle cost and CO_2 emission level. Based on the OMEGA core model output, the technology penetration and costs of the new vehicle mix are calculated via postprocessors.

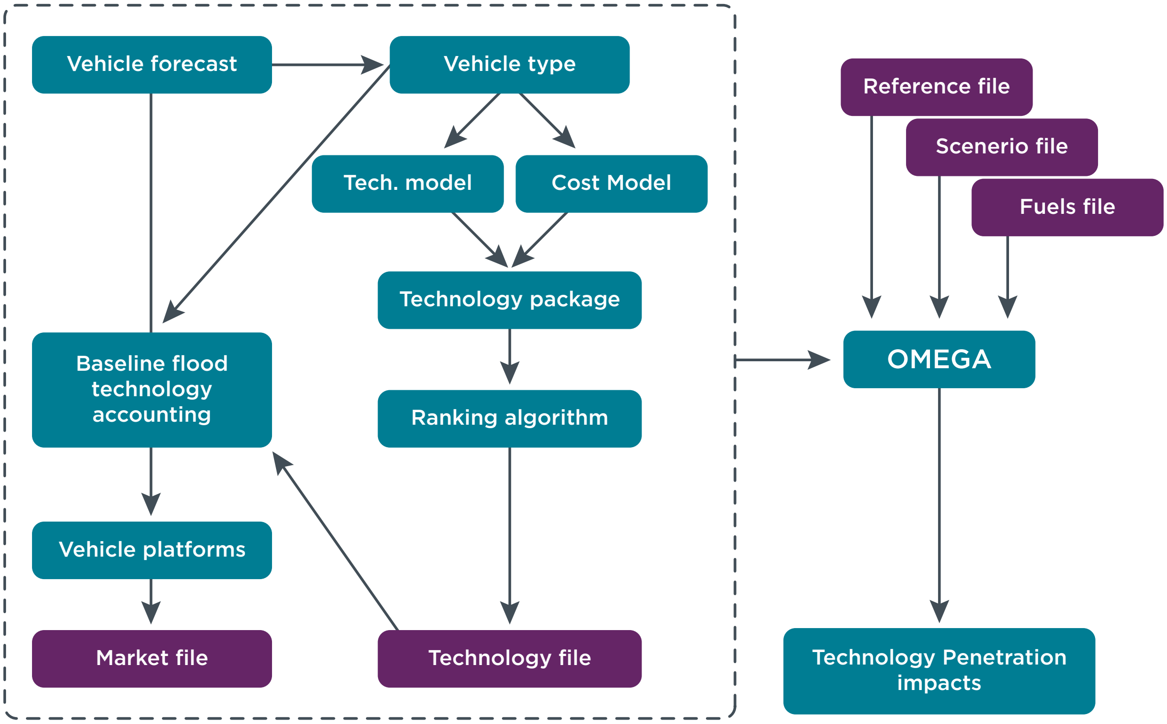

Figure 4. OMEGA model general structure and information flow.

OMEGA uses five basic sets of input data: the vehicle market file, the technology file, the fuels file, the scenario file, and the reference file. Below is a list of model input requirements that have been modified for use with the Brazilian passenger car fleet.

1. THE MARKET FILE: VEHICLE MARKET FLEET CHARACTERIZATION

This file is the input that describes the vehicle fleet composition used by the model to estimate costs. In this analysis, vehicle sales projections were held constant for each segment, manufacturer, and model in order to isolate the impacts of improved vehicle technology. The market data worksheet is composed, on a vehicle-by-vehicle basis, of:

a. Vehicle index number
b. Manufacturer
c. Model
d. Vehicle type number
e. EPA vehicle class
f. Baseline sales
g. Annual sales
h. Tailpipe emissions, gCO_2/mi
i. Footprint, ft^2
j. Fuel
k. Combined average electricity consumption (EC; kWh/mi) for hybrids
l. Refrigerant type (for air conditioners)
m. Refrigerant lifetime leakage (not used)
n. Efficient technology penetration

The last item, the efficient technology penetration input, contains information on all of the technologies that are already available in the vehicle being sold in calendar year 2012. This basic set of information allows the model to avoid adding technology to models that are already sold with the technology. As an example, if a vehicle model sold in 2012 already has turbocharging technology, then the cost of adding that specific technology is zero for that model.

2. THE TECHNOLOGY FILE: TECHNOLOGY PACKAGE CHARACTERIZATION

Because a number of individual technologies that reduce CO_2 emissions are in use, and because a wide array of different combinations of such technologies are used in each vehicle type, OMEGA relies on a preset list of technology packages that can be applied to each vehicle type. The technology file thus contains costs and efficiency values for each of the technology packages by vehicle type.

OMEGA uses 19 different vehicle types to assign technology packages. Vehicle manufacturers typically develop several unique models based on a limited number of shared vehicle platforms, allowing for efficient use of design and manufacturing resources. A given platform typically consists of common vehicle architecture and structural components. U.S. EPA mapped about 200 platforms into 60 common platforms for OMEGA modeling. Those 60 common platforms were then grouped into 19 vehicle types, as those platforms could share the same fuel-efficient technology. The following list shows some examples of the platforms for each of the listed vehicle types. Platforms are defined by vehicle size, engine type, camshaft technology, and air management (boost) as follows:

1. Subcompact car, inline 4-cylinder (I4) double overhead cam (DOHC) or single overhead cam (SOHC), four valves per cylinder (4v) engine
2. Compact and midsize car, I4 DOHC or SOHC, 4v engine
3. Subcompact car, I4 SOHC/DOHC, 4v, boost; compact car, I4 SOHC/DOHC, 4v, boost; midsize car, V 6-cylinder (V6) DOHC 4v engine; large car, SOHC/DOHC, 4v engine
4. Midsize car, V6 SOHC, two valves per cylinder (2v) engine; large car, V6, overhead valve (OHV) 2v engine
5. Large car, V 8-cylinder (V8) DOHC 4v engine
6. Large car, V8 OHV 2v engine
7. Small multipurpose vehicle (MPV), I4 DOHC 4v engine
8. Midsize MPV, V6 DOHC 4v engine
9. Midsize MPV, V6 SOHC 2v engine
10. Midsize MPV, V6 OHV 2v engine
11. Large MPV, V8 DOHC 4v engine
12. Large MPV, V8 OHV 2v engine
13. Small truck, I4 DOHC 4v engine
14. Full-sized pickup truck, V6 DOHC 4v engine
15. Full-sized pickup truck, V6 OHV 2v engine
16. Full-sized pickup truck, V8 DOHC 4v engine
17. Full-sized pickup truck, V8 SOHC 2v engine
18. Full-sized pickup truck, V8 SOHC 3 valves per cylinder (3v) engine
19. Full-sized pickup truck, V8 OHV 2v engine

EPA developed a list of 50 fuel-efficient technology packages that can be applied to most vehicle types (for some vehicle types, certain technology packages are not applicable). Many of the individual technologies that make up these packages—including direct fuel injection, turbocharging, variable valve timing, continuously variable transmissions (CVTs), conventional automatic transmissions, cylinder deactivation, and engine downsizing—have been previously identified as important for the development of Brazil's domestic market in the coming years (ABDI, 2009). Technology packages and costs are also defined for each of three evaluation years: 2016, 2021, and 2025. In total, the technology file includes a total of 727 technology package estimates on cost and fuel economy benefits.

The cost data for each of the packages were determined by EPA through vehicle tear-down studies.[3] Such studies involve disassembling vehicle systems and components to identify each component part (down to the level of individual nuts and bolts) and then estimating and aggregating the manufacturing costs associated with each individual component. A list of component parts was developed and costed using the best (and most credible) available information. This generally involves information obtained from

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[3] U.S. Environmental Protection Agency, "Regulatory Impact Analysis: Final Rulemaking for 2017–2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards," EPA-420-R-12-016, August 2012.

parts suppliers and vehicle manufacturers. The individual technologies studied by EPA and used by OMEGA are presented in Table 1.

Brazil would enjoy the benefit of adopting technology that has already been developed and put into production in developed markets for several years. As an example, in Europe, gasoline direct injection (GDI) has been deployed since at least 2008, and now this technology is used by more than 30% of new vehicles sold in Europe (Mock, 2016). New technologies typically incur higher costs during the first cycles of production, but these costs are reduced over time as a result of (a) development of more efficient production techniques and (b) increasing sales volumes that reduce variable production costs. This means that Brazil will not face these technology development costs but will benefit from cost reductions due to production improvements and higher global technology sales. Although this analysis does not count several factors that may reduce incremental technology costs (i.e., learning and economies of scale), it also does not account for the potential impact of taxes on end user costs. To the extent that additional vehicle technologies increase the purchase price of vehicles sold, and consequently increase sales taxes (which tend to be higher in Brazil than in the United States),[4] this may provide a rationale for providing tax incentives for more-efficient vehicles. This could take the form of continuing a reduction in the tax on industrialized products (IPI), as instituted by Inovar-Auto from 2013 to 2017, or it could take the form of a redesigned IPI that scales depending on the fuel efficiency of the vehicle.

Table 1. List of fuel-saving technologies in OMEGA.

Abbreviation	Meaning
Mass tech	Mass technology applied, expressed as a negative
True mass	Net mass reduced
Mass penalty	Mass increase due to technology
TDS 18/24/27	Turbocharging and downsizing at 18-, 24-, or 27-bar BMEP (brake mean effective pressure)
AT6/8	Automatic transmission (six- or eight-speed)
DCT6/8	Dual-clutch transmission (six- or eight-speed)
MT	Manual transmission
HEG	High-efficiency gearbox
EGR	Cooled exhaust gas recirculation
HEV	Hybrid electric vehicle
EV	Full electric vehicle
PHEV	Plug-in hybrid electric vehicle
SS	12V stop-start
LRRT	Lower-rolling-resistance tires
IACC	Improved accessories
EFR	Engine friction reduction
DI	Stoichiometric gasoline direct injection (GDI)
DSL	Advanced diesel
AERO	Active aerodynamic technologies (e.g., grill shutters)

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[4] Contesini, L. (September 2014). "Aqui vs. lá fora: por que o carro no Brasil é tão caro?" *Flatout!*; www.flatout.com.br/aqui-vs-la-fora-por-que-o-carro-brasil-e-tao-caro/.

In addition to developing current cost estimates for fuel economy technologies, the EPA work also includes the development and application of learning factors (which are used to forecast future year costs from developed base year costs) and the current state of development for each potential fuel economy technology. Technologies that are in a more advanced stage of development are assumed to undergo relatively minor cost declines over time, whereas emerging technologies are subject to greater reductions expected to accrue as manufacturers gain design and production experience.

The benefits were first determined at the individual technology level and later integrated into OMEGA as aggregate benefits under technology packages. Estimates of the fuel economy benefits of a given technology were based on detailed vehicle simulation modeling. Such estimates are necessary to define the specific benefits associated with both individual technologies and packages of multiple technologies (as required to determine "how much" technology is required to attain a specific standard). Simulation modeling is the state-of-the-science approach to evaluating the effects of a given technology on vehicle performance, relying on detailed physics-based algorithms and associated input data to represent the relationships among all of a vehicle's systems. Once defined, these relationships can be evaluated over any defined driving cycle (such as the FTP-75 and highway driving cycles used by U.S. fuel economy programs and by the Brazilian regulations for light-duty vehicles) to derive associated fuel economy estimates. Substituting alternative technologies for one or more of the vehicle components allows for associated fuel economy effects to be isolated. The development of the required physical models is quite demanding, but the resulting impact estimates are quite rigorous. When considered in conjunction with the general reusability of the developed component models, simulation modeling has become the industry standard alternative to the actual production and testing of a physical vehicle (during the early stages of vehicle design).

Table 2 presents a subset of technology package data for the compact car, I4 DOHC/SOHC 4v class; the complete set covers 49 technology packages for this type of vehicle (one package is not applicable). Note that costs and CO_2 reduction benefits are provided by technology package, not as individual technologies. Data for the other 18 vehicle types and evaluation years are in the same format. Although too voluminous to reproduce in this report, the complete dataset is publicly available.[5]

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[5] The complete EPA dataset is available as document EPA-HQ-OAR-2010-0799-11837 "FRM OMEGA model, OMEGA inputs and outputs & GREET 2011 (DVD)" in U.S. EPA rulemaking docket EPA-HQ-OAR-2010-0799. The DVD was placed in the docket on August 1, 2012. A physical copy of the DVD can be obtained from docket-customerservice@epa.gov.

Table 2. Example: U.S. EPA technology cost and CO_2 reduction estimates for compact car I4 DOHC, 2021.

Tech package number	Technology package components	Transmission	Cost (2010 USD)	CO_2 reduction
0	Passenger car (auto) 4VDI4 with MPFI+4sp (baseline package)	4sp AT	$0	0.0%
1	Auto 4VDI4+X1+DCP+WR0%+6sp	6sp DCT-dry	$350	24.6%
2	Auto 4VDI4+X1+DCP+WR5%+6sp	6sp DCT-dry	$388	26.5%
3	Auto 4VDI4+X2+DCP+WR5%+6sp	6sp DCT-dry	$432	28.0%
4	Auto 4VDI4+X2+DCP+WR5%+8sp	8sp DCT-dry	$541	31.0%
5	Auto 4VDI4+X3+DCP+WR10%+6sp	6sp DCT-dry	$705	31.7%
6	Auto 4VDI4+X4+DCP+WR5%+8sp	8sp DCT-dry	$745	34.1%
7	Auto 4VDI4+X5+DCP+WR10%+8sp	8sp DCT-dry	$923	36.6%
8	Auto 4VDI4+X2+HEG+DCP+DVVL+WR10%+8sp	8sp DCT-dry	$1024	36.8%
9	Auto 4VDI3+X3+DCP+GDI+TDS24+WR10%+6sp	6sp DCT-dry	$1570	40.2%
10	Auto 4VDI4+X5+HEG+DCP+DVVL+WR10%+8sp	8sp DCT-dry	$1293	40.0%

Note: X1 = LUB+EFR1+ASL2+IACC1+EPS+Aero1+LDB+LRRT1
X2 = LUB+EFR1+ASL2+IACC1+EPS+Aero1+LDB+LRRT2
X3 = LUB+EFR1+ASL2+IACC2+EPS+Aero2+LDB+LRRT1
X4 = LUB+EFR1+ASL2+IACC2+EPS+Aero2+LDB+LRRT2
X5 = EFR2+ASL2+IACC2+EPS+Aero2+LDB+LRRT2
X6 = EFR2+ASL2+IACC2+EPS+Aero2+LDB+LRRT1
X7 = EFR2+ASL2+IACC1+EPS+Aero2+LDB+LRRT2

Note: Acronyms listed here are described in the List of Acronyms annex at the end of this report.

3. THE SCENARIO FILE: DEFINITION OF REGULATORY SCENARIOS AND OTHER ECONOMIC PARAMETERS

In the scenario file, the user must specify the year, type of compliance target (CO_2 or MPG), type of compliance function (single value, piecewise linear, or S-shaped), and the names of the other input files that describe the vehicle fleet, technology packages, and fuel properties as previously described. Adjustments to the scenario file were made to run Brazilian targets.

4. THE FUELS FILE

Fuel properties of gasoline, such as energy density and carbon density, were taken from EPA's original files. Payback results were evaluated in postprocessing rather than using the fuels file information. For this postprocessing, ethanol and gasoline are assumed to have energy intensities of 21.27 and 31.66 MJ/liter, respectively.

5. THE REFERENCE FILE

This file describes vehicle survival rates and miles driven for both vehicle classes, cars and light-duty trucks. It is used to estimate total tons of CO_2 emitted by each vehicle class when calculating costs within the OMEGA framework.

OMEGA MODEL APPLIED TO BRAZIL'S FLEET

The OMEGA modeling for the Brazilian fleet required the development of input files to reflect Brazilian conditions. The technology input files for each of the regulatory stages, Inovar-Auto Equation 1 2017 ("Brazil 2017") and European equivalent 95 gCO_2/km ("Brazil 2023"), were the only files not modified for the analysis; they are the same files as originally designed by EPA for studying manufacturer compliance with the U.S. GHG standards.

Market file

A market file was created for the Brazilian fleet based on the database developed by the ICCT and described by Posada and Façanha (2015).

Reference file

The reference input file was modified with respect to the original EPA input file to reflect vehicle activity in Brazil for cars and light-duty trucks. The lifetime vehicle activity used in this analysis was 247,760 km for all passenger car segments (equivalent to 16 years over the national inventory scrap curves). Note that the targets are the same for all vehicles, whereas the U.S. EPA program has distinct targets for cars and light trucks (SUVs and pickups). For the payback analysis, a conservatively short vehicle lifetime of 15 years was applied; vehicles lasting longer than that would result in additional fuel savings benefits that are not captured in the payback results.

Scenario file

To determine the technology costs associated with a next-phase program, we studied two GHG target scenarios:

1. **Baseline Inovar-Auto 2017:** The first analysis is to determine the costs associated with meeting the current requirements of the Inovar-Auto program for 2017. The requirements of Equation 1 were applied, because this equation determines whether each manufacturer qualifies for the 30% reduction in IPI. Equation 1 indicates a 12.1% improvement in new vehicle efficiency relative to 2012 (Façanha, 2013). The costs of compliance with the Inovar-Auto program in 2017 are estimated by comparison to the level of technology in the 2013 new passenger car fleet. The costs of technology for this scenario are then used as the baseline for evaluating the incremental costs of the next-phase program.

2. **Brazil 2023:** This scenario considers a next-phase program to adapt the European Union's 2021 target for new passenger cars to Brazil's fleet, with full phase-in by 2023. Because both Brazil and the European Union establish corporate average energy consumption and CO_2 targets based on vehicle mass, the sales-weighted average energy consumption target for each manufacturer in Brazil takes into account that manufacturer's distribution of vehicle sales by mass. The European target is defined as

   $$CO_2\ (g/km) = 95 + [0.0333(M - Mo)]$$

   where M is the mass of the vehicle and Mo is the average of the last 3 years of vehicle mass, averaged across all vehicles sold by the manufacturer.

Converting the EU target into a Brazil 2023 target structure yields the following equation:

$$VE\ (\text{MJ/km}) = 0.7791 + (0.000445 \times M)$$

where *VE* is the vehicle efficiency target in MJ/km and *M* is the sales-weighted average mass of vehicles sold. Note that for the 2023 target, the value of *M* was kept constant and equal to 2013 values. Changes in average mass, although possible as a result of changes in market preferences, result in unpredictable shifts to lower or higher values.

The incremental costs of this next-phase program are estimated using the Inovar-Auto 2017 curve as a baseline. This means that the total incremental cost of technology relative to 2013 is equal to the estimated cost under Inovar-Auto in 2017 plus the cost of the next-phase (2023) program.

The energy consumption curves evaluated for each of the baseline and target scenarios are shown in Figure 5. The targets shown here in MJ/km were converted to gCO_2/mi in order to run the scenarios according to OMEGA's input design.

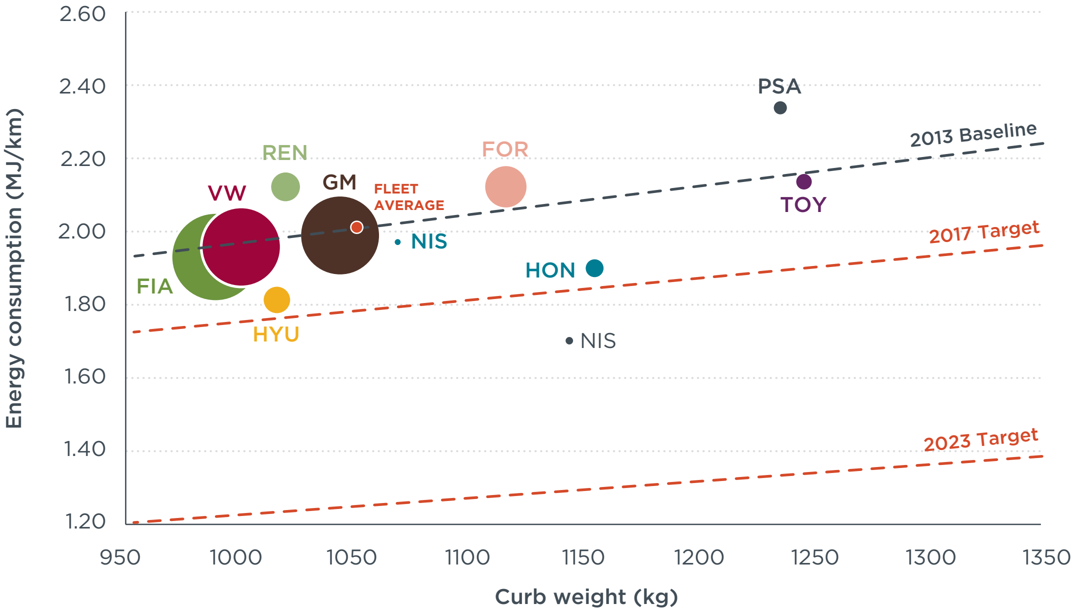

Figure 5. Energy consumption and CO_2 targets for passenger cars in Brazil. FIA, Fiat Chrysler; VW, Volkswagen; REN, Renault; HYU, Hyundai; GM, General Motors; NIS, Nissan; FOR, Ford; HON, Honda; PSA, Peugeot Citroën; TOY, Toyota.

Inovar-Auto provides flexibilities to manufacturers to encourage the adoption of fuel-efficient technologies that result in real-world benefits, but which are not fully accounted for on the regulatory certification tests (FTP-75 and HWFET). These allowable credits reduce the stringency of the 2017 target by the equivalent of 2.1 gCO_2/mi (Table 3). For OMEGA modeling purposes, a credit was included in the 2017 target to account for those technologies while taking into consideration their market penetration rate, as not all the listed off-cycle technologies are going to be deployed in all segments and in all vehicle models. Because OMEGA already allocates off-cycle credits to start-stop and active grill shutters, these technologies do not affect the modeled 2017 target.

Those technologies listed in Inovar-Auto but not included in OMEGA's technology file—for example, gear shift indicator and tire pressure monitoring system—affect the target according to calculations involving their listed credit value and penetration rate estimates based on engineering judgment. The analysis conservatively assumed that 100% of the fleet receives the ethanol credit, given that virtually all vehicles sold today (~97%) have flex-fuel engines. The model does not include limitations to off-cycle values for high-performance vehicles,[6] as they represent less than 0.3% of the fleet modeled, with a negligible impact on estimated costs and technology adoption rates.

Table 3. Manufacturer credits allowed under the current Inovar-Auto program.

Credits	Credit value under Inovar-Auto (MJ/km)	Credit value (liters/km)	Credit value (gCO_2/mi)	% use	Total credit (g/mi)
Start-stop	0.023	0.00078	2.7	Included*	—
Active grill shutter	0.005	0.00017	0.6	Included*	—
Gear shift indicator	0.013	0.00046	1.6	50%	0.8
Tire pressure monitor	0.013	0.00046	1.6	50%	0.8
Ethanol	0.004	0.00014	0.5	100%	0.5
Total credit modeled					**2.1**

* *Included means that this particular technology and the off-cycle credit that it generates have already been included as part of the OMEGA technology file.*

The target values for OMEGA modeling applied to the Brazilian vehicle fleet are shown in Table 4. The values listed correspond to the energy efficiency (converted to gCO_2/mile) target points A and B (corresponding to masses of 500 kg and 3500 kg, respectively) needed to draw the line for each standard.

Table 4. CO_2 emission targets used for OMEGA modeling of NOM 163 target scenarios. Point A represents the lower left endpoint in the target curve; point B represents the upper right endpoint in the target curve.

Scenario	Target point A (mass)	Target point A (gCO_2/mi)	Target point B (mass)	Target point B (gCO_2/mi)
Inovar-Auto 2017, Equation 1	500	174.6	3500	388.6
Brazil 2023	500	120.5	3500	281.3

Technology file

The original list of fuel-saving technologies and their cost was maintained in Brazil's fleet OMEGA modeling. In total, 332 models representing 2,326,860 units (76% of total vehicle sales) fit the 19 different OMEGA predefined vehicle types that were used for the technology projection. Energy consumption data for the remaining 24% of vehicle sales were not reported by manufacturers.

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[6] Portaria n° 117 de 15 de Abril de 2016 establishes correction factors to off-cycle values for sports cars, off-road vehicles (sales 500 units), and LCVs. Those correction factors apply only to the first 2,000 units sold by the manufacturer; the remainder would not benefit from the correction factor.

Some considerations on adapting the OMEGA model to Brazilian vehicles
Note that for this analysis, technology files were not modified to account for the impact of fuel quality differences between the United States and Brazil. OMEGA estimates of technology effectiveness were developed for technologies certified with a fuel with no ethanol content, while the Brazilian certification allows for ethanol content up to 22% (ABNT, 2012). Whereas the U.S. vehicle market uses commercial gasoline with 10% ethanol content (E10), commercial gasoline in Brazil has substantially higher ethanol content. This difference in fuel quality is expected to have an impact primarily on those technologies related to combustion improvements, such as turbocharging and direct injection; marginal impacts can be expected for hybridization technologies with Atkinson-cycle engines. A review of ethanol content effects on fuel efficiency by AVL and Ford (Stein et al., 2013) shows that the increase in octane number (ON) due to higher ethanol content has substantial benefits in terms of vehicle fuel consumption. Higher ethanol content increases the knock-limited brake mean effective pressure (BMEP), enabling higher thermal efficiency by downsizing the engine displacement or downspeeding the engine rpm. Higher ON also allows for an increase in compression ratio (CR), with immediate thermal efficiency gains. Stein et al. (2013) also reported that at low loads (characteristic of urban driving), higher ethanol content resulted in increased thermal efficiency due to lower combustion temperatures; at high loads, fuel efficiency and emissions improved because of a combination of favorable combustion phasing, higher heat of vaporization, and lower combustion and exhaust temperatures. Stein et al. (2013) concluded that higher ethanol content enables improved vehicle efficiency and CO_2 emissions through downsizing, downspeeding, and/or increased CR. With respect to the effect of ethanol on the Atkinson cycle used in hybrid vehicles, a paper by Petrobras suggests that use of E25 in a U.S.-market Toyota Prius had no significant effect in performance (Colnago et al., 2010). Yet Toyota suggests that the use of high-ON fuel with 20% ethanol content could enable further improvements in thermal efficiency for Atkinson-cycle engines used in hybrid vehicles (Nakata, 2014). Because CR thermal efficiency gains have already been exploited in Brazil and an additional increase in ethanol content could enable further gains in thermal efficiency, it can be safely assumed that the benefits of engine downsizing (with turbocharging and GDI) applied in OMEGA and in this analysis are conservatively low. Thus, it is possible that the adoption of these technologies in Brazil (as well as hybrid vehicles using Atkinson-cycle engines) could yield greater efficiency benefits at very low cost, resulting in a lower cost of compliance with Brazil 2023 standards than estimated here.

Fuels file

Fuel properties for gasoline, such as energy density and carbon density, were taken from EPA's original files. Payback results were evaluated in postprocessing, as described below. Because fuel pricing does not play a role in forecasting within the model, there was no need to modify the fuels file in any way.

METHODS FOR PAYBACK ANALYSIS

A key responsibility of regulatory agencies is to make sure that policies will have benefits that outweigh the costs to society. For vehicle efficiency and CO_2 regulations, an additional criterion for decision-making is the extent to which fuel savings will pay back the cost of vehicle technology to buyers of more efficient vehicles.

This analysis considers three methods for consumer payback under a next-phase vehicle energy consumption program for passenger cars in Brazil. The first two methods compare the cumulative discounted benefits (in the form of reduced fuel expenditures) with the incremental cost of vehicle technology, first for the buyer of an average vehicle and second for the new vehicle fleet in 2023. The benefits are counted over 15 years to reflect a conservatively short vehicle lifetime, as some vehicles in Brazil may remain in the fleet for 25 years or more. The third payback method reflects how many years it might take for buyers of an average new vehicle to recoup their investment, after which any fuel savings would represent a net gain when taking into account the value of time preference. This section describes the methods for calculating payback according to each of these methods, including the inputs for discount rate, vehicle mileage, and fuel prices.

Discount rate

The discount rate represents the rate at which individuals or societies are willing to trade current consumption for future consumption. This rate is compounded over time to reflect preferences for near-term consumption as well as the opportunity cost of private investment. For investments made by consumers that yield private returns, the discount rate can be approximated by starting with the real rate of return on private investments (also called the real interest rate, equal to the nominal interest rate minus inflation) and adjusting for the impacts of risk, taxation, and imperfect operation of capital markets (U.S. EPA, 2010). For this reason, the actual rate at which individuals can trade current consumption for future consumption tends to be lower than the real interest rate if individuals are investing cash. If, on the other hand, individuals are borrowing to make a purchase (for example taking out an auto loan to purchase a car), the consumer discount rate may be better approximated by the real interest rate on the loan. In cases where investments have benefits to society at large, several factors can justify using a lower discount rate: 1) governments can typically borrow at a lower interest rate than individuals or businesses; and 2) investments with long-term social impacts (such as GHG mitigation) require a lower discount rate in order to appropriately value impacts on future generations (US EPA, 2010).

This analysis balances the valuation of future costs and benefits from a private and a social perspective, applying a central discount rate of 7% per year. Sensitivity analysis is also conducted using discount rates of 3%, 5%, and 10% per year. The central discount rate of 7% is comparable to actual real interest rates (less inflation) on consumer mortgages and auto loans in Brazil. In 2015, nominal interest rates on the favorable end have been quoted at 13.6% (on a mortgage from Banco do Brasil) and 16.6% (on auto loans offered by Volkswagen) (Rapoza, 2015); however, these rates are not necessarily indicative of the rates available to all consumers. Subtracting the 12-month inflation rate in March 2015 (measured by the IPCA index) of 8.13% (Banco Central do Brasil, 2015) from these consumer interest rates yields a real interest rate of 5.5% and 8.5% on the quoted mortgage and auto loan rates, respectively. Coincidentally, the central discount rate of 7% used in this analysis is similar to the average real interest rate of these quoted loans.

Vehicle mileage

Annual distance traveled per vehicle is an important determinant of payback period: The farther that vehicles travel each year, the more fuel they save relative to baseline vehicle technology. Vehicle travel also tends to decline as vehicles age. For this analysis, estimates of annual distance per vehicle by age were based on data from IEMA (2013), assuming an average distance traveled of 19,500 km the first year, decreasing by 3% each year (Figure 6).

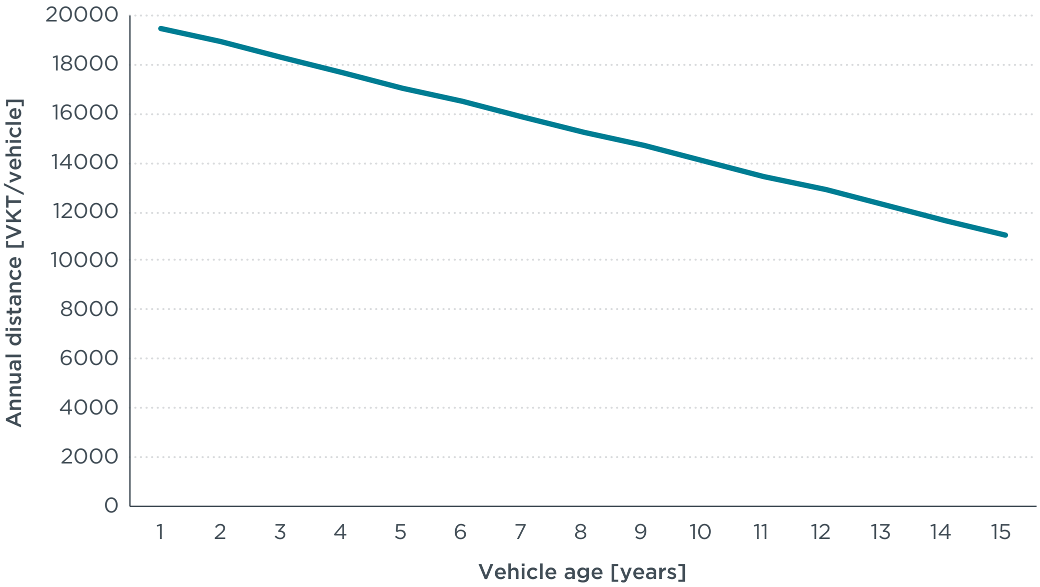

Figure 6. Average annual distance traveled by vehicle age.

Fuel prices

Fuel prices are an important determinant of fuel savings over the lifetime of the vehicle; variations in fuel price also affect the length of time it takes for consumers to recoup the incremental cost of efficient vehicle technology. As shown in Figure 7, historical prices of gasoline in Brazil and the United States are highly correlated (with a correlation coefficient of 0.88); these prices are similarly correlated with the international price of crude oil. In absolute terms, however, retail prices of gasoline in Brazil have historically been higher than in the United States. From 2001 to 2016, this difference has averaged 0.43 USD/liter (Figure 7). In addition to the effects of international crude oil prices, fuel prices in Brazil are affected by currency exchange rates, which have fluctuated in recent years in response to macroeconomic trends in Brazil. In 2015 and 2016, the retail price of gasoline in Brazil (measured in USD) fell to a 10-year low in response to the international price of crude oil falling from more than $100/bbl to less than $50/bbl; however, fuel prices are not expected to remain at this low level. Instead, the U.S. Energy Information Administration and Pöyry Management Consulting each project that the price of oil will recover to about $80 to $90/bbl in the 2025 time frame (Figure 8). When international oil prices have previously been at this level, the historical price of gasoline in Brazil has ranged between 1.1 and 1.5 USD/liter.

For the analysis of fuel savings for model year 2023 vehicles, a conservative central gasoline (E27) price of 1.1 USD/liter is applied. This central value is close to the average price observed from 2013 to 2016 (Table 5). To ensure that our payback results hold over a range of fuel prices, we also estimate fuel savings over 15 years at fuel prices of 0.8 USD/liter and 1.4 USD/liter (± ~30% from our central estimate). This range more than covers the actual variation in fuel prices observed from year to year in Brazil over the period 2013–2016. Because E27 and E100 have a similar price when normalized by energy content (USD/MJ), the payback results are expected to be similar regardless of the ethanol blend consumed.

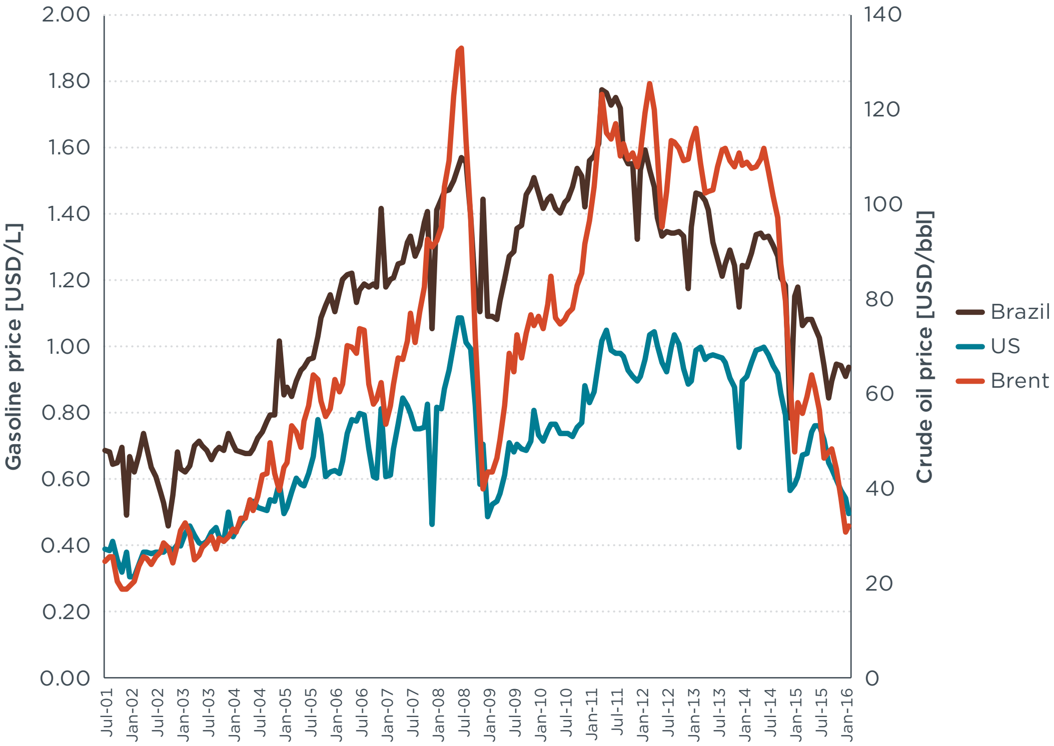

Figure 7. Historical price of international crude oil and gasoline in Brazil and the United States, 2001–2016. Sources: U.S. gasoline prices from U.S. EIA (2016b); Brent crude oil prices from U.S. EIA (2016a). Brazil gasoline prices in Brazilian reals (BRL) from ANP (2016a), converted to USD based on IMF (2016).

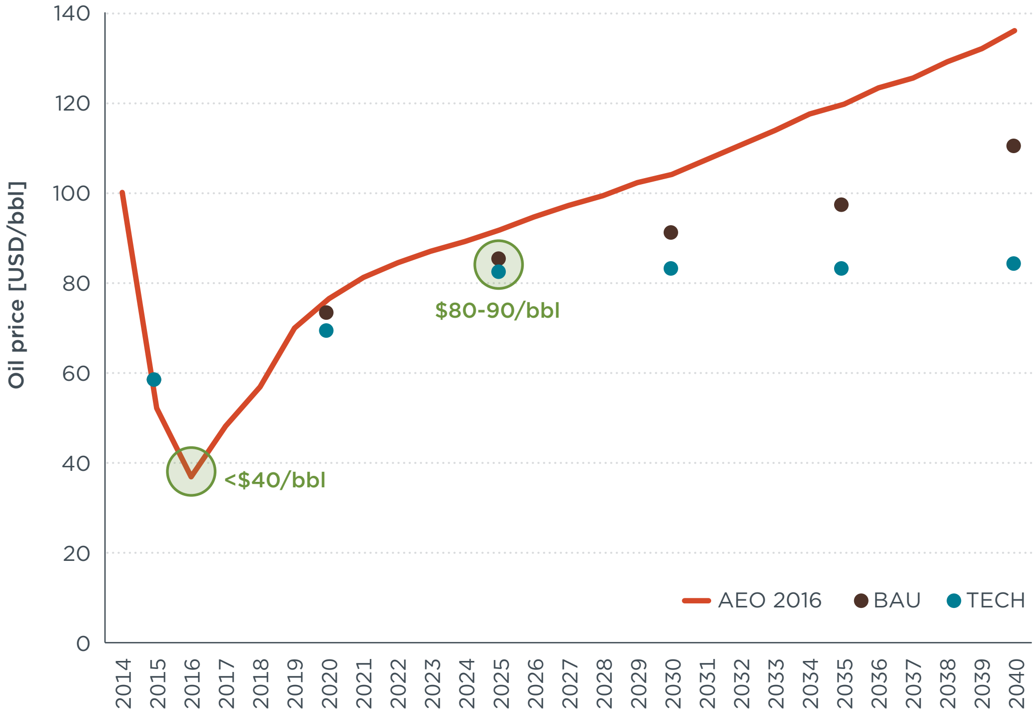

Figure 8. Crude oil price projections, 2016–2040. Sources: AEO 2016 reference case (U.S. EIA, 2016a); BAU and TECH scenarios from Summerton et al. (2016).

Table 5. Historical fuel prices and exchange rates in Brazil, 2013–2016.

Variable	Unit	Year				Average, 2013–2016	Source
		2013	2014	2015	2016		
Ethanol (E100)	BRL per liter	1.97	2.07	2.23	2.76	2.26	ANP (2016a)
Gasoline (E27)	BRL per liter	2.85	2.98	3.34	3.69	3.22	ANP (2016a)
Exchange rate	USD per BRL	0.46	0.43	0.30	0.27	0.36	IMF (2016)
Ethanol (E100)	USD per liter	0.91	0.88	0.67	0.74	0.80	Calculated*
Gasoline (E27)	USD per liter	1.32	1.27	1.00	0.98	1.14	Calculated*

**Prices in USD are calculated using actual exchange rates provided in the table.*

Cumulative discounted fuel savings

For each of the three payback methods, the cumulative discounted value of fuel savings (i.e., the reduction in fuel expenditures) is estimated over a specified time period (e.g., 15 years). The formula for the sum of discounted energy/fuel savings is defined as follows:

$$S = \sum_{t=0}^{p} \left[(E_{base} - E_{final}) \times D_t \times F_t \times \frac{1}{(1+r)^t} \right]$$

where

S is the sum of discounted energy/fuel savings (measured in USD)

p is the number of years over which energy/fuel savings are calculated

$t = 0$ is the time of the vehicle purchase

E_{base} is the energy/fuel consumption of the baseline vehicle (MJ/km)

E_{final} is the energy/fuel consumption of the more efficient vehicle (MJ/km)

D_t is the annual distance driven in each year (km)

F_t is the price of fuel per unit energy in a given year (USD/MJ)

r is the discount rate

Energy/fuel savings are not discounted during the first year of travel (the same year as the vehicle purchase).

Per-vehicle energy/fuel savings and technology costs over 15 years

This payback metric compares the sales-weighted average incremental technology cost for a model year 2023 vehicle with the cumulative discounted energy/fuel savings over 15 years (as defined above), also averaged across vehicle models using a sales-weighted approach. The formula for sales-weighted incremental technology cost is defined as follows:

$$C_{avg} = \sum_{m=1}^{n} \left[(C_{final,m} - C_{base,m}) \times \frac{\text{Sales}_m}{\text{Total sales}} \right]$$

where

C_{avg} is the sales-weighted average incremental technology cost for a model year 2023 vehicle

C_{final} is the total cost of technology for a given vehicle model under the 2023 standards

C_{base} is the total cost of technology for a given vehicle model under the current (2017) program

($C_{\text{final}} - C_{\text{base}}$ is defined as the incremental technology cost for a given vehicle model)

m represents a single vehicle model

n represents the total number of vehicle models

Sales_m represents the number of units sold for a given vehicle model in 2023

Total sales represents the total number of units sold for all vehicle models in 2023

New fleet energy/fuel savings and technology costs over 15 years

New fleet energy/fuel savings and technology costs are equivalent to the per-vehicle costs in the previous section multiplied by the projected number of vehicle sales. This metric compares technology costs and fuel savings over 15 years for new cars sold in 2023, the year when the extended standards would be fully phased in for new vehicles. In other words, this metric captures the costs and benefits of the extended standards for the new passenger car fleet in 2023; somewhat smaller costs and benefits would be expected from model years 2018 to 2022 (because the technologies are not completely phased in), and larger costs and benefits would be expected for model years after 2023 if there is an increase in the volume of vehicle sales. Subtracting the incremental costs of technology for model year 2023 vehicles from their expected energy/fuel savings over 15 years is termed the "net benefits" (over 15 years) of the standards for cars sold in 2023.

Consumer payback periods

A consumer payback period is defined as the number of years it takes for cumulative discounted fuel savings to pay back the cost of fuel-saving vehicle technology. All additional fuel savings after the end of the payback period are a net benefit to the vehicle owner. In addition to incremental technology cost and the associated reduction in energy consumption, the payback period is influenced by the discount rate, annual vehicle travel, and fuel prices (Table 6).

Table 6. Impact of discount rate, mileage, and fuel price assumptions on consumer payback period.

Factor	Assumption	Impact of higher value on payback period
Discount rate	7% (sensitivity at 3%, 5%, 10%)	Lengthen
Annual vehicle travel	19,500 km the first year, decreasing ~3% each year	Shorten
Fuel price	0.038 USD per MJ (1.1 USD/liter for E27)	Shorten

Payback periods were calculated for each vehicle model, then sales-weighted to develop an average for the new vehicle fleet and each segment. The method for calculating the payback period of a given vehicle model is as follows:

Find p, where: $$(C_{final} - C_{base}) = \sum_{t=0}^{p} \left[(E_{base} - E_{final}) \times D_t \times F_t \times \frac{1}{(1+r)^t} \right]$$

where

C_{final} is the total cost of technology for a given vehicle model under the 2023 standards

C_{base} is the total cost of technology for a given vehicle model under the current (2017) program

($C_{\text{final}} - C_{\text{base}}$ is defined as the incremental technology cost for a given vehicle model)

p is the number of years over which energy/fuel savings are calculated

$t = 0$ is the time of the vehicle purchase

E_{base} is the energy consumption of the baseline vehicle (MJ/km)

E_{final} is the energy consumption of the more efficient vehicle (MJ/km)

D_t is the annual distance driven in each year (km)

F_t is the price of fuel per unit energy in a given year (USD/MJ)

r is the discount rate

Real-world fuel economy adjustment

According to the U.S. EPA, CAFE two-cycle testing (FTP-75 and HWFET) is a good but not perfect measure of real-world fuel consumption. Given that Brazil also applies CAFE two-cycle testing to certify passenger vehicle fuel consumption, we apply an adjustment factor to estimate real-world fuel consumption from the test cycle estimates produced by OMEGA. A similar real-world fuel consumption adjustment was previously used by the Brazilian government (INMETRO, 2011). In the absence of a specific adjustment factor for the Brazilian market, we apply the same adjustment factor estimated by U.S. EPA. This adjustment is detailed below.

The fuel savings model includes adjustment factors to better reflect real-world fuel economy values. Adjustment factor values used in this analysis come from a U.S. EPA methodology that accounts for important factors that affect fuel economy in real-world operation, such as the use of air conditioning, aggressive acceleration, high-speed operation, and other factors not accounted for under CAFE 2-cycle testing. Generally, these factors range from 0.785 to 0.85, with the largest adjustments associated with model years after 2004 and the smallest adjustments associated with model years before 1990. The value assumed for Brazil in this report to convert 2-cycle data to real world values is a constant 0.785 for all values. This adjustment factor is applied to fuel economy values for all model years and scenarios, resulting in higher real-world fuel consumption estimates (i.e. lower fuel economy). However, since it applies to all scenarios, the real-world fuel savings of vehicle efficiency standards are actually higher than measured on the test cycle, because the absolute difference between scenarios is greater (though the percent difference is the same). Further details on the methodology use to estimate this real-world fuel economy adjustment factor can be found in the EPA report on fuel economy trends (U.S. EPA, 2015). It is acknowledged that this analysis used the US based adjustment factor developed by EPA as there is not known adjustment factor available for the Brazilian market.

Projected greenhouse gas and energy use impacts

In addition to direct benefits to consumers, the Brazil 2023 program would improve the overall efficiency of Brazil’s passenger vehicle fleet. These benefits will increase over time as new vehicles (subject to the 2023 program) begin to account for a larger share of the in-use passenger vehicle fleet. Using the ICCT’s Global Transportation Roadmap model (ICCT, 2016a), the projected impacts on passenger vehicle GHG emissions and energy use in Brazil were estimated for the period 2015–2035. The absolute fleetwide GHG and energy impacts depend on the future rate of growth in the passenger vehicle fleet and associated vehicle activity; this analysis assumes an annualized growth rate of 2.7% for passenger VKT. Ethanol from sugarcane feedstock is assumed to continue to account for 51% of total on-road gasoline and ethanol fuel demand (ANP, 2016b). For more information on the Roadmap model, see Miller and Façanha (2014).

RESULTS

TECHNOLOGY PENETRATION

This section presents the projected technology adoption in 2023 by OMEGA for the Brazilian fleet, by vehicle segment for each of the scenarios. The analysis shown here illustrates a **potential** technology pathway toward compliance; manufacturers may choose other pathways to compliance, depending on marketing strategies, consumer preferences, and technology development.

Meeting Inovar-Auto 2017 Targets

According to OMEGA, the least-cost pathway to have met the requirements of the Inovar-Auto 2017 target includes more-efficient transmissions in the low-cost vehicle segments, turbocharged and downsized GDI engines, and more-efficient automatic transmissions in the higher-end segments. A detailed database of vehicle sales in 2017 would be needed to confirm whether these technologies have been adopted in practice and whether all manufacturers have met the Inovar-Auto 2017 target.

Projected technology adoption for 2023

OMEGA uses aggregate technology packages to estimate the cost of compliance while taking into account the synergies that occur between technologies. The projected penetration for each of the technologies included in these packages is described below. See the Appendix for brief descriptions of each technology. In general, technology adoption rates increase as energy consumption targets become more stringent.

Gasoline direct injection, turbocharging, and downsizing

GDI, turbocharging, and downsizing, used in combination, are the main technologies that are poised to gain market share as the energy consumption targets become more stringent, from close to 4% for Inovar-Auto 2017 to more than 98% for Brazil 2023. OMEGA projects that naturally aspirated engines will be largely replaced by turbocharged, downsized GDI engines across all segments by 2023 (Figure 9).

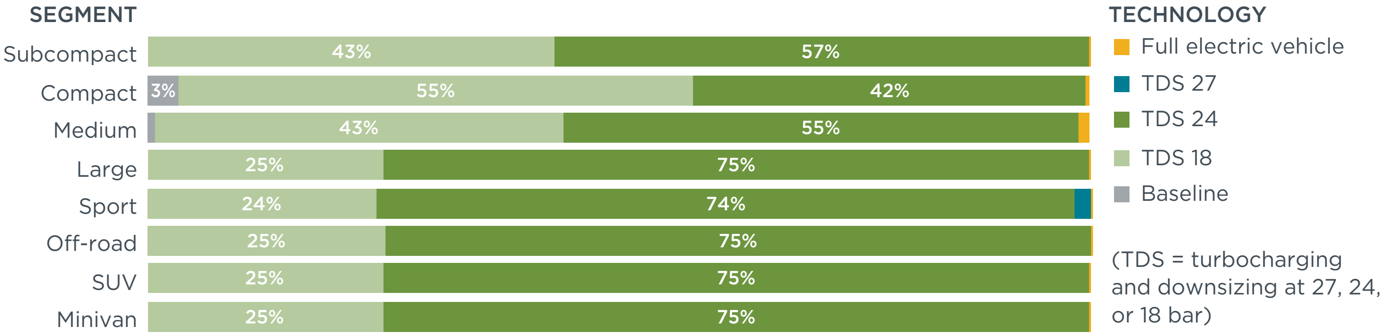

Figure 9. Market share of turbocharging and engine downsizing, Brazil 2023 scenario.

Transmissions

OMEGA estimates that by 2023, the market share of manual transmissions will be replaced with advanced transmissions such as dual-clutch transmissions (DCTs) in most segments (Figure 10). The historical trend in favor of conventional automatic transmissions and a reduction in the manual-transmission market has been confirmed by market changes between 2013 and 2016 (Araujo, 2016; Posada & Façanha, 2013). CVTs are more common among vehicles produced by Japanese manufacturers but were discarded by EPA in its 2012 OMEGA analysis.

Nonetheless, CVTs could also be considered as a technical solution for advanced transmissions; this type of transmission has gained a substantial market share in the United States, from 1.4% in 2005 to more than 18% in 2015. Automatic transmissions are expected to remain the most popular technology for off-road vehicles and minivans.

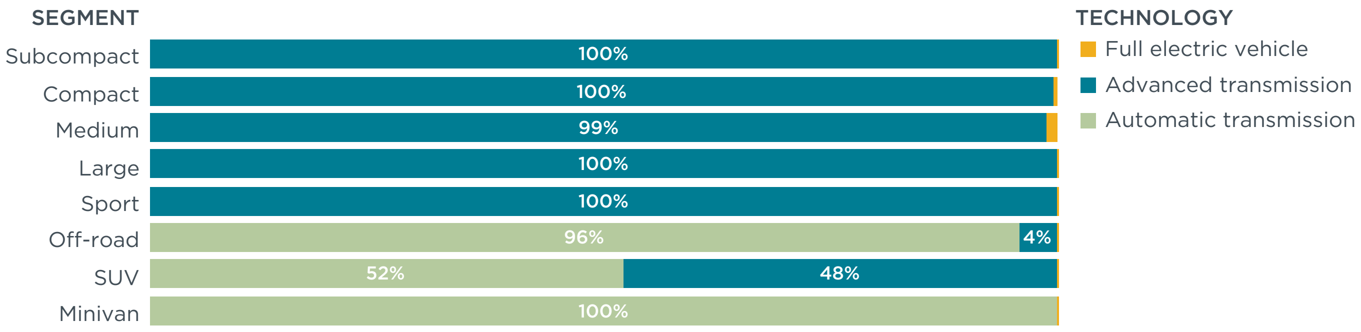

Figure 10. Market share of manual, automatic, and advanced transmissions, Brazil 2023 scenario. Advanced transmissions include dual-clutch transmissions (DCTs) and continuously variable transmissions (CVTs). Manual-transmission vehicle sales are expected to be negligible in 2023.

Hybrids and electric vehicle technologies

OMEGA estimates that the internal combustion engine will remain the dominant technology to meet the evaluated targets for Brazil in 2023. Sale of vehicles with advanced technologies, such as hybrid electric vehicles (HEV) and plug-in hybrid electric vehicles (PHEV), are projected to remain low (Figure 11). MHEVs and start-stop technology could play a role in meeting the 2023 targets, particularly for larger vehicle segments; start-stop systems are expected to gain substantial market share only in the SUV and minivan segments. EVs are projected to appear only in the medium-size vehicle segment.

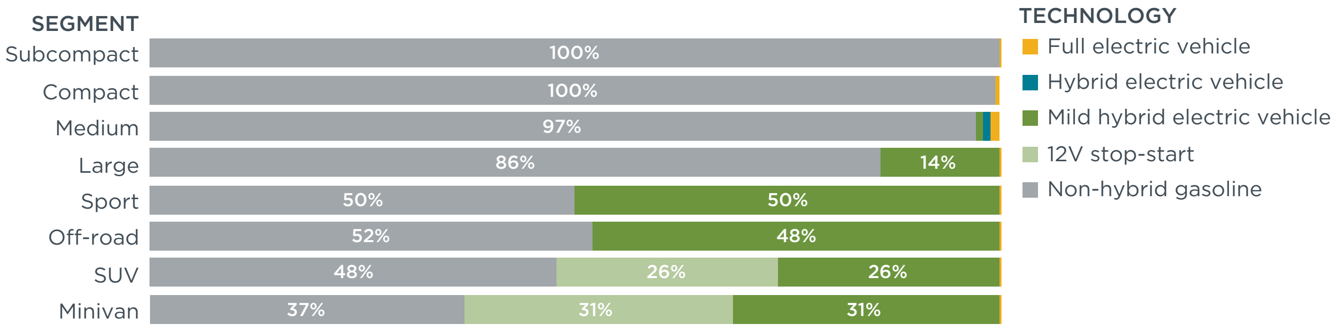

Figure 11. Market share of advanced powertrain technologies (hybrids and EVs), Brazil 2023 scenario.

Other fuel-saving technologies

The remaining set of technologies, such as high-efficiency gearboxes, engine friction reduction, low-rolling-resistance tires, and improved accessories and cooled exhaust gas recirculation (EGR), are expected to be deployed across a greater percentage of new cars. Figure 12 shows the projected market uptake to meet targets for 2023.

Improved accessories are projected to be required in most vehicles across all segments. Low-rolling-resistance tires, high-efficiency gearboxes, and engine friction reduction technologies are expected to be present in almost all Brazilian vehicle segments, including cars and SUVs. Note, however, that OMEGA does not model performance (sports car) or towing (pickup truck) requirements, each of which may result in the incorporation of EGR in these segments. With respect to aerodynamic improvements, the OMEGA model does not output that information.

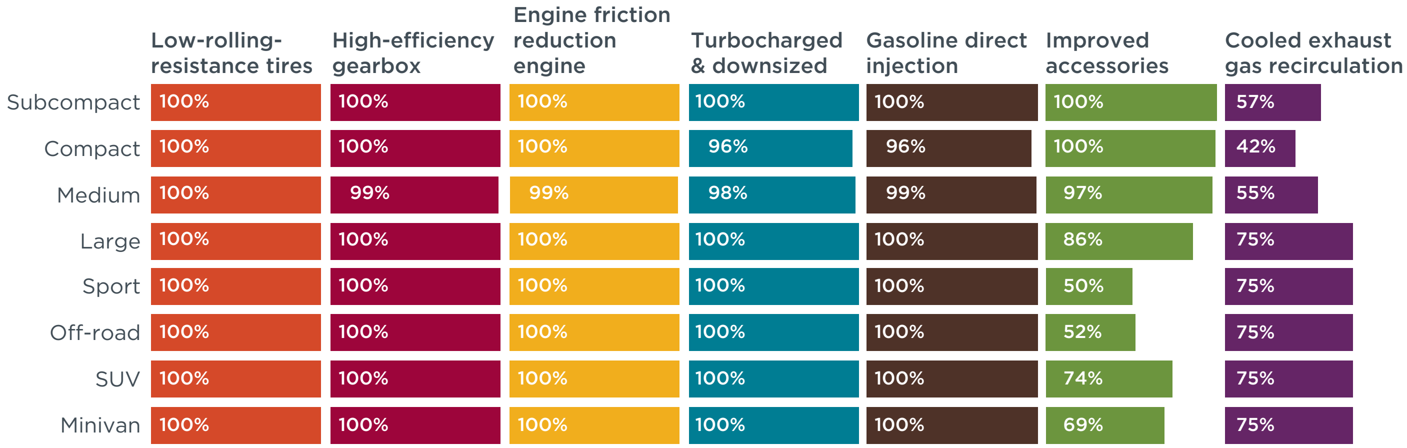

Figure 12. Technology market uptake by segment with Brazil 2023 targets.

COST PER VEHICLE IN 2017 AND 2023

This section presents the projected costs due to the adoption of technologies under different regulatory scenarios in Brazil. Sales-weighted average per-vehicle costs are presented for each passenger car segment and manufacturer. These costs exclude the impact of IPI taxes and other fees. Unless otherwise noted, all costs are presented in 2016 USD. These costs can be converted to BRL using actual exchange rates. For reference, the average IMF representative exchange rate for the first five months of 2016 was 1 BRL = 0.27 USD (IMF, 2016).

Costs of Inovar-Auto 2017 relative to 2013 baseline

OMEGA estimates that manufacturers will have spent an average of $409 to meet Inovar-Auto's 2017 target, equivalent to an 11% reduction in energy consumption or an estimated 2.6% annual improvement in energy consumption versus the 2013 fleet (Table 7). Higher costs are estimated for vehicle segments that were farther from the 2017 target in 2013, such as off-road, SUV, and minivan segments.

Table 7. Cost of technology to meet Inovar-Auto 2017 targets compared with 2013 base year (2016 USD).

Cost by Segment [2016 USD]

Sub compact	Compact	Medium	Large	Sports	Off-road	SUV	Minivan	Average
393	360	452	424	356	726	472	736	409

Average Cost [2016 USD]

356 **736**

Energy Consumption Reduction by Segment [%]

Sub compact	Compact	Medium	Large	Sports	Off-road	SUV	Minivan	Average
10%	9%	12%	13%	14%	17%	18%	18%	11%

Percent Reduction

9% **18%**

Costs of Brazil 2023 relative to Inovar-Auto 2017

Assuming that all manufacturers selling vehicles in Brazil have already met the requirements of Equation 1 under Inovar-Auto 2017, OMEGA estimates that manufacturers will spend an average of $1,660 to meet the evaluated 2023 target, corresponding to an additional 29% reduction in energy consumption (Table 8). Segments dominated by larger vehicles are expected to require a slightly greater percentage improvement than those dominated by smaller vehicles; hence, segments with larger vehicles tend to have somewhat higher costs. However, such vehicles are also expected to have higher fuel savings.

Table 8. Costs to meet evaluated Brazil 2023 target compared to Inovar-Auto 2017 (2016 USD).

Cost by Segment [2016 USD]

Sub compact	Compact	Medium	Large	Sports	Off-road	SUV	Minivan	Average
1,654	1,597	1,680	1,831	1,763	2,103	2,404	2,017	1,660

Average Cost [2016 USD]

1,597 **2,404**

Energy Consumption Reduction by Segment [%]

Sub compact	Compact	Medium	Large	Sports	Off-road	SUV	Minivan	Average
29%	29%	29%	31%	28%	33%	33%	33%	29%

Percent Reduction

28% **33%**

RESULTS OF PAYBACK ANALYSIS

When fully phased in, the 2023 program would have substantial benefits for buyers of new passenger cars in Brazil. At a fuel price of 1.1 USD/liter and a 7% discount rate, the average buyer of a model year 2023 vehicle would save about $4040[7] (2016 USD) in fuel costs over a 15-year period, compared to initial technology costs of $1660 (Figure 13). Over 15 years, this represents a net gain of $2380, with additional fuel savings possible after this period. Although the first owner may not directly capture all of these savings (if, for example, the vehicle is sold after 7 years), these should be reflected in the resale value of the vehicle, because more fuel-efficient vehicles will reduce fuel expenditures for buyers of secondhand vehicles.

Figure 14 presents these costs and benefits for the entire fleet of model year 2023 vehicles (effectively the per-vehicle results multiplied by the volume of vehicle sales; as

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[7] For the payback analysis, all costs and benefits are given in terms of 2016 USD. Values in 2010 USD can be converted to 2016 USD by multiplying by 1.1. Source: U.S. Bureau of Labor Statistics, CPI Inflation Calculator (http://data.bls.gov/cgi-bin/cpicalc.pl?).

explained earlier, vehicle sales are conservatively held constant, such that the fleetwide impacts could be significantly higher with sales growth). In total, model year 2023 vehicles would generate $8.5 billion (2016 USD) in fuel savings over 15 years, about 2.4 times the initial cost of $3.5 billion. In other words, the expected benefits of the standards for model year 2023 vehicles outweigh the costs by a factor of 2.4:1. These benefits do not include the additional value to society as a result of GHG mitigation.

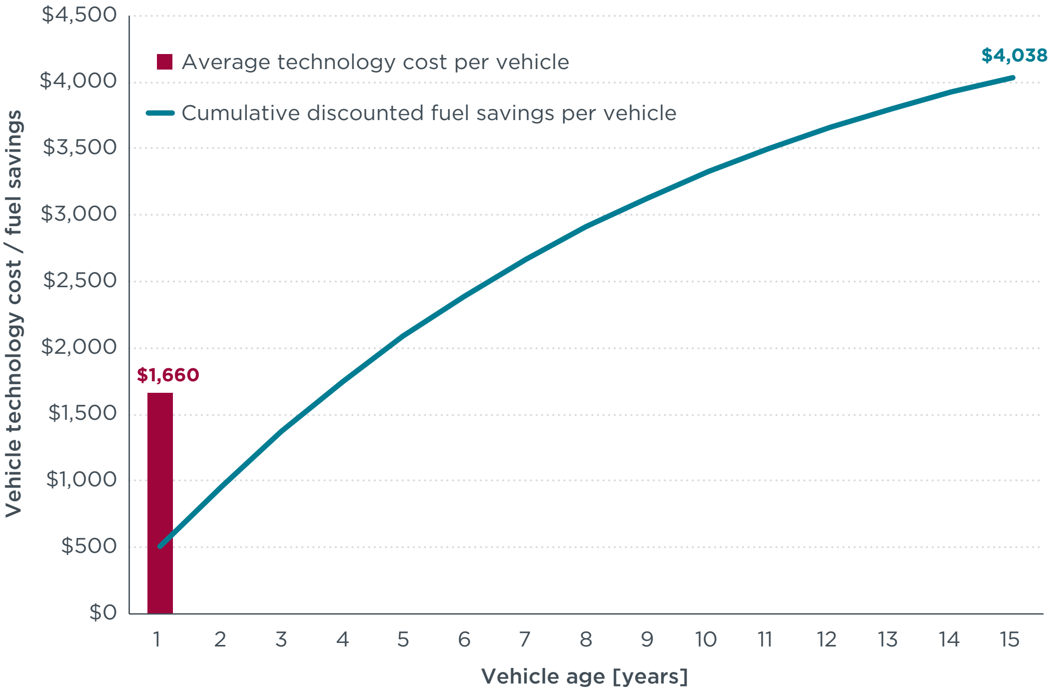

Figure 13. Per-vehicle fuel savings and costs over 15 years for new cars sold in 2023 (2016 USD).

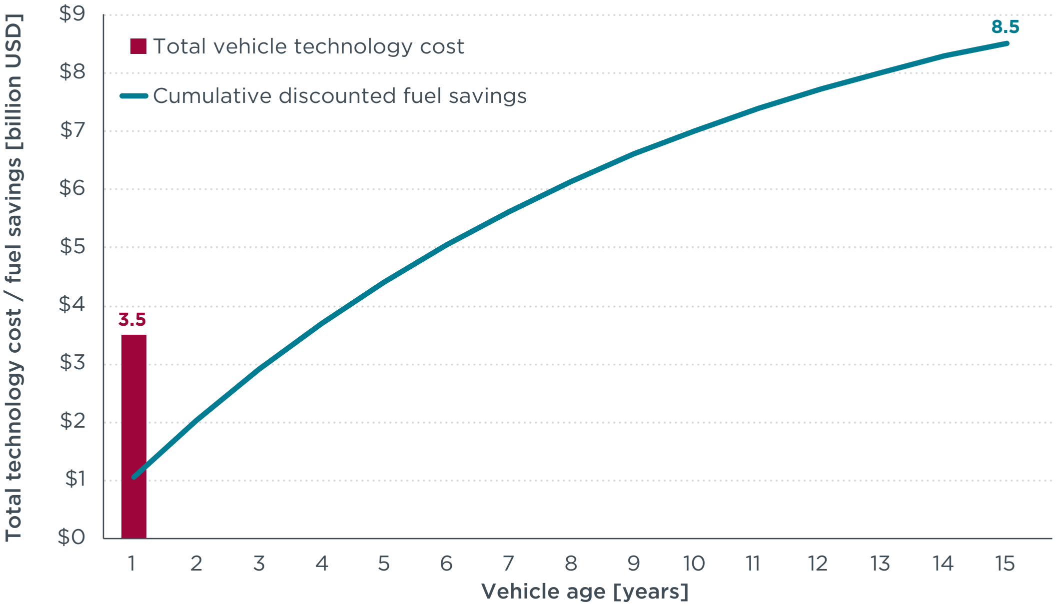

Figure 14. Fleet fuel savings and technology costs over 15 years for new cars sold in 2023 (2016 USD).

Table 9 compares the total benefits of the standards for model year 2023 vehicles to their costs over a wide range of fuel price and discount rate assumptions. If discount rates range from 3% to 10% and fuel prices range from 0.8 to 1.4 USD/liter, the standards would result in benefits that outweigh the costs in all cases.

Table 9. Sensitivity of fuel savings and benefit-cost ratio for model year 2023 passenger vehicles to fuel price and discount rate. Total incremental vehicle technology costs are estimated at 3.5 billion 2016 USD.

	Fuel price (USD/liter)	Discount rate			
		3%	5%	7%	10%
Cumulative discounted fuel savings (billion 2016 USD)	**0.8**	7.6	6.8	6.2	5.4
	1.1	10.5	9.4	8.5	7.4
	1.4	13.2	11.9	10.8	9.4
Benefit-cost ratio (unitless)	**0.8**	2.2	1.9	1.8	1.5
	1.1	3.0	2.7	2.4	2.1
	1.4	3.8	3.4	3.1	2.7

Although estimates of net benefits and benefit-cost ratio are the most representative measures of the value added by the adoption of standards, another metric of interest for consumers is the length of time it takes to pay back the incremental cost of vehicle technology. Because many considerations factor into manufacturer suggested retail prices and end user prices, the incremental cost of technology may not translate into a one-for-one increase in vehicle purchase price. Nonetheless, the following payback periods can provide a helpful metric for how long it could take for vehicle efficiency technologies to effectively pay for themselves. Figure 15 shows the average consumer payback period for model year 2023 vehicles over a range of assumptions for discount rate and fuel price. For example, at a fuel price of 1.1 USD/liter and a 7% discount rate, the average vehicle would result in fuel savings that pay back the incremental cost of technology in less than 4 years.

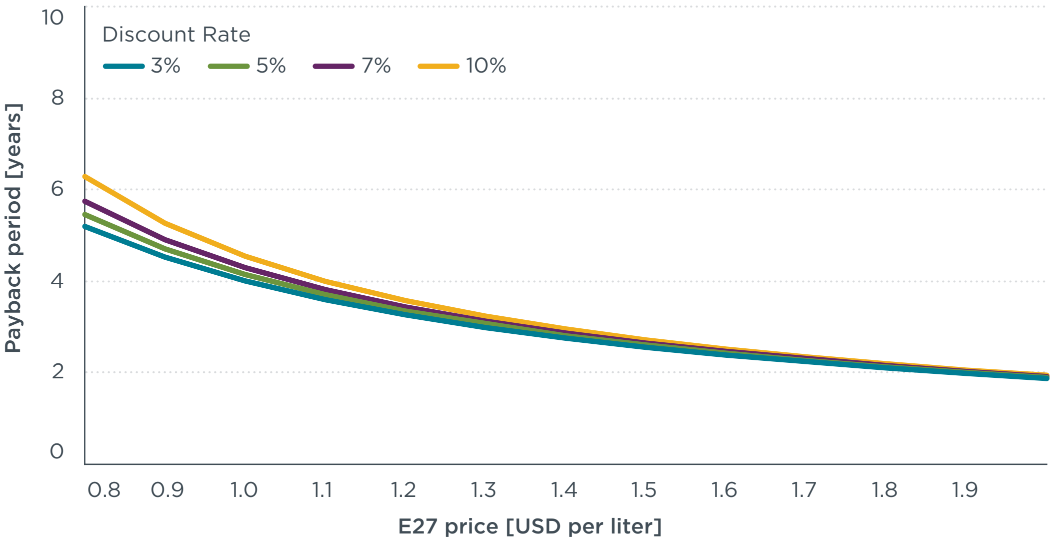

Figure 15. Consumer payback period by discount rate and fuel price for new cars sold in 2023.

In addition to direct benefits to consumers, the evaluated Brazil 2023 program would have substantial benefits in terms of the climate and energy impacts of Brazil's passenger vehicle fleet. By 2035, the Brazil 2023 program could achieve a 23% reduction in projected GHG emissions and fuel consumption, preventing the annual release of 35 million tonnes of CO_2 equivalent and saving the energy equivalent of 250,000 barrels of oil per day (Figure 16). These benefits are roughly twice those expected with the Inovar-Auto 2017 program (projected in 2035 and compared to a baseline with 2013 efficiency levels).

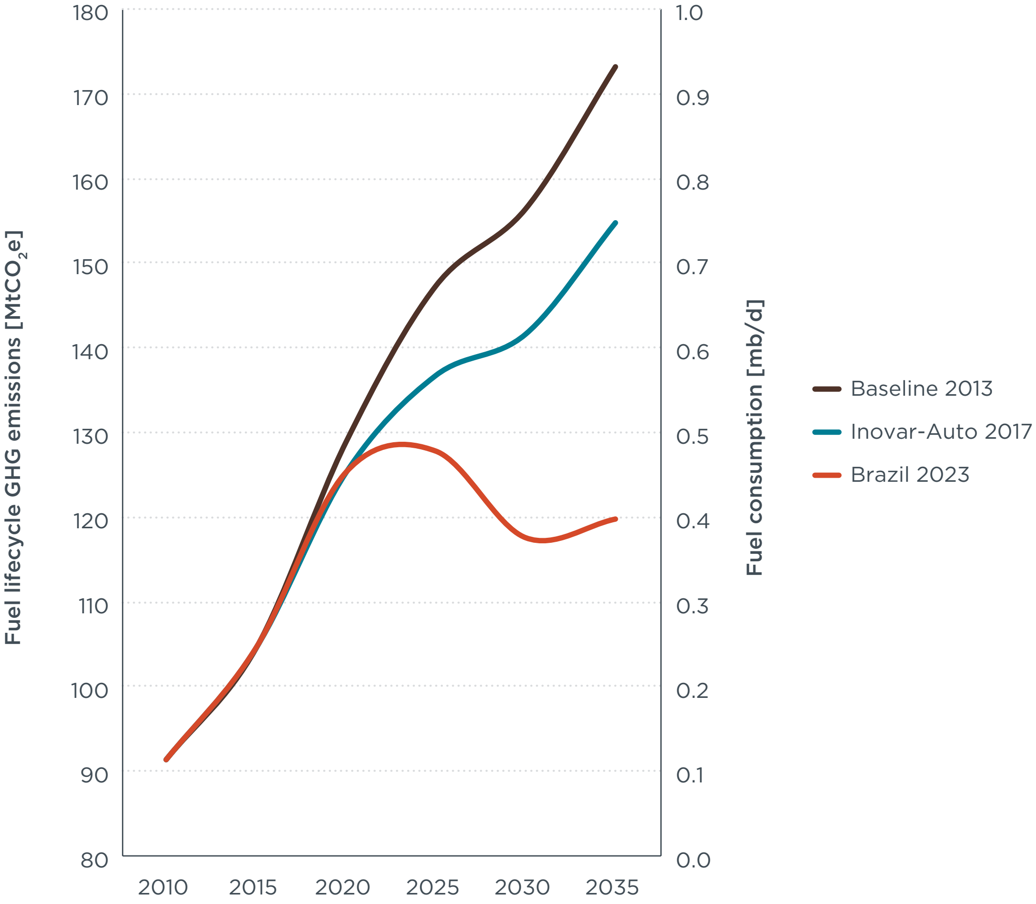

Figure 16. Energy and GHG impacts of passenger vehicle efficiency programs in Brazil, 2010–2035. Fuel consumption (mb/d, million barrels of oil-equivalent per day) includes energy content of gasoline and ethanol. Ethanol is assumed to continue to account for 51% of total on-road gasoline and ethanol demand.

COMPARISON WITH EUROPEAN UNION 95 GCO$_2$/KM COST ESTIMATES

This section compares OMEGA's estimated costs for the light-duty vehicle fleet in Brazil with available studies of the cost of meeting the European CO_2 targets in 2020–2021. OMEGA-estimated costs are comparable, on average, to cost values incurred for European cars to meet the 95 gCO_2/km target in 2021, according to a study commissioned by the ICCT in 2012 (Meszler et al., 2012). Global engineering firms Ricardo Inc. and FEV carried out that study under a contract for the ICCT. Another report on the same topic by TNO contains information on average passenger vehicle fleet costs to reach the same targets but using an older vehicle baseline, 2002, and corrections to reach 2009 technology uptakes; Table 10 presents two cost values from that report, which gave a range of cost options and assumptions (TNO, 2011). The cost incurred to reduce CO_2 emissions by one percentage point ranges between $57.2 and $34.3, depending on the baseline and cost assumptions.

Table 10. Comparison of OMEGA cost estimates for targets in Brazil and Europe (2016 USD).

	Brazil 2023	EU (95 gCO_2/km)	
Variable	**ICCT**	**Ricardo/FEV/ICCT[a]**	**TNO[b]**
Baseline year	2017 (Equation 1)	2010	2002
Fleet average energy/CO_2 reduction	29%	32%	40%
USD per 1% energy/CO_2 reduction	$57.2	$52.1	$34.3 to $49.5
Segment			
Subcompact/compact	$1600	$1406	—
Medium	$1680	$1310	—
Large/luxury	$1830	$1875	—
SUV	$2400	$1875	—
Minivan	$2017	$1860	—
Off-road	$2100	—	—
Fleet average	**$1660**	**$1665**	**$1371 to $1978**

[a] Original cost data for 2015 in euros multiplied by 1.11 to convert to 2016 USD. Source: Meszler et al. (2012).

[b] Original cost data in 2009 euros, multiplied by 1.21 for inflation and USD currency conversion. Source: TNO (2011).

CONCLUSIONS

We evaluated the costs and benefits of extending Brazil Inovar-Auto's program to 2023 based on energy efficiency standards equivalent to the CO_2 emissions standards set by the European Union for passenger vehicles in 2020–2021. The analysis was carried out by adapting the U.S. EPA's OMEGA model to the Brazilian passenger vehicle fleet market.

The technology projections show that improvements to the internal combustion engine, adoption of turbocharged and downsized GDI engines, more efficient transmissions, and basic technology improvements (low-rolling-resistance tires, high-efficiency gearboxes, and engine friction reduction technologies) constitute the core of least-cost technologies needed to reach the 2023 target. The evaluated 2023 program would result in minimal powertrain electrification, mainly via start-stop systems and mild hybrids. Plug-in electric vehicles are estimated to be a least-cost solution for less than 1% of the Brazilian fleet in 2023, and then only for a few vehicle segments.

We find that a Brazil 2023 program based on the European Union's passenger vehicle standards could reduce energy consumption of new cars by 29% between 2017 and 2023, equivalent to a decrease of 36% from 2013 levels. At a fuel price of 1.1 USD/liter and a discount rate of 7%, the average new car sold in 2023 would save consumers about $4,040 (2016 USD) over 15 years, about 2.4 times the cost of additional vehicle technology ($1,660). The cost estimates derived in this report are based on cost data developed for the OMEGA model by EPA in 2012; since EPA revised its technology costs downward in the 2016 version of OMEGA—and considering that higher ethanol content in Brazil could enable greater benefits than assumed in OMEGA—the cost estimates presented here are considered conservatively high.

OUTLOOK FOR FUTURE RESEARCH

A more refined analysis of the technologies and costs of 2023 targets could be carried out once model year 2015 data on energy consumption and sales are compiled and validated. A more recent dataset would allow for starting the analysis with a baseline that more closely resembles the current fleet, thus improving the quality of predictions for model year 2023. Additionally, U.S. EPA has released a new version of the OMEGA model for the midterm evaluation of the U.S. GHG and CAFE standards covering model years 2022 to 2025 (U.S. EPA, 2016); this updated model could be used to better reflect new technology developments and cost changes that have occurred since the release of the previous model in 2012. The *Draft Technical Assessment Report* issued by EPA as part of the midterm evaluation (see ICCT, 2016b) suggests that technology innovation is advancing more quickly than had been anticipated. As a result, the costs to comply with progressively lower energy consumption during the period 2020–2025 continue to decline from those initially estimated in 2012. This suggests that future analysis using the 2016 version of OMEGA would result in lower cost estimates for the same Brazil 2023 program.

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LIST OF ACRONYMS

ANP	National Agency of Petroleum (Brazil)
BRL	Brazilian Real
CAFE	Corporate Average Fuel Economy, which is the name of the US fuel economy regulatory program. As used in this report, CAFE includes all associated definitions, testing, and reporting requirements.
CO_2	carbon dioxide
CO_2e	carbon dioxide-equivalent
E100	ethanol (100 percent)
E27	gasoline blend with 27 percent ethanol content
EU	European Union
FTP	Federal Test Procedure
g	gram (unit of mass)
GHG	greenhouse gas
ICCT	International Council on Clean Transportation
IEMA	Instituto de Energia e Meio Ambiente (Brazil)
IMF	International Monetary Fund
IPI	tax on industrialized products (Brazil)
km	kilometer
L	liter (unit of fuel volume)
mb/d	million barrels of oil-equivalent per day
MDIC	Ministry of Industry, Trade and Services (Brazil)
MJ	megajoule (energy unit)
$MtCO_2$	million metric tons of carbon dioxide
OMEGA	Optimization Model for Reducing Emissions of Greenhouse Gases from Automobiles
PC	Passenger car
TAR	Technical Assessment Report
US	United States
US EIA	United States Energy Information Administration
US EPA	United States Environmental Protection Agency
USD	United States dollars ($)
VKT	vehicle-kilometers traveled

ADDITIONAL ACRONYMS IN THE LIST OF TECHNOLOGIES USED IN OMEGA

0sp	a zero speed (electric vehicle) transmission. This acronym is not a technically accurate acronym since it really signifies the lack of a transmission, such as in an electric vehicle where an electric motor is directly connected to the drive wheels.
4VDI3	a four valve DOHC I3 engine.
4VDI4	a four valve DOHC I4 engine.
4sp	a four-speed transmission.
6sp	a six-speed transmission.
8sp	an eight-speed transmission.
Aero1	aerodynamic drag reduction level 1.
Aero2	aerodynamic drag reduction level 2.
ASL1	advanced shift logic level 1.
ASL2	advanced shift logic level 2.
AT	automatic transmission. AT6 is AT with 6 gear ratios; AT8 is AT with 8 gear ratios.
CVT	a continuously variable transmission that can change gear ratio continuously between a maximum and minimum value.
DCP	dual cam phasers.
DCT	dual clutch transmission. DCT6 is a DCT with 6 gear ratios; DCT8 is a DCT with 8 gear ratios
DOHC 4v	a dual overhead cam engine with four valves per cylinder.
DVVL	discrete variable valve lift.
EFR1	engine friction reduction level 1.
EFR2	engine friction reduction level 2.
EGR	exhaust gas recirculation.
EPS	electric power steering.
EV	Electric Vehicle; a vehicle exclusively powered by energy stored on a battery and electric motor. Tesla and Nissan Leaf are examples of EVs; a Toyota Prius is not an EV.
EV75 mile	an electric vehicle with a 75-mile range.
EV100 mile	an electric vehicle with a 100-mile range.
GDI	gasoline direction injection.
HEG	high efficiency gearbox.
HEV	hybrid electric vehicle.
IACC1	improved accessories level 1.
IACC2	improved accessories level 2.
I4	an inline engine constructed as a single row of four cylinders.
kW	Kilowatt, an international system unit for power

LDB	low drag brakes.
LRRT1	a low rolling resistance tires level 1.
LRRT2	a low rolling resistance tires level 2.
LUB	low friction lubricant.
MHEV	a mild hybrid electric vehicle.
MPFI	multi port fuel injection.
MT	a manual transmission.
OHV 2v	an overhead valve engine with two valves per cylinder.
REEV20	a range extended electric vehicle (plug in hybrid electric vehicle) with a 20 mile all electric range.
REEV40	a range extended electric vehicle (plug in hybrid electric vehicle) with a 40 mile all electric range.
SAX	secondary axle disconnect.
SOHC 2v.	a single overhead cam engine with two valves per cylinder.
SOHC 3v.	a single overhead cam engine with three valves per cylinder.
SS	start stop (idle off) technology.
TDS18	an 18 bar turbocharged downsized engine.
TDS24	a 24 bar turbocharged downsized engine.
TDS27	a 27 bar turbocharged downsized engine.
V6	a six-cylinder engine constructed as two banks of three cylinders offset at an angle (typically 60 to 90 degrees) from the crankshaft.
V8	an eight-cylinder engine constructed as two banks of four cylinders offset at an angle (typically 60 to 90 degrees) from the crankshaft.

APPENDIX

Table 11. U.S. EPA cost/benefit estimates example for compact car I4 DOHC, 2021 costs.

Tech package number	Technology package components	Transmission	Cost (2010 USD)	CO_2 reduction
0	Passenger car (auto) 4VDI4 with MPFI+4sp (baseline package)	4sp AT	0	0.0%
1	Auto 4VDI4+X1+DCP+WR0%+6sp	6sp DCT-dry	350	24.6%
2	Auto 4VDI4+X1+DCP+WR5%+6sp	6sp DCT-dry	388	26.5%
3	Auto 4VDI4+X2+DCP+WR5%+6sp	6sp DCT-dry	432	28.0%
4	Auto 4VDI4+X2+DCP+WR5%+8sp	8sp DCT-dry	541	31.0%
5	Auto 4VDI4+X3+DCP+WR10%+6sp	6sp DCT-dry	705	31.7%
6	Auto 4VDI4+X4+DCP+WR5%+8sp	8sp DCT-dry	745	34.1%
7	Auto 4VDI4+X5+DCP+WR10%+8sp	8sp DCT-dry	923	36.6%
8	Auto 4VDI4+X2+HEG+DCP+DVVL+WR10%+8sp	8sp DCT-dry	1,024	36.8%
9	Auto 4VDI3+X3+DCP+GDI+TDS24+WR10%+6sp	6sp DCT-dry	1,570	40.2%
10	Auto 4VDI4+X5+HEG+DCP+DVVL+WR10%+8sp	8sp DCT-dry	1,293	40.0%
11	Auto 4VDI4+X5+HEG+DCP+GDI+TDS18+WR10%+8sp	8sp DCT-dry	1,801	44.2%
12	Auto 4VDI4+X2+HEG+DCP+GDI+TDS18+WR15%+8sp	8sp DCT-dry	1,780	43.0%
13	Auto 4VDI4+X5+DCP+GDI+TDS18+WR10%+8sp	8sp DCT-dry	1,573	42.2%
14	Auto 4VDI3+X6+DCP+GDI+TDS24+WR10%+8sp	8sp DCT-dry	1,729	42.9%
15	Auto 4VDI3+X2+HEG+DCP+GDI+SAX+TDS24+EGR+WR10%+8sp	8sp DCT-dry	2,122	45.8%
16	Auto 4VDI3+X3+DCP+GDI+TDS24+EGR+WR10%+6sp	6sp DCT-dry	1,857	42.4%
17	Auto 4VDI3+X6+DCP+GDI+TDS24+EGR+WR15%+8sp	8sp DCT-dry	2,266	46.5%
18	Auto 4VDI3+X3+DCP+GDI+TDS24+EGR+WR15%+6sp	6sp DCT-dry	2,106	44.1%
19	Auto 4VDI4+X5+DCP+GDI+TDS18+WR15%+8sp	8sp DCT-dry	1,822	43.9%
20	Auto 4VDI4+X5+HEG+DCP+GDI+TDS18+WR15%+8sp	8sp DCT-dry	2,049	45.8%
21	Auto 4VDI4+X2+HEG+DCP+GDI+MHEV+TDS18+WR10%+8sp	8sp DCT-dry	2,996	48.2%
22	Auto 4VDI3+X3+DCP+GDI+SS+SAX+TDS24+EGR+WR15%+6sp	6sp DCT-dry	2,532	45.2%
23	Auto 4VDI3+X2+HEG+DCP+GDI+MHEV+TDS24+EGR+WR10%+8sp	8sp DCT-dry	3,499	51.8%
24	Auto 4VDI4+X5+DCP+GDI+SS+SAX+TDS18+WR15%+8sp	8sp DCT-dry	2,247	45.0%
25	Auto 4VDI4+X7+DCP+GDI+MHEV+SAX+TDS18+WR15%+8sp	8sp DCT-dry	3,325	50.2%
26	Auto 4VDI4+X2+HEG+DCP+GDI+MHEV+TDS18+WR15%+8sp	8sp DCT-dry	3,245	49.4%
27	Auto 4VDI4+X5+HEG+DCP+GDI+SS+TDS18+WR15%+8sp	8sp DCT-dry	2,387	46.4%
28	Auto 4VDI4+X5+HEG+DCP+GDI+SS+SAX+TDS18+WR15%+8sp	8sp DCT-dry	2,475	46.7%
29	+IACC1+EPS+Aero2+LDB+LRRT2+EV75 mile+WR20%+0sp		15,359	100.0%
30	Auto 4VDI3+X6+DCP+GDI+SS+SAX+TDS27+EGR+WR15%+8sp	8sp DCT-dry	3,187	48.0%
31	+IACC1+EPS+Aero2+LDB+LRRT2+EV75 mile+WR20%+0sp		15,359	100.0%
32	Auto 4VDI4+X2+HEG+DCP+DVVL+GDI+HEV+SAX+ATKCS+WR15%+8sp	8sp DCT-dry	4,822	54.4%
33	Auto 4VDI4+X7+DCP+DVVL+GDI+HEV+SAX+ATKCS+WR15%+8sp	8sp DCT-dry	4,815	54.9%
34	+IACC1+EPS+Aero2+LDB+LRRT2+EV100 mile+WR20%+0sp		18,032	100.0%
35	Auto 4VDI3+X6+DCP+GDI+SS+SAX+TDS24+EGR+WR15%+8sp	8sp DCT-dry	2,691	47.5%
36	Auto 4VDI4+X5+HEG+DCP+DVVL+GDI+SS+SAX+TDS18+WR15%+8sp	8sp DCT-dry	2,617	47.1%
37	Auto 4VDI4+X7+HEG+DCP+DVVL+GDI+ATKCS+REEV20+WR20%+8sp	8sp DCT-dry	12,786	74.4%
38	Auto 4VDI4+X7+HEG+DCP+DVVL+GDI+ATKCS+REEV40+WR20%+8sp	8sp DCT-dry	16,229	83.9%
39	+IACC1+EPS+Aero2+LDB+LRRT2+EV150 mile+WR20%+0sp		24,801	100.0%
40	Auto 4VDI4+X7+HEG+DCP+DVVL+GDI+HEV+ATKCS+WR15%+8sp	8sp DCT-dry	4,955	56.3%

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Tech package number	Technology package components	Transmission	Cost (2010 USD)	CO$_2$ reduction
41	Auto 4VDI3+X6+DCP+DVVL+GDI+SS+SAX+TDS24+EGR+WR15%+8sp	8sp DCT-dry	2,833	47.6%
42	Auto 4VDI3+X3+DCP+GDI+SS+SAX+TDS27+EGR+WR15%+6sp	6sp DCT-dry	3,027	45.8%
43	Auto 4VDI3+X6+DCP+GDI+SS+SAX+TDS27+EGR+WR15%+8sp	8sp DCT-dry	3,187	48.0%
44	Auto 4VDI3+X5+HEG+DCP+DVVL+GDI+SS+SAX+TDS24+WR15%+8sp	8sp DCT-dry	2,816	48.5%
45	Auto 4VDI3+X6+DCP+GDI+SS+SAX+TDS27+EGR+WR15%+8sp	8sp DCT-dry	3,187	48.0%
46	Auto 4VDI4+X2+HEG+DCP+DVVL+GDI+HEV+SAX+ATKCS+WR15%+8sp	8sp DCT-dry	4,822	54.4%
47	Auto 4VDI4+X7+HEG+DCP+DVVL+GDI+HEV+SAX+ATKCS+WR15%+8sp	8sp DCT-dry	5,043	56.6%

Note: X1 = LUB+EFR1+ASL2+IACC1+EPS+Aero1+LDB+LRRT1
X2 = LUB+EFR1+ASL2+IACC1+EPS+Aero1+LDB+LRRT2
X3 = LUB+EFR1+ASL2+IACC2+EPS+Aero2+LDB+LRRT1
X4 = LUB+EFR1+ASL2+IACC2+EPS+Aero2+LDB+LRRT2
X5 = EFR2+ASL2+IACC2+EPS+Aero2+LDB+LRRT2
X6 = EFR2+ASL2+IACC2+EPS+Aero2+LDB+LRRT1
X7 = EFR2+ASL2+IACC1+EPS+Aero2+LDB+LRRT2

Table 12. Technologies projected by OMEGA. Source: EPA's joint technical support document (EPA, 2012).

Technology	Code	Description
Turbocharging and downsizing	TDS 18, TDS 24, TDS 27	Turbocharging increases the specific power level, allowing a reduced engine size while maintaining performance. OMEGA considers three levels of boost—18-bar, 24-bar, and 27-bar BMEP (brake mean effective pressure)—as well as three levels of downsizing: 18-bar BMEP is applied with 33% downsizing, 24-bar BMEP is applied with 50% downsizing, and 27-bar BMEP is applied with 56% downsizing. EGR is also used for the 24- and 27-bar systems, and the 27-bar system uses a two-stage turbocharger. Downsizing represents a change in engine configuration from four cylinders (I4) to smaller I4 or I3, from V6 to I4, and from V8 to V6 or I4.
Gasoline direct injection	DI	GDI injects fuel at high pressure directly into the combustion chamber. This provides evaporative cooling of the air/fuel charge within the cylinder, which allows for higher compression ratios and increased thermodynamic efficiency. GDI is generally paired with TDS to further support engine downsizing for improved efficiency.
Automatic transmissions	AT6, AT8	Conventional ATs are optimized by adding additional forward gears, which reduces gear ratio spacing and increases the overall gear ratio spread. This enables the engine to operate more efficiently over a broader range of vehicle operating conditions, with options for six and eight gears.
Manual transmission	MT	Improvements to MTs include 6-speed manual transmissions, which offer an additional gear ratio, often with a higher (numerically lower) overdrive gear ratio than that of the fifth gear in a baseline 5-speed manual transmission.
Dual-clutch transmission	DCT6, DCT8	DCTs resemble manual transmissions, but instead of the driver operating a foot-pedal clutch, the vehicle's computer controls shifting and launch functions. Because DCTs use separate clutches for even-numbered and odd-numbered gears, the next expected gear is preselected, which allows for faster, smoother shifting.
Advanced diesel	DSL	Diesel engines have good fuel efficiency due to reduced pumping losses and a combustion cycle that operates at a high compression ratio, with a very lean air/fuel mixture. This technology requires the addition of relatively costly emissions control equipment, including NO$_x$ after-treatment and diesel particulate filters.
Start-stop system	SS	Also known as idle-stop or 12V micro hybrid and commonly implemented as a 12-volt belt-driven integrated starter-generator, this is the most basic hybrid system that facilitates idle-stop capability. This system replaces a conventional alternator with an enhanced-power starter/alternator, both belt-driven, and a revised accessory drive system.
Mild-hybrid electric vehicle	MHEV	MHEVs provide regenerative braking and acceleration assist capacity in addition to idle-stop capability. A higher-voltage battery is used, with greater energy capacity than baseline automotive batteries. The higher voltage allows the use of a smaller, more powerful electric motor and reduces the weight of the motor, inverter, and battery wiring harnesses. This system replaces a standard alternator with an enhanced-power, higher-voltage, higher-efficiency belt-driven starter. The battery capacity is smaller than that of HEV batteries.

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Technology	Code	Description
Hybrid electric vehicle	HEV	A full hybrid vehicle has larger-capacity electric motors and batteries, enabling higher rates of regenerative braking energy and acceleration assist, as well as limited operation on the electric motor alone. An example of a hybrid vehicle is the Toyota Prius.
Plug-in hybrid electric vehicle	PHEV	PHEVs are hybrid electric vehicles with the means to charge their battery packs from an outside source of electricity (usually the electric grid). These vehicles have larger battery packs than HEVs with more energy storage and a greater capability to be discharged.
Electric vehicle	EV	EVs are vehicles with all drive and other systems powered by energy-optimized batteries charged primarily from grid electricity. OMEGA includes EVs with ranges of 75, 100, and 150 miles as potential technologies.
Low-rolling-resistance tires, level 2	LRRT2	Relative to the now-common LRRTs available on baseline vehicles, second-generation LRRTs offer further reduction of frictional losses associated with the energy dissipated in the deformation of the tires under load.
High-efficiency gearbox	HEG	Improvement in seals, bearings, and clutches, surface super finishing of gearbox parts, and advances in lubrication are intended to reduce frictional and other parasitic load in the system for an automatic, DCT, or manual transmission.
Improved accessories, level 2	IACC2	Second-generation improved accessories include high-efficiency alternators, electrically driven (i.e., on-demand) water pumps and cooling systems, and alternator regenerative braking (different from traditional regenerative braking on hybrids which is managed by electric motor system). This excludes other electrical accessories such as electric oil pumps and electrically driven air conditioner compressors.
Engine friction reduction, level 2	EFR2	The second generation of components to reduce engine friction includes low-tension piston rings, roller cam followers, improved material coatings, more optimal thermal management, piston surface treatments, and other improvements in the design of engine components and subsystems that improve engine operation.
Cooled exhaust gas recirculation	EGR	Increase in the exhaust gas recirculation rate used in the combustion process to increase thermal efficiency and reduce pumping losses. Levels of cooled exhaust gas recirculation approach 25% by volume in the highly boosted engines modeled by EPA.
Active aerodynamics	AERO	Reducing the aerodynamic drag of a vehicle helps to reduce fuel consumption. OMEGA considers two levels of aerodynamic improvements: changes to vehicle shape, and active aerodynamics technologies such as active grill shutters. Active grill shutters close off the area behind the front grill under highway driving conditions, reducing vehicle aerodynamic drag and thus fuel consumption.
Weight reduction	WR	Vehicle weight reduction (also referred to as “downweighting” or “lightweighting”) reduces the energy needed to overcome inertial forces, thus yielding lower fuel consumption and GHG emissions.

Table 13. OMEGA model technologies for Brazil (Ford as example).

Manufacturer Name	Model	Reg Class	Vehicle Type Number	Car or Truck	Friction Rdxn	VVT	VVLT	Deac	Fuel Type	Fuel injection system	Boost	Downsize	Aggressive shift	Early torque lock	Transmission	Stop-Start/ Hybrid/ Full EV	Plug-in	Alternator & electrification	Power steering	Aero	Low RR tires	Axle disconnect	Weight Factors %	2010 CO$_2$
FORD	FORD FIESTA 1.0 8V VHC ROCAN FLEX III	Subcompact Cars	1	C											6sp MT							SAX-NA	BASE:0, CAP:0, PHEV20:7, PHEV40:12, P2HEV:5, EV75:0, EV100:6, EV150:19, DSL:0, MHEV:3.5,	259
FORD	FORD FIESTA 1.6 8V VHC ROCAN FLEX III	Subcompact Cars	1	C											6sp MT							SAX-NA	BASE:0, CAP:0, PHEV20:7, PHEV40:12, P2HEV:5, EV75:0, EV100:6, EV150:19, DSL:0, MHEV:3.5,	229
FORD	FORD KA 1.0 8V FLEX II	Subcompact Cars	1	C											6sp MT							SAX-NA	BASE:0, CAP:0, PHEV20:7, PHEV40:12, P2HEV:5, EV75:0, EV100:6, EV150:19, DSL:0, MHEV:3.5,	239
FORD	FORD FIESTA 1.6 8V VHC ROCAN SEDAN FLEX III	Subcompact Cars	1	C											6sp MT							SAX-NA	BASE:0, CAP:0, PHEV20:7, PHEV40:12, P2HEV:5, EV75:0, EV100:6, EV150:19, DSL:0, MHEV:3.5,	229
FORD	FORD FOCUS 1.6 16V GLX FLEX II	Subcompact Cars	1	C											6sp MT							SAX-NA	BASE:0, CAP:0, PHEV20:7, PHEV40:12, P2HEV:5, EV75:0, EV100:6, EV150:19, DSL:0, MHEV:3.5,	231
FORD	FORD FIESTA II 1.6 16V SE FLEX	Subcompact Cars	1	C											6sp MT							SAX-NA	BASE:0, CAP:0, PHEV20:7, PHEV40:12, P2HEV:5, EV75:0, EV100:6, EV150:19, DSL:0, MHEV:3.5,	229
FORD	FORD FOCUS 2.0 16V SEDAN GLX FLEX II	Compact Cars	2	C											6sp MT							SAX-NA	BASE:0, CAP:2, PHEV20:7, PHEV40:12, P2HEV:5, EV75:1, EV100:7, EV150:19, DSL:0, MHEV:3,	299
FORD	FORD FUSION II 2.0 16V TI-VCT ECOBOOST TITANIUM AUTO AWD	Midsize Cars	3	C		VVTC-OHC-I				DI-I4	TURB18-I	V6 DOHC to I4 wT	ASL1	TORQ	6sp AT								BASE:0, CAP:5, PHEV20:7, PHEV40:12, P2HEV:5, EV75:1, EV100:7, EV150:19, DSL:0, MHEV:2.5,	299
FORD	FORD FOCUS 2.0 16V GLX AUTO FLEX II	Subcompact Cars	1	C																		SAX-NA	BASE:0, CAP:0, PHEV20:7, PHEV40:12, P2HEV:5, EV75:0, EV100:6, EV150:19, DSL:0, MHEV:3.5,	299
FORD	FORD FIESTA 1.0 8V VHC ROCAN SEDAN FLEX III	Subcompact Cars	1	C											6sp MT							SAX-NA	BASE:0, CAP:0, PHEV20:7, PHEV40:12, P2HEV:5, EV75:0, EV100:6, EV150:19, DSL:0, MHEV:3.5,	259
FORD	FORD FIESTA II 1.6 16V SEDAN SE FLEX MEX	Subcompact Cars	1	C											6sp MT							SAX-NA	BASE:0, CAP:0, PHEV20:7, PHEV40:12, P2HEV:5, EV75:0, EV100:6, EV150:19, DSL:0, MHEV:3.5,	229
FORD	FORD FIESTA II 1.6 16V SE FLEX MEX	Subcompact Cars	1	C											6sp MT							SAX-NA	BASE:0, CAP:0, PHEV20:7, PHEV40:12, P2HEV:5, EV75:0, EV100:6, EV150:19, DSL:0, MHEV:3.5,	229
FORD	FORD FUSION II 2.0 16V TI-VCT ECOBOOST TITANIUM AUTO	Midsize Cars	3	C		VVTC-OHC-I				DI-I4	TURB18-I	V6 DOHC to I4 wT	ASL1	TORQ	6sp AT							SAX-NA	BASE:0, CAP:5, PHEV20:7, PHEV40:12, P2HEV:5, EV75:1, EV100:7, EV150:19, DSL:0, MHEV:2.5,	299
FORD	FORD FIESTA II 1.6 16V TITANIUM FLEX	Subcompact Cars	1	C											6sp MT							SAX-NA	BASE:0, CAP:0, PHEV20:7, PHEV40:12, P2HEV:5, EV75:0, EV100:6, EV150:19, DSL:0, MHEV:3.5,	229
FORD	FORD FUSION II 2.5 16V AUTO FLEX	Midsize Cars	2	C									ASL1	TORQ	6sp AT							SAX-NA	BASE:0, CAP:5, PHEV20:7, PHEV40:12, P2HEV:5, EV75:1, EV100:7, EV150:19, DSL:0, MHEV:3,	355
FORD	FORD FOCUS 2.0 16V TITANIUM FLEX II	Subcompact Cars	1	C											6sp MT							SAX-NA	BASE:0, CAP:0, PHEV20:7, PHEV40:12, P2HEV:5, EV75:0, EV100:6, EV150:19, DSL:0, MHEV:3.5,	299
FORD	FORD FOCUS II 1.6 16V SE FLEX	Subcompact Cars	1	C											6sp MT							SAX-NA	BASE:0, CAP:0, PHEV20:7, PHEV40:12, P2HEV:5, EV75:0, EV100:6, EV150:19, DSL:0, MHEV:3.5,	231
FORD	FORD FOCUS II 2.0 16V SEDAN SE POWERSHIFT FLEX	Subcompact Cars	1	C						DI-I4			ASL1		6sp DCT-wet							SAX-NA	BASE:0, CAP:0, PHEV20:7, PHEV40:12, P2HEV:5, EV75:0, EV100:6, EV150:19, DSL:0, MHEV:3.5,	299
FORD	FORD FOCUS II 2.0 16V SE POWERSHIFT FLEX	Subcompact Cars	1	C						DI-I4			ASL1		6sp DCT-wet							SAX-NA	BASE:0, CAP:0, PHEV20:7, PHEV40:12, P2HEV:5, EV75:0, EV100:6, EV150:19, DSL:0, MHEV:3.5,	299
FORD	FORD FIESTA II 1.6 16V SEDAN TITANIUM FLEX	Subcompact Cars	1	C											6sp MT							SAX-NA	BASE:0, CAP:0, PHEV20:7, PHEV40:12, P2HEV:5, EV75:0, EV100:6, EV150:19, DSL:0, MHEV:3.5,	229
FORD	FORD FOCUS II 1.6 16V S FLEX	Subcompact Cars	1	C											6sp MT							SAX-NA	BASE:0, CAP:0, PHEV20:7, PHEV40:12, P2HEV:5, EV75:0, EV100:6, EV150:19, DSL:0, MHEV:3.5,	231
FORD	FORD COURIER 1.6 8V VHC L FLEX	Compact Cars	2	C											6sp MT							SAX-NA	BASE:0, CAP:2, PHEV20:7, PHEV40:12, P2HEV:5, EV75:1, EV100:7, EV150:19, DSL:0, MHEV:3,	230
FORD	FORD COURIER 1.6 8V VHC XL FLEX	Compact Cars	2	C											6sp MT							SAX-NA	BASE:0, CAP:2, PHEV20:7, PHEV40:12, P2HEV:5, EV75:1, EV100:7, EV150:19, DSL:0, MHEV:3,	230
FORD	FORD ECOSPORT 2.0 16V XLT AUTO FLEX II	Special Purpose Vehicle, SUV 2WD	7	T																		SAX-NA	BASE:0, CAP:20, PHEV20:7, PHEV40:12, P2HEV:5, EV75:1, EV100:7, EV150:19, DSL:0, MHEV:2.5,	294
FORD	FORD FOCUS 2.0 16V SEDAN TITANIUM AUTO FLEX II	Compact Cars	2	C																		SAX-NA	BASE:0, CAP:2, PHEV20:7, PHEV40:12, P2HEV:5, EV75:1, EV100:7, EV150:19, DSL:0, MHEV:3,	299
FORD	FORD FOCUS II 2.0 16V TITANIUM POWERSHIFT FLEX	Subcompact Cars	1	C						DI-I4			ASL1		6sp DCT-wet							SAX-NA	BASE:0, CAP:0, PHEV20:7, PHEV40:12, P2HEV:5, EV75:0, EV100:6, EV150:19, DSL:0, MHEV:3.5,	299
FORD	FORD FOCUS II 2.0 16V SEDAN S POWERSHIFT FLEX	Subcompact Cars	1	C						DI-I4			ASL1		6sp DCT-wet							SAX-NA	BASE:0, CAP:0, PHEV20:7, PHEV40:12, P2HEV:5, EV75:0, EV100:6, EV150:19, DSL:0, MHEV:3.5,	299
FORD	FORD FOCUS II 2.0 16V SEDAN TITANIUM POWERSHIFT FLEX	Subcompact Cars	1	C						DI-I4			ASL1		6sp DCT-wet							SAX-NA	BASE:0, CAP:0, PHEV20:7, PHEV40:12, P2HEV:5, EV75:0, EV100:6, EV150:19, DSL:0, MHEV:3.5,	299
FORD	FORD FOCUS II 1.6 16V S POWERSHIFT FLEX	Subcompact Cars	1	C											6sp MT							SAX-NA	BASE:0, CAP:0, PHEV20:7, PHEV40:12, P2HEV:5, EV75:0, EV100:6, EV150:19, DSL:0, MHEV:3.5,	231
FORD	FORD KA 1.6 8V SPORT FLEX II	Subcompact Cars	1	C											6sp MT							SAX-NA	BASE:0, CAP:0, PHEV20:7, PHEV40:12, P2HEV:5, EV75:0, EV100:6, EV150:19, DSL:0, MHEV:3.5,	232
FORD	FORD FOCUS II 1.6 16V SEDAN S FLEX	Subcompact Cars	1	C											6sp MT							SAX-NA	BASE:0, CAP:0, PHEV20:7, PHEV40:12, P2HEV:5, EV75:0, EV100:6, EV150:19, DSL:0, MHEV:3.5,	231
FORD	FORD FOCUS II 1.6 16V SEDAN SE FLEX	Subcompact Cars	1	C											6sp MT							SAX-NA	BASE:0, CAP:0, PHEV20:7, PHEV40:12, P2HEV:5, EV75:0, EV100:6, EV150:19, DSL:0, MHEV:3.5,	231